Management of Radon Data in the State of Ohio, U.S.A.

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Abstract: The objective of this research paper is to create a public awareness in understanding the radon gas problem, discuss efficient data management methods and analyses of indoor radon gas concentrations, and mitigate the indoor radon gas concentrations to below acceptable level in the state of Ohio. The Ohio Radon Information System (ORIS) is a compendium of five databases or modules, viz. the "Homes" database, the "Water" database, the "Schools" database, the "Mitigation" database, and the "Tester" database. Over the years, the radon database (made available by testing laboratories, Ohio Department of Health (ODH), Ohio Environmental Protection Agency (EPA), and universities) has been expanded to 145,849 radon gas observations for homes; 1,283 radon gas observations for drinking water; 1,147 radon gas observations for schools; 26,374 radon gas observations for mitigation systems; and 76,727 radon gas observations by testers. Analysis of the homes data shows that "Licking County" is the only county having a geometric mean (GM = 8.41 pCi/l) of radon gas concentration greater than 8 pCi/l in Ohio. Zip code 43930, in "Jefferson County," accounts for a maximum GM radon gas concentration of 39 pCi/l. Of the 216 public and 1,067 private water supply systems, only 2 public and 65 private water supply systems have shown radon gas concentrations to exceed 1000 pCi/l. Analysis of the schools data reveals that a school in "Belmont County" to show a maximum radon gas concentration of 85.5 pCi/l, with 11 rooms out of the 39 school rooms tested greater than 4 pCi/l. The performance analysis of the mitigation systems identified the Sub Slab Depressurization (SSD) systems to be the best performers in mitigating the radon gas concentration to below 4 pCi/l in Ohio. Analysis of the tester's data showed two counties: Harrison (GM = 10.25 pCi/l); and Perry (GM = 8.65 pCi/l) to have a GM of radon gas concentration greater than 8 pCi/l in Ohio.

Keywords: Radon, database, environmental management system, Ohio, indoor air pollution, Ohio Radon Information System (ORIS), mitigation systems, data analysis, Radon gas environmental monitoring.

INTRODUCTION

Radon gas is a naturally occurring, colorless, odorless, radioactive gas. It is a by-product of the breakdown of uranium and radium. Radon gas is continuously released from rocks and soil containing these two elements. Radon gas drifts upward through the ground to the surface of the soil and seeps into the buildings through foundation cracks. Radon gas is formed naturally by radioactive decay of uranium present in geologic materials. The major sources of radon gas in Ohio are 'Ohio shale' and soil. Organic shale in Ohio is known to have elevated concentrations (10 ppm to 40 ppm) of uranium, five to 20 times the average levels in the earth's crust [1, 2]. When uranium decays, it forms radon gas that enters homes through soil, underground water, and water distribution systems and in a gaseous form through cracks and other openings [3].

Elevated radon gas levels have been discovered in virtually every state. The United States Environmental Protection Agency (U.S. EPA) estimates that as many as eight million homes throughout the country have elevated levels of radon gas [4]. Since 1988, EPA and the Office of the Surgeon General have recommended that homes below the third floor be tested for radon gas. EPA's action level for public safety is an indoor radon gas concentration of 4 pCi/l, where immediate measures should be taken to reduce the level to 2 pCi/l [5].

Radon gas is a national environmental health problem. It is a well-known human carcinogen, recognized as the second leading cause of lung cancer [4]. When inhaled, high indoor concentrations of radon gas can damage the lung tissue and increase the risk of cancer. An individual's risk of developing lung cancer from radon gas increases with the level of radon, the duration of exposure, and the individual's smoking habits [6]. As people spend most of their time at home, home is the most significant source of radon gas exposure. For school children, the school buildings are the second largest source of radon gas exposure, the first source being their homes.

Children are more sensitive to radon gas because they have smaller lungs and higher respiratory rates. According to the available estimates, 21,000 people die from lung cancer each year in the United States, due to exposure to indoor radon gas [4]. On an average, 900 deaths in Ohio alone are caused by lung cancer. This is because the average indoor radon gas concentration in the state is well above the national average of 1.3 pCi/l [1].

When high radon gas levels were discovered in eastern Pennsylvania in the early 1980s, the U.S. EPA initiated a radon gas mitigation campaign. In late 1980, the Ohio Department of Health (ODH) initiated an indoor radon gas pro-

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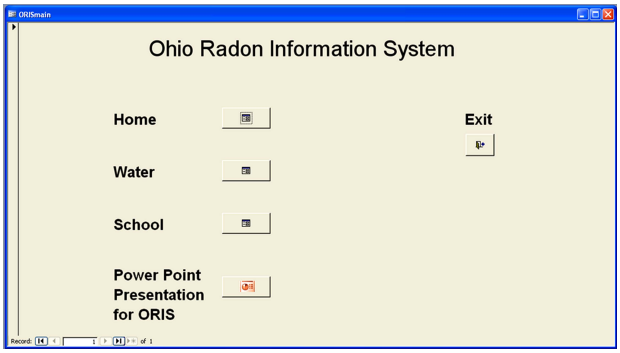

Fig. (1). Main form of the integrated radon gas database.

gram to reduce the number of deaths attributable to radon gas. During the 1990s, ODH started encouraging the reduction of radon gas concentrations in houses and schools to a safe level through a number of mitigation methods. In 2001, Ohio passed a law that required radon gas mitigation contractors to report mitigation data on homes to ODH [7]. As a result of the new law, two new databases were developed to study radon gas mitigation systems and to track observations by testers.

The University of Toledo, under several research grants from the ODH and the Ohio Air Quality Development Authority, developed the Ohio Radon Information Systems (ORIS), and a website [1, 2, 5, 8, 9]. The purpose of this database is to help the public understand the hazards of radon gas and, therefore, reduce any of its concentration levels that surpass the U.S. EPA's action limits.

This paper discusses the development of the five different databases and the respective results from the analysis of radon gas data for different counties and zip codes in Ohio. The analyses and results contribute significantly towards understanding the radon gas problem in Ohio.

RADON GAS DATABASES

The Ohio Radon Information System (ORIS) is one of the most comprehensive indoor radon gas databases available in the world. The extensive radon gas database maintained by the Department of Civil Engineering, The University of Toledo, is an integrated database of three sections: viz. "Homes", "Water", and "Schools", and separate databases on "Mitigation" and "Tester". A number of queries built into the SQL server and MS Access are run to analyze the data to get valuable results.

The "Homes" database provides information on the radon gas concentration measured using radon detectors in homes in Ohio. The "Homes" section, the most extensive of all the sections of the databases, began as an ORACLE/MS Access database [10]. It is currently handled by SQL Server 7.0/MS Access, as MS Access on its own is incapable of handling such a large database [11]. The data table is stored in SQL Server 7.0, and the interlinking between the MS Access and the Server is furnished with the help of linked tables and pass through queries. The "Water" and "School" databases are smaller in size and, therefore, handled by MS Access. This integrated database is a user-friendly environment wherein the entire system can be accessed through MS Access forms (screens). A single form called ORIS main allows access to the entire database (refer Fig. **1**). New data can be added using these MS Access front ends. Resultantly, complete knowledge of MS Access and SQL Server, when the duties of database maintenance change hands, can be eliminated. Microsoft Excel 2007 is also being used to handle such a large database. Currently, the "Homes" database is the largest database with 145,849 data points, as of December 2009. It can be observed from literature that limited studies have given a detailed description of the structure of the database [8, 12] and only one study provided a comprehensive analysis of radon gas concentration and house construction parameters [13].

Table 1. Number of Records on Radon Gas Concentration in Homes Database and Supplier Information

Organization	Number of Records	Year
The University of Toledo	50626	Before 1989
Airchek, Inc.	59568	1990-2009
Maintenance Management.	75	1990-1998
Delaware Health Department	1175	1990-1998
Radonics, Inc.	4079	1990-2009
RSSI/Radiation Safety Services, Inc.	1350	1990-1998
Radon Testing Corp., Inc.	6487	1990-2009
Solar Testing Laboratories	3289	1990-1998
Key Technology, Inc.	713	1990-2009
Radalink, Inc.	5197	1990-2009
Landauer, Inc.	8422	1990-2009
Niton Corporation	733	1990-1998
Radon Systems	259	1999
Licking County Department	671	1999
Globe Spec	1065	1999-2009
Lake County	92	1999
Warren	102	1999-2009
Valle Inc.	49	1999
Bass Home Inspection	722	1999-2009
Miscellaneous	1175	
Total	145849	

Data for homes are provided by various organizations and radon gas testing laboratories as electronic files. Table **1** shows the sources of the data received and their contributions.

The raw data provided by these labs are then preprocessed for inclusion in the "Homes" database. The "Homes" database consists of one main table and a number of associated queries, as given below for the analysis of the data.

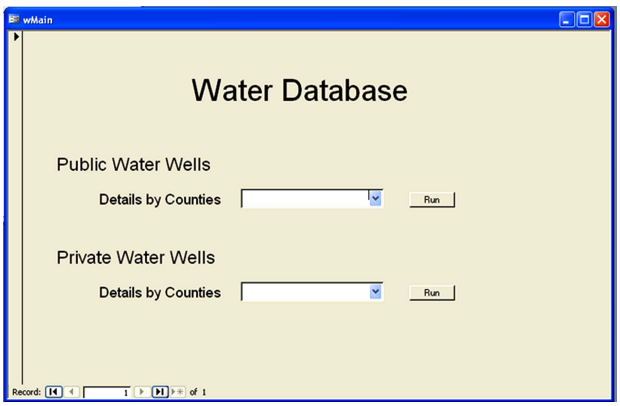

Fig. (2a). Water database access form.

4) Counties with GM of radon gas concentration > 4 pCi/l: This query lists all the counties with GM of radon gas concentration greater than 4 pCi/l.

5) Counties with GM of radon gas concentration > 8 pCi/l: This query lists all the counties with GM of radon gas concentration greater than 8 pCi/l.

6) Zip codes with GM of radon gas concentration > 4 pCi/l: This query lists all the zip codes with GM of radon gas concentration greater than 4 pCi/l.

The "Water" database has observations on radon concentrations in water across the state of Ohio and consists of two sets of controls viz. public water wells and private water wells. The information on public water wells was supplied by the Ohio EPA, and private water wells were obtained from the Master of Science theses completed at Ohio Universities. The list of MS theses used were listed on the radon website maintained by the air pollution research group (APRG) of the Department of Civil Engineering at The University of Toledo [14]. The associated county queries for each of these controls display information for all the public and private wells in that particular county (Fig. **2a** and Fig. **2b**). Currently, the "Water" database consists of 1,283 data points from 72 counties as of December 2009. Of these 1,283 water supply systems, 216 are public water wells and 1,067 are private wells.

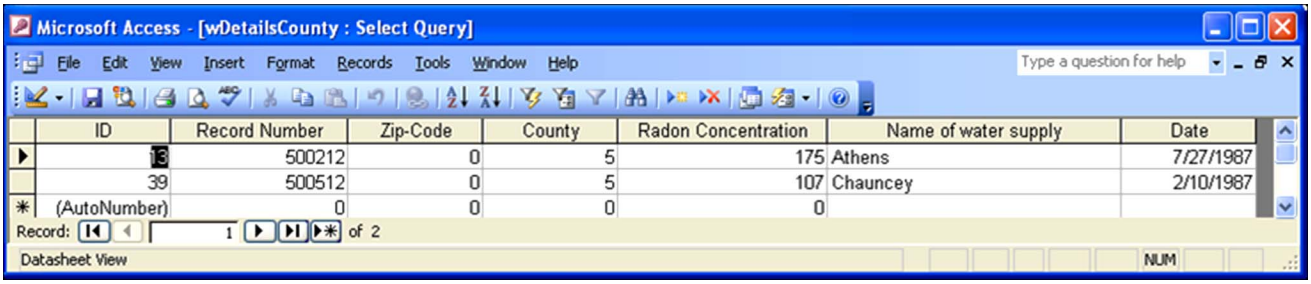

Fig. (2b). Public water supply county query.

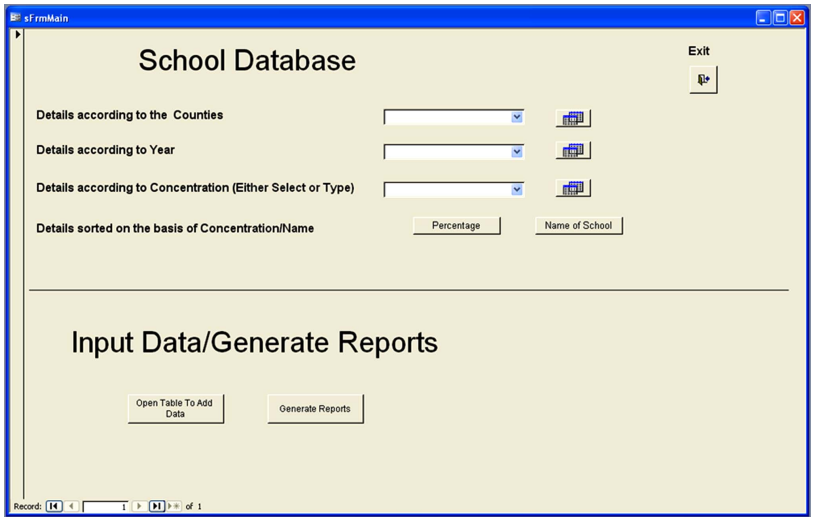

Fig. (3). School database main form.

1) Radon gas statistics based on counties: This query calculates the statistical parameters such as total number of radon gas measurements for a particular county, the maximum radon gas concentration in a particular county, the minimum radon gas concentration in a particular county, the arithmetic mean (AM) of radon gas concentrations, the geometric mean (GM) of radon gas concentrations, first quartile, third quartile, median, the standard deviation, and the variance all grouped according to the counties.

2) Overall statistics for the entire state of Ohio: This query displays the above-mentioned statistics for the entire state of Ohio.

3) Radon gas statistics based on zip codes: This query is similar to that of the county statistics and displays all statistics based on zip codes.

The "Schools" database is a collection of radon gas information measured in public and private schools in Ohio. The main form of the school database (Fig. **3**) has three sets

Table 2. Detailed School Information

Serial Number	Grades Span	School Name
IRN Number	District Name	School Street Address
County Number	District Street Address	School City
District Type	District City	School Zip Code
Miscellaneous Data	District Zip Code	School Telephone
District Number	District Telephone	Title
School Type	District County	Staff Name

of controls that are used for accessing and segregating the school data according to the county, year, and radon gas concentration. The 'Percentage' and 'Name of School' command buttons display the radon gas data based on the radon gas concentration and school name respectively.

The data on details of school and the measurements of radon gas concentrations in different schools of Ohio are provided by the ODH. Currently, the "Schools" database has 1,147 radon gas measurement data as of December 2009. The database consists of two main tables, besides forms for each table and related queries. The main table comprises of the data sent by ODH at regular intervals. The fields in the school database include 1) Name of School, 2) County, 3) Number of rooms tested for radon, 4) Number of rooms where the radon gas concentration exceeded the permissible level of 4 pCi/l, 5) Maximum radon gas concentration level observed in that school, and 6) Year in which the measurements were made. The second table records the complete information on the schools, where these radon gas measurements were conducted. This table houses fields as given in Table **2**.

Table **2** was born out of the exhaustive data provided by the Ohio Board of Regents on the public and private schools in Ohio, and gives the complete information on schools. Forms created for each of these tables, using the Form Wizard provided by MS Access, help as a front-end application to manipulate the data in the tables and to add new data. It also helps users avoid the complexity posed by the table structure. A number of queries built in MS Access help in the analysis of the school data. The results of the queries provide an insight into the levels of radon gas concentrations in the schools of Ohio. Queries along with a description are given below.

1) Number of schools tested by county and year: This query gives the list of the number of schools tested in each county on a yearly basis. The list is grouped based on the year.

2) Number of schools tested by year: This query gives the number of schools in Ohio that are tested each year. It contains data from 1990 to 2009.

3) Schools with radon gas concentrations ≥ 4 pCi/l: This query identifies all the schools in Ohio that have a maximum radon gas concentration greater than or equal to 4 pCi/l. This table lists the name of the school, county, maximum radon gas concentration, and the year in which it was tested.

4) Schools with radon gas concentrations ≥ 8 pCi/l: This query gives the list of all the schools in the state of Ohio that have a maximum radon gas concentration greater than or equal to 8 pCi/l. It also contains the same fields, as mentioned above.

5) Schools with radon gas concentrations ≥ 20 pCi/l: This query lists all the schools in the state of Ohio that have a maximum radon gas concentration greater than or equal to 20 pCi/l.

6) Schools by percentage of rooms tested having radon gas concentration ≥ 4 pCi/l: This query shows the percentage of rooms in every school which have a radon gas concentration greater than or equal to 4 pCi/l.

7) Schools with more than 15 rooms having radon gas concentration ≥ 4 pCi/l: This query is designed to retrieve the names of all the schools from the database which have more than 15 rooms in which the concentration of radon gas is greater than or equal to 4 pCi/ l.

8) School statistics: This query gives the total number of schools tested in each county, the maximum and minimum school radon gas concentration in the counties, the AM and GM of radon gas concentration in the counties, the standard deviation and the variance for the counties. A total of 63 counties have been tested as of December 2009.

The "Mitigation" database is a collection of radon gas mitigation systems installed in Ohio homes. The "Mitigation" database is prepared in MS Access to store, update, retrieve, and analyze the mitigation data [15]. Licensed contractors perform the mitigation tests and submit the results to the ODH. This data is manually entered into an Excel sheet in one main table. The data are checked for accuracy and transcription errors. The stored data is updated every quarter of the year and the reports of the analysis are submitted to the ODH for each quarter. Currently, the "Mitigation" database has 26,374 data points, as of December 2008. The database includes information pertinent to 1) license number of the contractor; 2) name of the contact; 3) telephone number; 4) street address of the contact; 5) zip code, city, county, and state; 6) type of mitigation system; 8) start and finish dates of the mitigation test; 9) pre-mitigation and post mitigation levels; 10) quarter of the year; and 11) year.

Data are analyzed by transferring the Excel sheet to MS Access. The data consists of both complete and incomplete information. Complete information implies records have both the pre-mitigation and post-mitigation levels. Missing values are assigned codes for convenience. "NA" represents missing values of an alpha-numeric type, while "-1" indicates missing numeric parameters. For ease of data entry and use of the mitigation systems and their combinations, the quarter of the year are also assigned distinct codes.

Analysis of the data is performed by using a number of queries (listed below) built in MS access for this purpose.

1) Number of records by each license number of the contractor: This query gives the total number of tests performed by each contractor.

2) Counties with pre-mitigation level > 4 pCi/l: This query identifies the counties which have the pre-mitigation level more than 4 pCi/l.

3) Average removal efficiency by each type of system: This query gives the average percent removal achieved and the standard deviation for each type of system.

4) Pre-mitigation level between 4 pCi/l and 20 pCi/l: This query identifies the records that have the pre-mitigation level between 4 pCi/l and 20 pCi/l.

5) Pre-mitigation level > 20 pCi/l: This query identifies the records that have the pre-mitigation level greater than 20 pCi/l.

Only complete data are considered for the analysis. Queries have been designed in a manner that they account for all kinds of missing data. Operations such as counting the number of records in a particular category and grouping the data based on specific criteria are performed by the queries. The results of the queries provide an insight into the effectiveness of the mitigation program conducted across Ohio.

The "Tester" database is a collection of the radon test systems installed in Ohio homes. The "Tester" database maintenance procedure is similar to that of the maintenance procedure adopted for the "Mitigation" database. The tester database is also prepared in MS Access to store, update, retrieve, and analyze the tester data. The APRG in the Civil Engineering Department at The University of Toledo receives radon gas tester results from licensed testers through ODH. This data is manually entered into an Excel sheet in one main table, and the data are checked for accuracy and to avoid transcription errors. The stored data is updated every quarter of the year and the reports of the analysis are submitted to the ODH for each quarter. Currently, the tester database has 76,727 data points as of December 2008. The database includes information on 1) license number of the tester; 2) name of the contact; 3) street address of the contact; 4) zip code, city, county, and state; 5) device code; 6) test type; 7) start and finish dates of the test; 8) radon gas concentration level; 9) quarter of the year; and 10) and year in which the measurements were made.

Data are analyzed by transferring the Excel sheet to MS access. The data consists of both complete and incomplete information. Incomplete information relates to any missing radon gas concentration values. Missing values are assigned codes of "-1" or "NA" for numeric and alpha-numeric parameters respectively. Analysis of the data is carried out by using a number of queries (listed below) built in MS access for this purpose.

1) Number of records by each license number of the tester: This query gives the total number of tests completed by each tester.

2) Counties with radon gas concentration level > 4 pCi/l: This query identifies the counties which have the radon gas concentration level more than 4 pCi/l.

3) Radon gas statistics for each county: This query computes statistics such as total number of radon gas measurements, maximum and minimum radon gas concentrations, AM, GM, standard deviation, and variance, all grouped according to the counties.

4) Radon gas statistics for each zip code: This query is similar to that of the county statistics and displays all statistics based on zip codes.

Only complete data are considered for the analysis. Queries have been designed in a manner that they account for all kinds of missing data. "Tester" database management is similar to "Mitigation" database management, and the query results provide further insight into the radon gas testing program in Ohio.

RESULTS AND DISCUSSION

The analysis of radon gas data in each of the database provides an insight into the distribution of radon gas concentration across Ohio, and reveals zip codes, counties, and schools that have a real-time radon gas issue. The results further help the concerned authorities take necessary steps toward mitigating radon gas and evaluating the effectiveness of the various programs undertaken to reduce the radon gas levels to below the EPA action limit. Common statistical parameters are calculated and quoted separately.

The home database includes measurements from all the 88 counties in Ohio. The analysis of homes data revealed 25 counties having GM of radon gas concentration greater than 4 pCi/l, while Licking County (GM = 8.41 pCi/l) is the only county with the GM of radon gas concentration greater than 8 pCi/l. Of the available 1,491 zip code areas in the homes database, 32.19% have GM radon gas concentrations over 4 pCi/l, and 1.98% have concentrations over 8 pCi/l. The zip code 43930 in Jefferson County accounts for a maximum GM radon gas concentration of 39 pCi/l. The GM of radon gas concentration is 3.67 pCi/l for Ohio, based on the 145,849 records. Figs. (**4** and **5**) display the spatial distribution of GM of the radon gas concentration in Ohio for different counties and zip codes respectively. From Fig. (**4**), one can observe Jefferson County to have its GM radon gas concentration value between 2 pCi/l and 4 pCi/l, despite the location of zip code 43930 with the highest GM radon gas concentration value of 39 pCi/l within the same county. This can be explained on studying the influence of uranium concentrations on radon gas concentrations in Ohio. The uranium concentration map for Ohio is available on the ORIS website [16]. Zip code 43930 had relatively higher uranium concentration as compared to the uranium concentrations monitored in other zip codes of Jefferson County. Also, the availability of only three data points for zip code 43930 could have resulted in the highest GM for radon gas concentrations for the same zip code. A more detailed analysis of the uranium and radon gas concentrations across the state of Ohio showed that majority of the zip codes having radon gas GM concentration greater than 4 pCi/l to be having have higher uranium concentrations. From these observations, one can conclude that uranium concentrations and radon gas concentrations in Ohio correlated well.

Of the 1,283 water supply systems, 216 are public water wells and 1,067 are private wells. Of the 216 public water wells, only two showed radon concentration greater than 1000 pCi/l. However, none of the public water supply systems have concentrations greater than 1500 pCi/l. Table **3** shows the statistics for radon concentration in the private water wells in Ohio counties. From Table **3**, one can observe

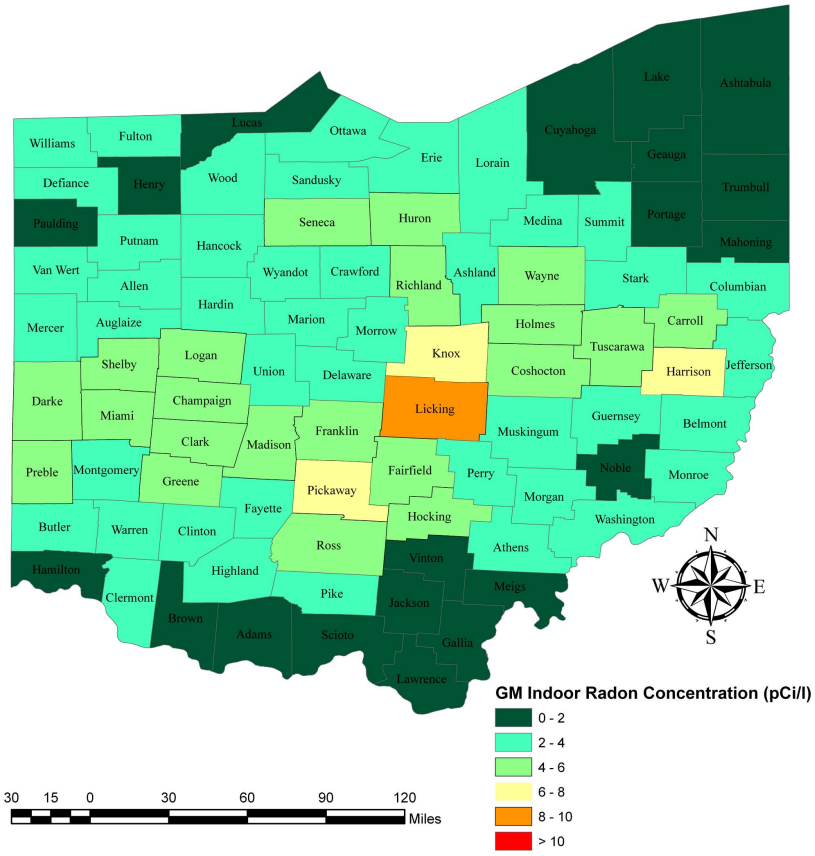

Fig. (4). Geometric mean indoor radon gas concentration in Ohio counties.

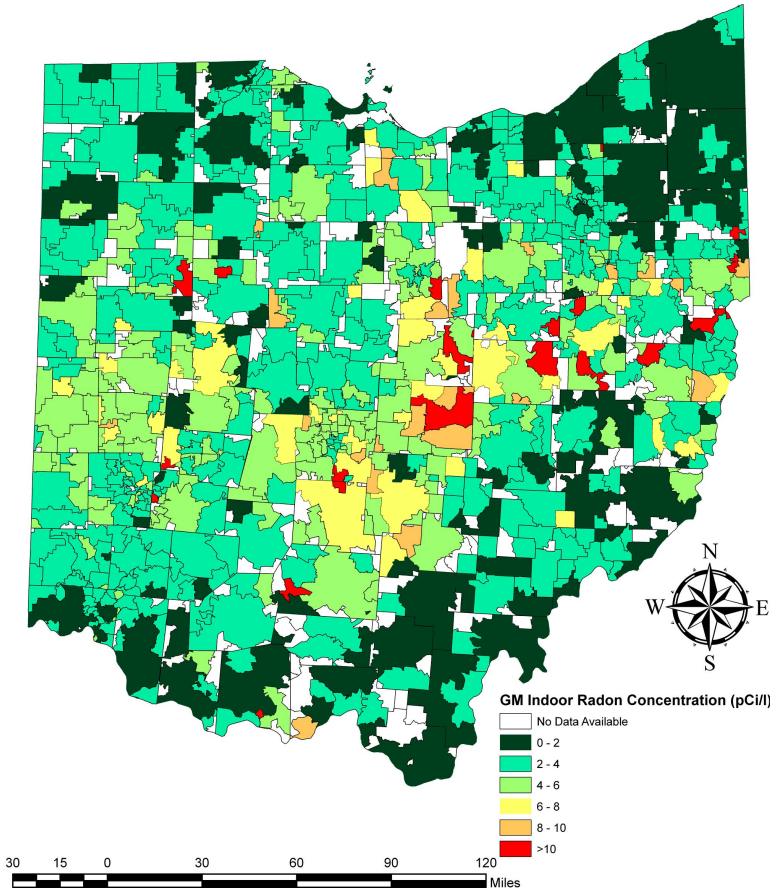

Fig. (5). Geometric mean indoor radon gas concentrations in Ohio zip codes.

Table 3. Radon Concentration in Private Water Wells in Counties of Ohio

Counties	Total Number of Wells	Maximum Radon Concentration (pCi/l)	Minimum Radon Concentration (pCi/l)	Average Radon Concentration (pCi/l)	Number of Wells with Radon Concentration ≥ 1000 pCi/l
Butler	7	571	217	415.00	0
Champaign	80	1491	73	355.85	2
Clark	8	1386	172	436.88	1
Clermont	1	163	326	163.00	0
Crawford	78	1021	13	143.42	1
Darke	1	231	231	231.00	0
Delaware	60	2314	2	599.12	13
Erie	181	3104	20	285.82	6
Fulton	3	172	119	147.00	0
Greene	4	703	200	438.75	0
Hamilton	2	380	213	296.50	0
Hancock	7	470	180	322.86	0
Hardin	49	996	44	238.73	0
Henry	1	510	510	510.00	0
Huron	149	2010	5	230.82	7
Logan	212	7511	25	553.99	28
Marion	74	1574	26	257.61	3
Miami	4	413	174	248.00	0
Montgomery	6	637	249	406.67	0
Morrow	93	3425	25	303.15	4
Ottawa	2	150	130	140.00	0
Paulding	1	190	190	190.00	0
Preble	3	782	184	507.67	0
Sandusky	3	130	80	96.67	0
Seneca	9	220	80	129.89	0
Union	5	334	82	210.40	0
Warren	4	542	340	442.00	0
Williams	8	245	148	185.25	0
Wood	6	560	200	320.00	0
Wyandot	6	180	96	132.00	0

65 private wells to have radon concentrations exceeding 1000 pCi/l. Of these 65 wells, 28 were located in Logan County, while 13 were found in Delaware County. It is interesting to note that from the available data on private wells, seven private wells have radon gas concentration greater than 3000 pCi/l.

The ODH School Testing Program has covered 63 counties and 1,147 schools (Figs. **6** and **7**). The number of schools having maximum radon gas concentration >= 4 pCi/l and 8 pCi/l in at least one room are 259 and 133 respectively. Analysis of the schools data reveals that a school in "Belmont County" showed a maximum radon gas concentration of 85.5 pCi/l, with 11 rooms out of the 39 school rooms tested greater than 4 pCi/l.

Table **4** presents the number of schools having maximum radon gas concentration >= 20 pCi/l in at least one room is 20. Fig. (**8**) shows the school counties with percentage of rooms greater than 4 pCi/l. The map reveals that Pike county schools have approximately 50-60% of rooms greater than 4 pCi/l. In Ohio, based on current data available at The University of Toledo for 1,147 schools, it is estimated that approximately 27.6% of schools have a potential for at least one room in excess of the EPA action level (4 pCi/l) compared to 19.3% nationwide.

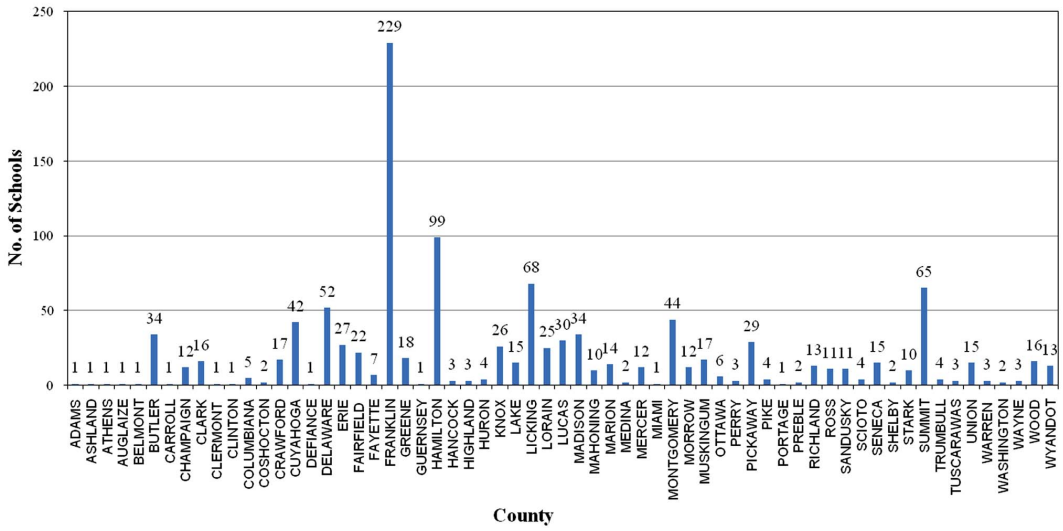

Fig. (6). Number of schools tested per county.

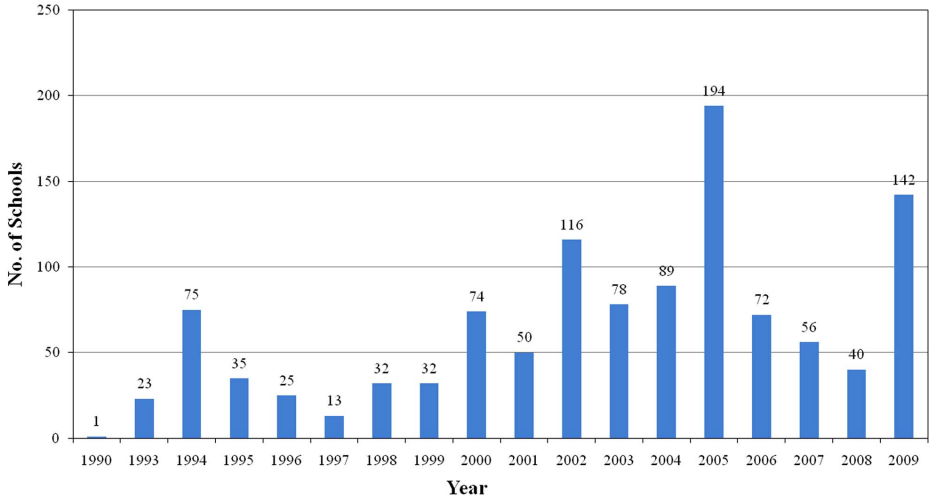

Fig. (7). Number of schools tested per year.

Table 4. Schools Having Radon Concentrations >= 20 pCi/l

School Name	County	Rooms Tested	Maximum Radon Gas Concentration >=20PCI/L	Year
OLNEY FRIENDS SCHOOL	BELMONT	39	85.5	2009
SOUTH MAIN ELEMENTARY	WOOD	11	70.3	1996
EAST PRIMARY ELEMENTARY SCHOOL	PIKE	33	53	2000
NORTH ELEMENTARY	COLUMBIANA	20	48	2005
WEST MUSKINGUM HIGH SCHOOL	MUSKINGUM	39	44.9	2001
WORTHINGWAY MIDDLE SCHOOL	FRANKLIN	41	39.8	1998
LIT BASES@HUBBARD	FRANKLIN	19	34.5	2007
BECK URBAN ACADEMY	FRANKLIN	17	33.8	2007
DUNLOE ELEMENTARY	FRANKLIN	32	32.3	2006
TOBOSO ELEMENTARY	LICKING	15	29.3	2004
COLUMBIA ELEMENTARY	KNOX	3	29	2004

Table 4. cont…….

School Name	County	Rooms Tested	Maximum Radon Gas Concentration >=20PCI/L	Year
BEATTY PARK @ EASTGATE	FRANKLIN	28	27	2007
NORTH RIDGE LOCAL SCHOOL DISTRICT	LICKING	123	24.6	2009
FAIRFIELD MIDDLE SCHOOL	BUTLER	135	24	2003
WALDO ELEMENTARY SCHOOL	MARION	15	23.9	1997
OAK GROVE ELEMENTARY	WASHINGTON	12	22	2002
ASBURY ELEMENTARY	FRANKLIN	29	21.8	2006
PRECIOUS BLOOD CATHOLIC SCHOOL	MONTGOMERY	19	21.7	2008
GRANIVILLE CHRISTIAN ACADEMY	LICKING	41	20.7	2003
PLEASANT STREET ELEMENTARY	KNOX	5	20.2	2000

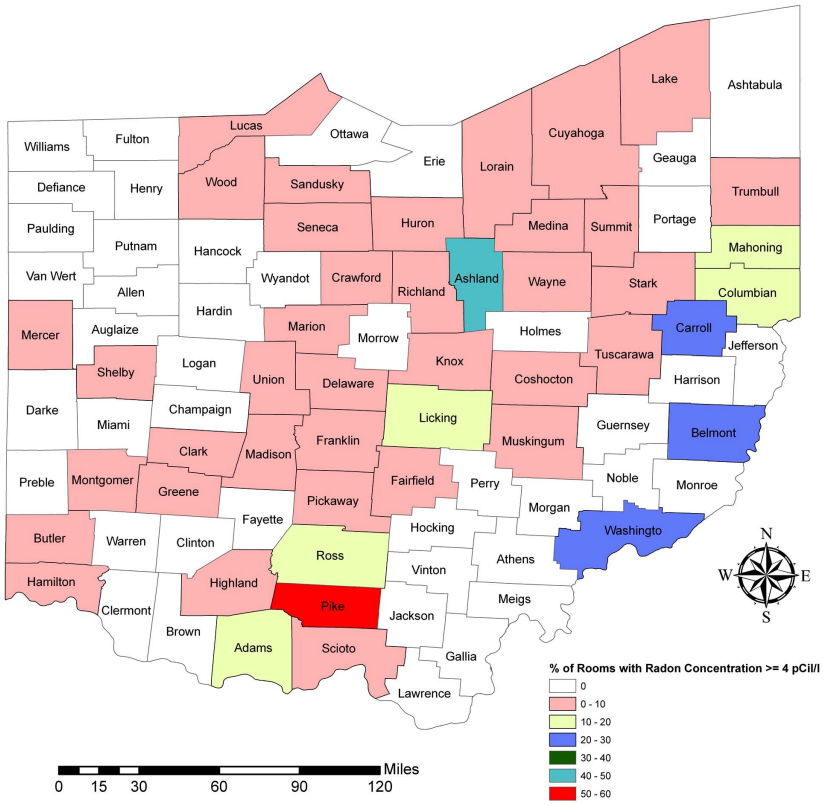

Fig. (8). Counties with percentage of school rooms with radon gas concentration >= 4 pCi/l .

"Mitigation" database query results provide an insight into the effectiveness of the mitigation program conducted in the state. The results of the data analysis pertain to the collection period of January 2001 to December 2008.

The total number of records and the number of complete records by quarter are shown in Table **5**. Out of 26,374 records reported, 20,321 records (about 77.61 %) were found complete (i.e., having pre-mitigation and post-mitigation levels). It can be observed from Table **5** that the percentage of complete records is increasing over the years. The efforts by ODH were productive because the percent of complete records increased from 2.32% to 97.18%, for the period from 2001 to 2008. The yearly average of complete records (percentage) has increased from 20.38% in 2001 to 95.09% in 2008. The number of records with pre-mitigation level between 4 pCi/l and 20 pCi/l for each year is shown in Table **6**. The number of records with percentage removal less than 50 percent for each year is shown in Table **7**. One can easily say that the mitigation installation in Ohio has been successful, because only a small percent of the installations with complete records have removal efficiency less than 50%. Table **8** presents the performance analysis of different mitigation systems used in Ohio for the year 2008. Statistical testing (based on the standard error of mean values that accounts for both the number of records per mitigation system and the respective standard deviation) of the percentage removal by

Table 5. Total Number of Mitigation Records

Quarter	Total Number of Records	Number of Complete Records	Total Records Submitted Yearly	Complete Records Submitted Yearly	Percentage Complete Records
Quarter 1 (Jan.-Mar. 2001)	647	15			2.32
Quarter 2 (Apr.-Jun. 2001)	940	169			17.98
Quarter 3 (Jul.-Sep. 2001)	953	208			21.83
Quarter 4 (Oct.-Dec. 2001)	978	325	3518	717	33.23
Quarter 1 (Jan.-Mar. 2002)	722	228			31.58
Quarter 2 (Apr.-Jun. 2002)	829	320			38.60
Quarter 3 (Jul.-Sep. 2002)	1041	512			49.18
Quarter 4 (Oct.-Dec. 2002)	716	472	3308	1532	65.92
Quarter 1 (Jan.-Mar. 2003)	651	530			81.41
Quarter 2 (Apr.-Jun. 2003)	1010	908			89.90
Quarter 3 (Jul.-Sep. 2003)	1018	807			79.27
Quarter 4 (Oct.-Dec. 2003)	825	619	3504	2864	75.03
Quarter 1 (Jan.-Mar. 2004)	454	411			90.53
Quarter 2 (Apr.-Jun. 2004)	705	686			97.30
Quarter 3 (Jul.-Sep. 2004)	36	36			100.00
Quarter 4 (Oct.-Dec. 2004)	877	846	2072	1979	96.47
Quarter 1 (Jan.-Mar. 2005)	680	650			95.59
Quarter 2 (Apr.-Jun. 2005)	229	220			96.07
Quarter 3 (Jul.-Sep. 2005)	1124	1076			95.73
Quarter 4 (Oct.-Dec. 2005)	838	795	2871	2741	94.87
Quarter 1 (Jan.-Mar. 2006)	898	864			96.21
Quarter 2 (Apr.-Jun. 2006)	844	796			94.31
Quarter 3 (Jul.-Sep. 2006)	825	776			94.06
Quarter 4 (Oct.-Dec. 2006)	835	797	3402	3233	95.45
Quarter 1 (Jan.-Mar. 2007)	579	509			87.91
Quarter 2 (Apr.-Jun. 2007)	802	783			97.63
Quarter 3 (Jul.-Sep. 2007)	999	931			93.19
Quarter 4 (Oct.-Dec. 2007)	714	653	3094	2876	91.46
Quarter 1 (Jan.-Mar. 2008)	849	800			94.23
Quarter 2 (Apr.-Jun. 2008)	1100	1059			96.27
Quarter 3 (Jul.-Sep. 2008)	1530	1437			93.92
Quarter 4 (Oct.-Dec. 2008)	1126	1083	4605	4379	96.18
	26374	20321			77.61

Table 6. Number of Records with Pre-Mitigation Level Between 4 pCi/l and 20 pCi/l for the Years 2001 to 2008 (Jan.-Dec.)

Year	Number of Records with Pre-ML Between 4 pCi/l & 20 pCi/l
2001	631
2002	1325
2003	2597
2004	1773
2005	2450
2006	1463
2007	2971
2008	3905

Table 7. Number of Records with % Removal Less than 50 for years 2001 to 2008

Year	Number of Records with Removal % Less Than 50	Percentage of Records with Removal % Less Than 50
2001	25	0.70%
2002	67	2.00%
2003	70	2.40%
2004	69	3.49%
2005	174	6.07%
2006	67	4.08%
2007	69	2.40%
2008	82	1.70%

Table 8. Average Removal Efficiency by Each Type of System for year 2008

Type of System	Number of Records	Average % Removal	Standard Deviation	Standard Error Mean
SSD	2649	82.83	13.65	0.265
SUMP/DTD	581	85.71	9.71	0.403
SSD/SMD	576	86.53	10.72	0.447
DTD	162	86.56	16.82	1.32
SUMP	45	87.33	11.97	1.78
SUMP/DTD/SMD	43	84.59	14.45	2.20
SUMP/SSD	37	79.53	17.39	2.86
SSD/DTD	35	87.03	9.63	1.63
SSD/SUMP/DTD	23	87.16	9.88	2.06
SMD	19	78.93	15.64	3.59

different mitigation systems revealed the Sub Slab Depressurization (SSD) system to be the best in mitigating the radon gas concentrations to below 4 pCi/l for all the years (refer to Table **8** for 2008 summary of percentage removal for different mitigation systems). Figs. (**9**) and (**10**) show the plots of variation of the removal efficiency with the pre-mitigation and post-mitigation levels for the best system. From Fig. (**9**), one can observe the efficiency of the mitigation systems to decrease with decrease in pre-mitigation level. This is because radon gas concentrations cannot be reduced below a certain level. From Fig. (**10**), it can be noted that average efficiency of the mitigation system decreases with an increase in the post-mitigation level.

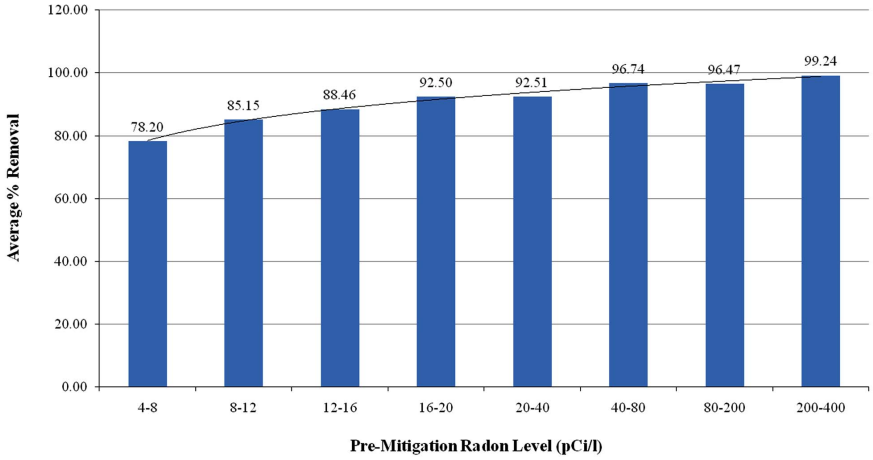

Fig. (9). Variation of removal efficiency with pre-mitigation level for the best performing system (SSD) for year 2008.

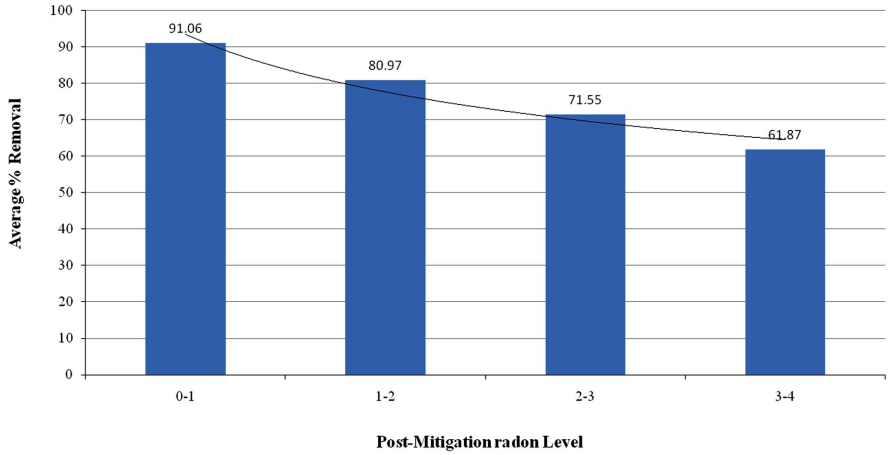

Fig. (10). Variation of removal efficiency with post-mitigation level for the best performing system (SSD) for year 2008.

"Tester" database query results provide more insight into the radon gas concentration levels observed in different counties and zip codes across Ohio. The results of the tester data analysis pertain to the collection period of January 2002 to December 2008. The total number of records and the number of complete records by quarter are shown in Table **9**. Out of 76,727 records reported, 76,280 records (about 99.41 %) were found complete (i.e., having radon gas test levels). It can be observed from Table **9** that there are very few incomplete records in the tester database since 2001. Table **10** provides the statistics for counties with tester radon gas GM >= 4 pCi/l. There are 28 counties that have radon gas test levels above 4 pCi/l (refer Table **10**). Harrison (GM = 10.25 pCi/l) and Perry (GM = 8.65 pCi/l) are the two counties to have GM of radon gas test levels greater than 8 pCi/l in Ohio.

ORIS ON THE WEB

The Ohio Radon Information System, an internet site on radon gas in Ohio is open to public, and was specifically developed to assist the State of Ohio in managing its indoor radon gas problem [17]. The main purpose of this site is to create awareness of the radon gas problem among Ohio's citizens, and provide information on methods of radon gas reduction, to minimize the threat to their health. Besides assisting homeowners, the site also serves various professional constituencies, including radon gas testers, building contractors, realtors, physicians, and government health officials. The information on the ORIS website mainly focuses on the radon gas in Ohio. The ORIS site is divided into the following nine sections: Information on Radon, Preventative Measures, Testing Procedures, Health Risks, Radon Concentrations across Ohio, Lists of Radon Professionals, Other Sources of Information, Geology of Radon, and F.A.Q. (Frequently Asked Questions) [5].

The ORIS website hosts the results from the analyses in the form of tables and Geographic Information System (GIS) [9] maps for the public along with information about radon gas, its health hazards, geologic controls and remediation strategies, and the geographic distribution of radon gas using an indoor radon gas database from 88 counties and more than 1400 zip codes in Ohio. The website hosts the publicly available results of all the radon gas tests in Ohio. The website covers a host of radon gas related issues and addresses some of the major public concerns. This website also has in-depth information from various reliable sources that, calculate important statistical parameters, use advanced computing techniques that are user friendly. It is a graphically superior and interactive website. To enhance the usability and information storehouse of the site, a complete database of the radon gas measurements, over the entire period, is incorporated. The main strength of the site is the

Table 9. Total Number of Tester Records

Quarter	Number of Records	Number of Complete Records	Records Submitted Yearly	Complete Records Submitted Yearly	Percentage of Complete Records (%)
Quarter 1 (Jan.-Mar. 2002)	449	446			99.33
Quarter 2 (Apr.-Jun. 2002)	722	710			98.34
Quarter 3 (Jul.-Sep. 2002)	3503	3408			97.29
Quarter 4 (Oct.-Dec. 2002)	2346	2286			97.44
			7020	6850	
Quarter 1 (Jan.-Mar. 2003)	3581	3492			97.51
Quarter 2 (Apr.-Jun. 2003)	1186	1181			99.58
Quarter 3 (Jul.-Sep. 2003)	3629	3618			99.70
Quarter 4 (Oct.-Dec. 2003)	1137	1136			99.91
			9533	9427	
Quarter 1 (Jan.-Mar. 2004)	1369	1364			99.63
Quarter 2 (Apr.-Jun. 2004)	793	793			100.00
Quarter 3 (Jul.-Sep. 2004)	248	247			99.60
Quarter 4 (Oct.-Dec. 2004)	2441	2434			99.71
			4851	4838	
Quarter 1 (Jan.-Mar. 2005)	3559	3557			99.94
Quarter 2 (Apr.-Jun. 2005)	2509	2507			99.92
Quarter 3 (Jul.-Sep. 2005)	3447	3444			99.91
Quarter 4 (Oct.-Dec. 2005)	2592	2587			99.81
			12107	12095	
Quarter 1 (Jan.-Mar. 2006)	2038	2033			99.75
Quarter 2 (Apr.-Jun. 2006)	6460	6439			99.67
Quarter 3 (Jul.-Sep. 2006)	2855	2851			99.86
Quarter 4 (Oct.-Dec. 2006)	2895	2882			99.55
			14248	14205	
Quarter 1 (Jan.-Mar. 2007)	3320	3314			99.82
Quarter 2 (Apr.-Jun. 2007)	4650	4632			99.61
Quarter 3 (Jul.-Sep. 2007)	2763	2759			99.86
Quarter 4 (Oct.-Dec. 2007)	2962	2954			99.73
			13695	13659	
Quarter 1 (Jan.-Mar. 2008)	3681	3675			99.84
Quarter 2 (Apr.-Jun. 2008)	5140	5124			99.69
Quarter 3 (Jul.-Sep. 2008)	3663	3629			99.07
Quarter 4 (Oct.-Dec. 2008)	2789	2778			99.61
			15273	15206	
			76727	76280	99.42

Table 10. Statistics for Counties with Tester Radon Gas Concentration >= 4 pCi/l

County	Number of Records	Maximum (pCi/l)	Minimum (pCi/l)	AM	GM	Standard Deviation	Variance
HARRISON	12	50.50	0.80	10.74	10.25	6.61	83.93
PERRY	9	36.60	1.70	10.70	8.65	12.22	62.29
ROSS	16	44.60	0.50	8.15	7.91	2.65	70.83
LOGAN	30	46.10	0.40	9.13	7.56	7.49	86.55
MASON	2	10.10	5.20	7.65	7.25	3.46	45.29

Table 10. Cont…

VAN WERT	4	16.70	0.80	6.82	6.77	1.20	40.75
ERIE	131	273.20	0.05	13.34	6.76	16.28	104.27
CARROLL	34	62.10	0.40	7.87	5.69	8.78	84.24
MADISON	37	36.60	0.50	7.46	5.59	7.44	94.59
PICKAWAY	35	22.60	0.40	6.31	5.48	3.95	69.38
DARKE	17	30.10	0.60	7.07	5.32	7.44	101.99
MARION	72	53.60	0.20	8.30	5.32	7.83	89.95
AUGLAIZE	13	13.10	0.50	5.52	5.08	2.48	54.11
COSHOCTON	8	7.80	0.70	5.30	5.08	2.40	77.56
PIKE	164	16.50	0.50	5.79	4.99	3.10	53.51
LICKING	585	296.60	0.20	9.75	4.98	13.80	135.96
KNOX	138	258.00	0.40	14.60	4.95	26.13	158.11
COLUMBIANA	116	77.10	0.20	8.83	4.93	10.09	105.32
CHAMPAIGN	24	36.80	1.00	5.72	4.90	6.07	59.69
HIGHLAND	6	8.80	2.30	4.88	4.88		
FAIRFIELD	254	54.00	0.20	7.58	4.86	7.41	97.47
PREBLE	21	21.70	0.10	5.37	4.61	4.47	69.15
GUERNSEY	4	6.70	1.30	4.50	4.50		
MORROW	29	22.50	0.30	5.24	4.25	3.76	69.50
STARK	1920	111.00	0.10	6.84	4.21	9.03	128.76
TUSCARAWAS	516	134.00	0.05	7.28	4.02	10.01	127.25
DELAWARE	1777	735.00	0.10	6.62	3.99	9.96	132.88
FRANKLIN	7821	939.00	0.05	6.88	3.98	10.07	144.01

availability to users. It has a large, interactive database on Ohio's indoor radon gas levels and geology. Information from these databases is available for every county and most zip code areas within the state.

CONCLUSION

An integrated radon gas information system has been successfully compiled from the data provided by government agencies, university researchers, and commercial testing companies. The information available from the database is useful in assessing the extent of the radon gas problems in Ohio's homes, public water systems, and schools. It was also possible to determine the best mitigation system to control radon gas problem in Ohio homes and identify the counties and zip codes with radon gas test levels greater than 4 pCi/l. The radon gas website developed during the project helps in creating awareness among Ohio's citizens on radon gas issue and provides information on radon gas reduction and mitigation deaths.

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