Relationship between Grain Size Distribution and Radon Content in Surficial Sediments of Wadi Arar, Saudi Arabia

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Abstract—**Surficial sediments with low radon content are desirable materials in construction applications. In this study, the relationship between grain size and radon content was investigated in sediments collected from seven sites in Wadi Arar, Saudi Arabia, with the intent of determining whether grain size analysis could be used for rapidly assessing the suitability of potential construction materials. Thirty-five samples were collected (five per site) and the grain size distribution was determined using sieves. Radon contents were measured on composite samples with a RAD7 radon detector. Among the sediment types (gravel, coarse sand, medium sand, fine sand, and silt and clay), the best linear correlations between grain size and radon contents were found for the coarse sand (negative slope, r=0.82) and fine sand (positive slope, r=0.78). Polynomial relationships were also tested. A fourth-degree polynomial equation effectively described the correlation between grain size and radon content (R^2 = 0.933). As shown by this model, the highest correlations with radon contents were detected at grain sizes smaller than 2.0 mm. Thus, grain size may be useful for preliminary site assessment work.**

Keywords-grain size distribution; Rad7; Radon; construction material; polynomial

I. INTRODUCTION

Radon in construction materials can pose health hazards to building occupants. Thus, knowledge of radon contents in potential source materials would be valuable before natural resources are extracted from particular sites. The health hazard of radon gas is due to its radioactivity. The link between radon and lung cancer has been already established through epidemiological studies in many countries [1-3]. Moreover, authors in [4] correlated radon concentrations with geodynamic, volcanic, and tectonic events. Authors in [5] observed that the radon exhalation rate increases with grain size. Their estimated values of radon exhalation rates for all studied samples were found to be lower than the internationally accepted value of 57–60 Bq m^{-2} h^{-1}. Authors in [6] presented an improvement on previous models of radon emanation from the soil by incorporating soil grain size in addition to moisture. Authors in [7] found that the correlations between raw values of radon concentrations, soil particle size fractions, and elevation were weak. Furthermore, as a result of differences in geological structure, lithology, and climate parameters, an anomaly of ^{222}Rn around Uro in western Sudan was reported in [8]. Regarding construction material selection, authors in [9] found that dune sands located east of Jeddah city should be mixed with crushed fine aggregates prior to use as a construction material, and authors in [10] found that the addition of both lime and cement has a pronounced effect on soil stability by changing its mineralogy. This research therefore makes an important contribution to the literature by highlighting radon as another important factor affecting the selection of construction materials. Wadis in Saudi Arabia are a common source of sediments for construction applications. This study investigates the relationship between sediment grain size and radon contents in Wadi Arar in Saudi Arabia. The objective is to determine if grain size can be used as a rapid assessment technique for predicting radon contents and assessing the suitability of sediments for construction applications.

II. METHODOLOGY

A. Site and Sampling Description

In this work, the relationship between radon content and the grain size of deposits along a 20 km stretch of Wadi Arar (Figure 1) was investigated. The radon content was measured using the RAD 7 technique. The soil is composed of Cretaceous sedimentary rocks such as sandstone, shale, and limestone. The Quaternary sediments within Wadi Arar have previously been investigated [11, 12] and classified as silty sand SM according to the unified soil classification system [11]. The CR-39 technique was previously used to determine the radon contents of Wadi Arar in northern Saudi Arabia [13, 14]. This study expands the results of [14], in which author developed a polynomial equation to determine radon content by incorporating grain size. developed a polynomial equation to determine radon content by incorporating grain size.

B. Samples

Thirty-five fresh surface disturbed samples were collected from seven locations labeled A, B, C, D, E, F, and G. Each location profile included five samples. Profile A was located at the NE point of Wadi Arar adjacent to Arar city, profile G was located in the SW direction facing Aljouf city. The remaining five profiles B, C, D, E, and F were located between A and G (Figure 1). A shovel was used to collect approximately 1 kg of sediment at each sampling point, and the samples were stored in 20 L plastic buckets and transported at room temperature to the laboratory of Northern Border University. The samples were analyzed within one week of collection.

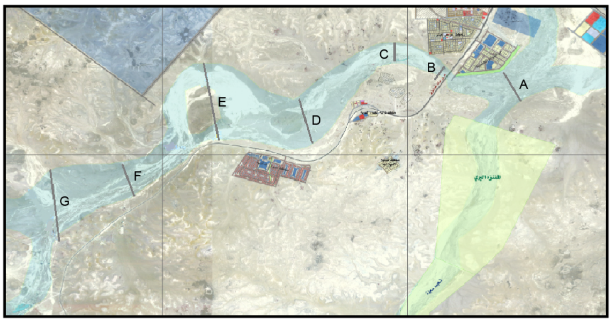

Fig. 1. The seven sampled locations in the study area

C. Radon Contents

Radon content was measured with a RAD7 electronic radon detector according to the methods described in [13]. A single radon concentration value was measured in a composite sample created from portions of the five sediment samples taken at each site. To ensure environmental safety with regard to the radon hazards, the maximum readings for the radon contents (Bq/m^3) were used.

D. Grain Size Distribution

The grain size distribution was determined using a mechanical shaker and a standard set of sieves, as in [14]. Percentages of the retained grains in nine sieves were calculated. The diameters of the used sieves were 4.75, 3.35, 2.0, 1.0, 0.85, 0.425, 0.25, 0.15, and 0.075 mm. According to the unified soil classification system (USCS), the geometric means of each profile were grouped into five groups: gravel (G), coarse sand (CS), medium sand (MS), fine sand (FS), and silt & clay (SC), based on the following sizes in mm:

$G \geq 4.75$

$4.75 > CS \geq 2$

$2 > MS \geq 0.425$

$0.425 > FS \geq 0.075$

$0.075 > SC$

E. Data Analysis

Microsoft Excel was used for the linear regressions and polynomial analysis.

III. Results

A. Mean and Variability

The harmonic mean of the maximum radon content was calculated and then the standard deviations (σ) and coefficients of variation (CV%) were determined. For the grain size distribution, the geometric means, σ, and CV% were constructed from [14] (Table I). According to statistical analysis of the geometric mean, σ and CV%, the relative quantitative distribution of different grain size fractions in Wadi Arar changes with location. Sites A and D show homogeneous grain size distributions, yet sites B, C, E, F, and G are characterized by significantly larger relative quantities of medium- sand, coarse sand, silt & clay, gravel and fine sand, respectively. Sites C, E, and F are also characterized by significant smaller relative quantities of fine sand, medium sand, and coarse sand, respectively. According to the coefficient of variation, the fine sand fraction is relatively more homogenous throughout the study area, whereas gravel is less homogeneous. According to harmonic mean, σ, and CV% values, high radon content was observed in location G.

B. Correlation between Radon Content and Grain Size

Correlation coefficients (r) were calculated to detect and compare the strength and direction of the linear relationship between radon content and various grain size fractions. Figure 2 shows the correlation between radon content and grain size fractions. According to hypothesis testing, coarse sand and fine sand show a highly significant correlation with radon content (P-values less than 0.05) with correlation coefficient values equal to -0.82 and 0.78, respectively. All other fractions show a weak correlation. According to the negative and weak correlation results, all grain sizes except fine sand are suitable for use as a construction material. At a coefficient of determination (R^2) equal to 0.93, and based on measurements obtained, the relationship between grain size and its correlation is a function of a fourth degree polynomial (Figure 3).

C. Polynomial Relationship

The main goal of this work is to find the best model for the maximum radon content in terms of various grain size class percentages because it is much simpler and cheaper to measure grain size percentage than radon content. The term 'best model' refers to the statistical polynomial fit between Rad7-max and grain size with the highest R^2 value. To achieve that target, the following two parameters must be calculated:

1. The degree of the polynomial
2. The grain size fraction or fractions with the highest R^2 value

As there are only seven profiles, the highest possible polynomial degree is six. The polynomial fit used is a statistical polynomial fit with a 95% confidence interval. The relationship between radon content and different grain size fractions was plotted, and the best fit line of the data was deduced for different functions that could represent the relationship, such as linear, logarithmic, power, or polynomial functions. According to the highest values of the coefficient of determination (R^2), the polynomial function was selected as the best function to represent the relationship between radon content and grain size contents. Figure 4 shows the plots and equations for all grain size contents using the fourth degree polynomial function.

TABLE I. MAX RADON CONTENT AND PERCENTAGES OF GRAIN SIZE FRACTIONS FOR GRAVEL (G), COARSE SAND (CS), MEDIUM SAND (MS), FINE SAND (FS), AND SILT AND CLAY (SC).

Site	Rn	G	CS	MS	FS	SC
A	35	19.23	13.82	22.55	19.63	24.77
B	35	10.57	14.63	27.91	18.98	27.91
C	38	16.2	15.49	22.56	18.01	27.74
D	40	13.13	13.1	20.71	19.88	33.18
E	42	9.77	10.98	17.29	20.56	41.4
F	43	31.62	7.57	20.56	20.45	19.8
G	45	11.2	9.91	24.68	23.2	30.99
Mean	39.38	16.29	12.17	22.49	20.32	28.73
σ	3.9	7.68	2.84	3.37	1.62	6.82
CV%	9.91	47.14	23.33	14.97	8	23.74

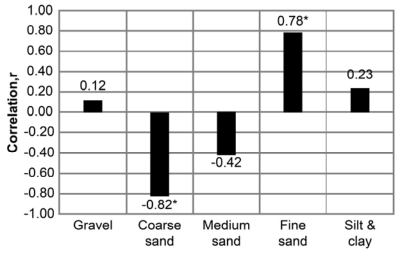

Fig. 2. Correlation between radon content and various grain size fraction (*Correlation is statistically significant at 0.05)

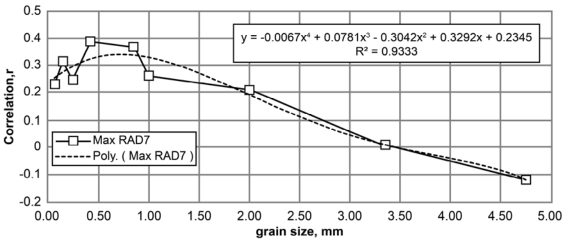

Fig. 3. Grain size vs. its correlation with radon content according to cumulative % passing

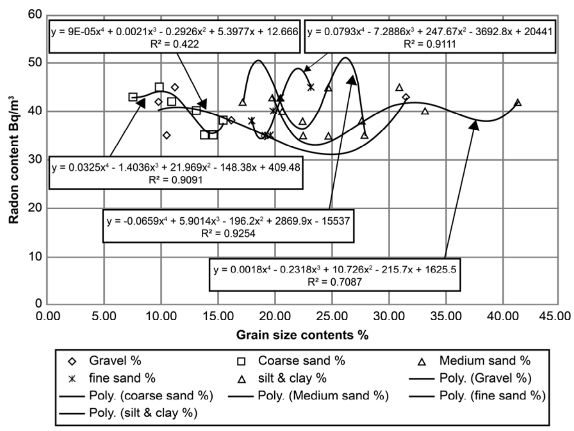

Fig. 4. Polynomial relationship between radon content and grain size contents

D. R^2 Versus Polynomial Degree

The polynomial is more representative when the value of R^2 is high. According to the best fit line of R^2 of each grain size fraction at different polynomial degrees (Figure 5), the relationship between R^2 and the degree of the polynomial can be classified into two clusters. The first cluster indicates a straight line relationship, which includes coarse sand, fine sand, and silt and clay, while the second cluster describes a curved model that includes medium sand and gravel. For the straight line models, coarse and fine sand reflects strong R^2 values for all polynomial degrees (>0.67 and 0.61, respectively), while the silt and clay fraction reflects strong R^2 values for the 3rd degree polynomial (0.61). For the curved models, strong R^2 values are observed for medium sand at the 4th degree polynomial (0.93) and for gravel at the 6th degree polynomial (1.00).

E. Relationship Strength

According to the value of R^2, the strength of the polynomial relationship between radon content and grain size can be classified into three categories: good, medium, and weak. Good relationships are observed for coarse and fine sand, which have the highest values of R^2 at different polynomial degrees. Medium relationships are found for medium sand and silt and clay, which have high R^2 values at the 4th or higher degree of the polynomial. A weak relationship is observed for the gravel fraction, which contains almost all the lowest R^2 values (Figure 5).

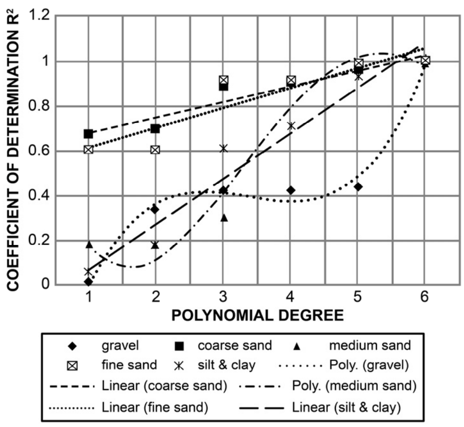

Fig. 5. R^2 values for different degrees of the polynomial function and different grain sizes

IV. STUDY COMPARISON

A comparison with [14] indicates that coarse sand and fine sand display highly significant correlations with both techniques used in these studies. The correlation between grain size and radon content measured using the Rad7 technique is generally higher than that measured using CR-39 (Figure 6). The relationship between the two correlations is linear, with an R^2 of 0.97 (Figure 7). The relationship between the R^2 values of both techniques is linear for fine sand and polynomial for all other fractions (Figure 8).

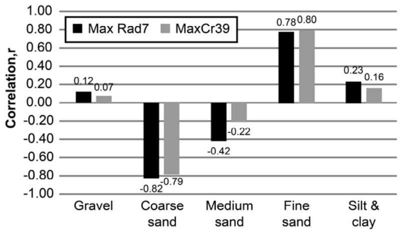

Fig. 6. Correlation between radon content and various grain size fractions for both CR-39 and Rad 7 techniques

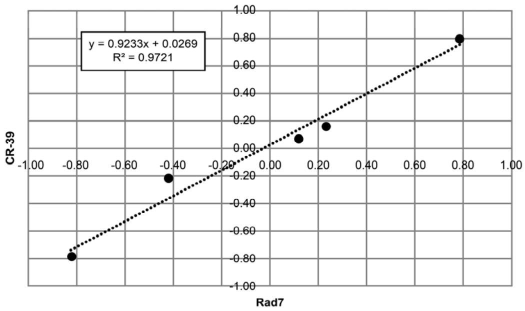

Fig. 7. Relationship between radon content and grain size correlations determined using CR-39 and Rad 7 techniques

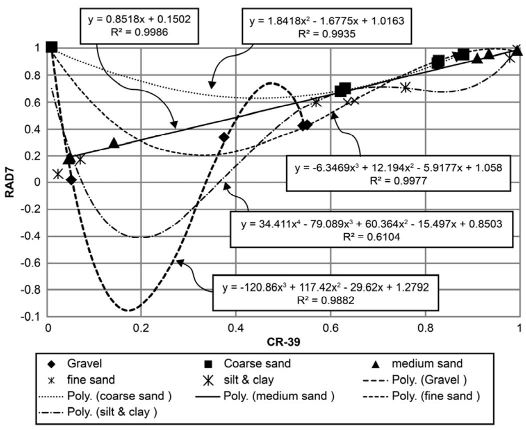

Fig. 8. Relationship between R^2 values for the correlations determined using Cr-39 and Rad7 techniques

V. CONCLUSIONS

The relationship between grain size and radon content was investigated in sediments collected from seven sites in Wadi Arar, Saudi Arabia, with the intent of determining whether grain size analysis could be used for rapidly assessing the suitability of potential construction materials. The main conclusions are as follows:

- The polynomial function is the best model to represent the relationship between radon content and grain size.
- Coarse sand has a correlation coefficient of -0.82 with radon content, which is a strong negative relationship.
- Fine sand has a highly positive correlation with radon content, with a correlation coefficient of 0.78.
- According to R^2 values, the strength of the polynomial relationship between radon content and grain size is good for coarse and fine sand, which have the highest R^2 values at all polynomial degrees, medium for sand and silt and clay, and weak for gravel.
- The relationship between the coefficient of determination R^2, and the polynomial degree shows two different behaviors: a straight line relationship for coarse sand, fine sand, and silt and clay, and a curved relationship for medium sand and gravel.
- According to the fraction type, both linear and polynomial relationships were representative.
- The Rad7 technique reflects higher correlations between grain size and radon content than the CR-39 technique.
- This research shows that fine sand grain size would make bad construction material.

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