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Determination of Radium concentration and radon exhalation rate in soil samples using CR-39

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ABSTRACT

Measurements of radium concentration, radon exhalation rate (surface and mass exhalation rates) were made for a number of 168 measurements of soil samples in some towns of the Gezira State in the central part of the Sudan. In this survey, we used the can technique, containing CR-39, to estimate the radium concentration and radon on exhalation rates from the soils of: El-Hosh, El-Managil and Medani towns in the Gezira State- Central Sudan. The results of radium concentrations and mass and surface exhalation rates from soil samples were found to be 91 ± 7 $Bq.kg^{-1}$, 0.10 ±0.01 $Bq.kg^{-2}.h^{-1}$ and 4.86 ± 0.66 $Bq.m^{-2}.h^{-1}$ for El-Hosh soils, 182 ± 48 $Bq.kg^{-1}$, 0.20 ±0.09 $Bq.kg^{-2}.h^{-1}$ and 9.77 ± 4.38 $Bq.m^{-2}.h^{-1}$ for El-Managil soils and 249 ± 14 $Bq.kg^{-1}$, 0.27 ±0.03 $Bq.kg^{-2}.h^{-1}$ and 13.35 ±1.30 $Bq.m^{-2}.h^{-1}$ for Medani soils. All the values of radium content in soil samples of study towns were found to be quite lower than the permissible value of 370 $Bq.kg^{-1}$ recommended by Organization for Economic Cooperation and Development and larger than the average global value of 30 $Bq.kg^{-1}$, the surface and mass exhalation rates were compared with other values in another countries.

Key words: Radium content, Radon exhalation rates, CR-39 detectors, Can technique, Soil.

INTRODUCTION

Radon is a naturally occurring odorless, colorless, tasteless, inert gas, which is imperceptible to our sense. However, it can change the physical properties of the surrounding medium. Its half- life allows it to migrate long enough to travel long distances and accumulate indoors. It is produced continuously from the decay of naturally occurring radionuclide such as U-238, U-235, Th-232. The isotope $_{222}$Rn, produced from the decay of U-238, is the main source (approximately 55%) of the internal radiation exposure to human life [1].

The radon concentration in the ground depends on the radium content and the permeability of the soil and the emanation power of soils and rocks [2-5].

Radium is a solid radioactive element under ordinary conditions of temperature and pressure. Radium is a decay product of uranium in the naturally occurring uranium series. When radium decays in soil, the resulting atoms of radon isotopes first escape from the mineral to air-filled pores. The rate at which radon escapes from soil into the surrounding air is known as radon exhalation rate of the soil into the atmosphere [6]. This may be measured by either per unit area or per unit mass of the soil. The measurement of radon exhalation rate in soil and building materials is helpful to study radon health hazard [7, 8]. Among many factors affecting radon exhalation, one of the most important is radium content of the bedrock or soil [9]. Being aware of the hazardous effects of radon exhalation on human health, it was necessary to conduct measurements of radium content in the soil. Higher values of ^{226}Ra in soil contribute significantly in the enhancement of environmental radon.

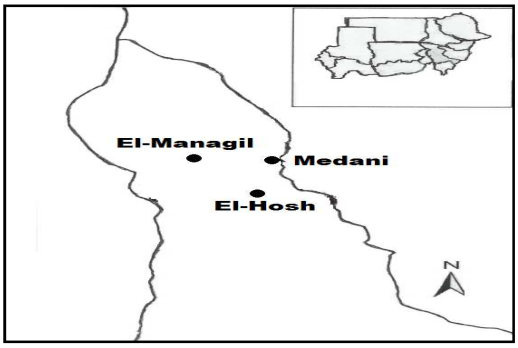
However, radon exposure shows an extreme variation from location to location and depends primarily on the exhalation rate of radon from the soil. Since radium present in the soil is the main source of indoor radon, the estimation of radium content along with the radon exhalation rate in the soil was carried out.

In the present study, investigations have been carried out to measure the radium content and radon exhalation rates in soil samples collected from some towns in Gezira State in Sudan by using can technique containing SSNTDs of type CR-39.

This survey is conducted to continue our various works of measuring indoor radon concentrations[10- 16], soil gas radon concentration[17], radon concentration and exhalation rates in building materials [7] and water [18, 19].

The aim of this work was to determine radium concentration and radon mass and surface exhalation rates from soil samples in El-Hosh , El-Managil and Medani towns in the Gezira State in the central part of Sudan.

Figure 1. The map of the Study area



MATERIALS AND METHODS

The can technique [20–22] was employed for the measurement of radium concentration, radon exhalation rates in soil samples from three towns of Gezira State in Sudan (Figure 1).

An amount of 5 kg from each sample was collected under the depth 30 cm within 1.5m of the foundations of the dwelling in selected locations, the samples were dried in a temperature controlled furnace (oven) at a temperature 100 ± 0.1°C for 24 h to ensure that moisture is completely removed, then the samples were crushed to a fine powder and sieved through a small mesh size to remove the larger grains size and render them more homogenous. About 250 g of each sample was placed in a plastic can of dimensions of 10 cm in height and 7.0 cm in diameter [7]. A passive method (can-technique) using SSNTDs for measurements of radium concentration and radon exhalation rate was used [2, 7, 23, 24].

A piece of CR-39 detector of size 2 × 2 cm was fixed on the top of inner surface of the can, in such a way, that it is sensitive surface always facing the sample. The can is sealed air tight with adhesive tape and kept for exposure of about three months. During exposure period, the detector is exposed freely to the emergent radon from the sample in the can so that it could record alpha particles resulting from the decay of radon in the remaining volume of the can. After that, the dosimeters were separated from the sample cup, collected and chemically etched in a 30% solution of KOH, at $(70.0 \pm 0.10)^{\circ}C$ for a period of 9 hours. The resulting α tracks were counted under an optical microscope of magnification 400X.

The radium concentration in soil was calculated using the relation: [2, 9, 24]:

$$C_{Radium} = \frac{\rho h A}{K T_e M} \qquad \text{..................(1)}$$

Where: C_{Radium} is the effective radium content of soil sample ($Bq \cdot kg^{-1}$), ρ is the track density (tracks per cm^2), M is the mass of the sample (kg), h is the distance between the detector and the top of the soil sample, A is the surface area from which radon is exhaled (m^2), M is the mass of the sample (kg), t is the exposure time and K is the calibration constant which was determined previously to be: K= 3.746×10^{-3} tracks.$cm^{-2}h^{-1}$ per Bq.m^{-3} [7, 24].

T_e is the effective exposure time, which is related to the actual exposure time t, by the relation [23, 24].

$$T_e = t - 1/\lambda(1 - e^{-\lambda t}) \qquad \text{…....................(2)}$$

In order to measure radon concentration and its exhalation rate, using the sealed can technique, the radon exhalation rate in terms of area E_x ($Bqm^{-2}h^{-1}$) is calculated by using Eq. (2), as: [7, 24, 25]:

$$E_x = \frac{\lambda VC}{A[t + \lambda^{-1}(exp(-\lambda t) - 1)]} \qquad \text{......................(3)}$$

Moreover, the radon exhalation rate in terms of mass E_M ($Bqkg^{-1}h^{-1}$) is determined by Eq. (3): [7, 25]:

$$E_M = \frac{\lambda VC}{M[t + \lambda^{-1}(exp(-\lambda t) - 1)]} \qquad \text{……………..(4)}$$

Where: C is the mean radon concentration measured by CR-39 ($Bq.m^{-3}h$), M is the mass of the sample (kg), t is the exposure time (hours), V is the hollow holder volume (m^3), A is the surface area from which radon is exhaled (m^2) and λ is the radon decay constant (h^{-1}).

RESULTS AND DISCUSSION

In the present work, the values of track density per cm^2, radium concentrations and radon surface and mass exhalation rates are determined in a number of 168 soil samples collected from different locations of El-Hosh, El-Managil and Medani towns in Sudan, the relationships between radium concentration and soil gas radon exhalation rates (mass and surface exhalation rates) were examined.

Table 1: Track density per cm^2, Radium concentration, surface exhalation rates of radon(Em) and mass exhalation rates of radon(Ea) different soil samples in El-Hosh town

No	Area	No of samples	$(\rho\pm\Delta\rho)\times10^3$ tracks.cm $^{-2}$	$(C\pm\Delta C)$ $Bq.kg^{-1}$	$(E_a\pm\Delta E_a)$ $Bq.m^{-2}h^{-1}$	$(E_m\pm\Delta E_m)$ $Bq.kg^{-2}h^{-1}$
1	E1	12	2.37 ± 0.29	82 ± 6	4.39 ± 0.53	0.09 ± 0.01
2	E2	12	2.62 ± 0.27	90 ± 5	4.85 ± 0.50	0.10 ± 0.01
3	E3	12	3.14 ± 0.40	108 ± 8	5.80 ± 0.74	0.12 ± 0.01
4	E4	12	2.61 ± 0.36	90 ± 7	4.83 ± 0.67	0.10 ± 0.01
5	E5	12	2.41 ± 0.46	83 ± 9	4.46 ± 0.86	0.09 ± 0.02
		60	2.63 ± 0.36	91 ± 7	4.86 ± 0.66	0.10 ± 0.01

- *E1, E2, E3, E4, and E5 are the regions of the study at El-Hosh town.*

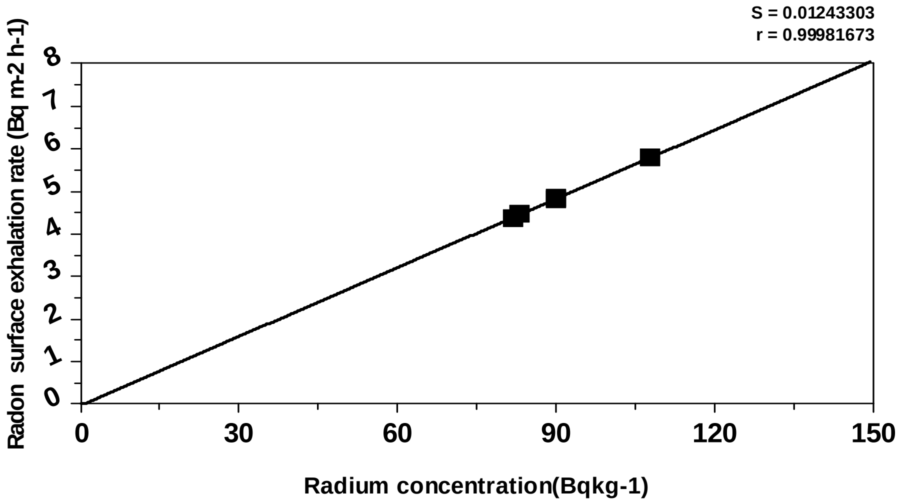


Figure 2. The correlation between radium concentration and Surface exhalation rate for El-Hosh town

Table 1 show the values of track density per cm^2, radium concentrations and surface and mass exhalation rates for soil samples collected from different places of Al-Hosh town. It is seen that the value of radium concentration varies from (82 ± 6) to (108 ± 8) $Bq.kg^{-1}$ with an average value of (91 ± 7) $Bq.kg^{-1}$. This value is the minimum value in this study, this may be attributed to that El-Hosh town is small agricultural town situated inside the Gezira National scheme, the soils sometimes found to be mixed with sands for these reasons the concentration values for soil samples were found to be minimum throughout the studied areas. The average values of surface and mass exhalation rates of radon from soil samples were found to be (4.86 ± 0.66) $Bq.m^{-2}h^{-1}$ and (0.10 ± 0.01) $Bq.kg^{-2}h^{-1}$ respectively.

Figure 2 and 3.Shows the correlation between the radium concentration and the exhalation rates. A positive correlation has been observed between radium concentration with both mass and surface exhalation rate as in soil of the study area. Radon flux density (i.e., ^{222}Rn exhalation rate) depends upon a number of parameters that behave in a stochastic and independent fashion, such as the radioactive disintegration of ^{226}Ra to produce radon, the direction of recoil of radon in the grain, the interstitial soil moisture condition in the vicinity of the ejected radon atom and its diffusion in the pore space [17, 24]. A series of radon exhalation measurements, including the present one, have demonstrated that radon flux density distribution is better represented by a log-normal distribution than by a normal distribution [24, 26].

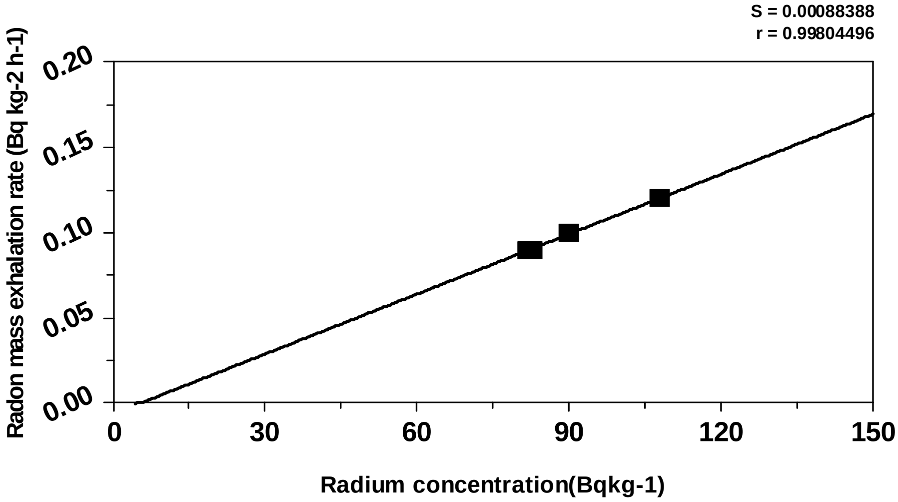


Figure 3. The correlation between radium concentration and mass exhalation rate for El-Hosh town

From table 2. The radium concentration from the soil samples of El-Managil town was found to vary from (178 ± 32) to (208 ± 66) Bq.kg^{-1}, with an average of (182 ± 48) Bq.kg^{-1}, this value is larger than that found for singa town[24]. The average values of surface and mass exhalation rates were found to be (9.77 ± 4.38) Bq.m^{-2}h^{-1} and (0.20 ± 0.09)Bq.kg^{-2}h^{-1}, these values could be compared with others from another areas as in table 4.

Table 2: Track density per cm^2, Radium concentration, surface exhalation rates of radon(*E*m) and mass exhalation rates of radon(Ea) different soil samples in El-Managil

No	Area	No of samples	$(\rho \pm \Delta\rho) \times 10^3$ tracks.cm^{-2}	$(C \pm \Delta C)$ Bq.kg^{-1}	$(E_a \pm \Delta E_a)$ Bq.m^{-2}h^{-1}	$(E_m \pm \Delta E_m)$ Bq.kg^{-2}h^{-1}
1	M1	12	5.18 ± 1.10	178 ± 32	9.57 ± 2.95	0.19 ± 0.06
2	M2	12	4.25 ± 1.06	146 ± 33	7.85 ± 3.04	0.16 ± 0.06
3	M3	12	6.06 ± 1.88	208 ± 66	11.19 ± 6.02	0.23 ± 0.12
4	M4	12	5.66 ± 1.94	195 ± 60	10.47 ± 5.48	0.21± 0.11
		48	5.18 ± 1.10	182 ± 48	9.77 ± 4.38	0.20 ± 0.09

- *M1, M2, M3, and M4 are the regions of the study at El-Managil town.*

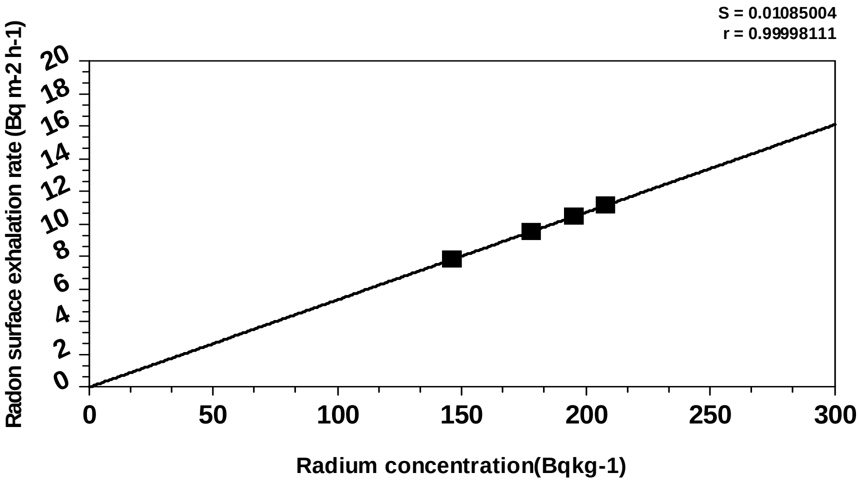


Figure 4. The correlation between radium concentration and surface exhalation rate for El-Managil town

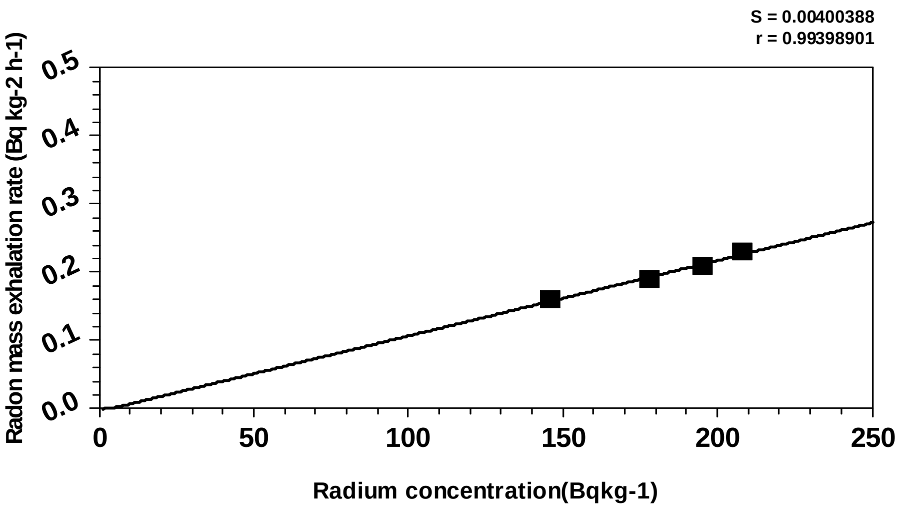


Figure 5. The correlation between radium concentration and mass exhalation rate for El-Managil town

Figures 4 and 5 shows the correlation between radium concentration with both surface and mass exhalation rates for El-Managil town, there is a linear correlation appeared throughout these figures, this findings are similar to that found in others studies[27, 28].

Table 3 Track density per cm^2, Radium concentration, surface exhalation rates of radon(*E*m) and mass exhalation rates of radon(Ea) different soil samples in Medani

No	Area	No of samples	$(\rho\pm\Delta\rho)\times10^3$ tracks.cm^{-2}	$(C\pm\Delta C)$ Bq.kg^{-1}	$(E_a\pm\Delta E_a)$ Bq.m^{-2}h^{-1}	$(E_m\pm\Delta E_m)$ Bq.kg^{-2}h^{-1}
1	W1	12	6.55 ± 0.62	225 ± 21	12.10 ± 1.15	0.24 ± 0.02
2	W2	12	8.25 ± 0.57	284 ± 20	15.24 ± 1.05	0.31 ± 0.02
3	W3	12	7.45 ± 0.76	256 ± 26	13.77 ± 1.40	0.28 ± 0.03
4	W4	12	7.33 ±0.75	252 ± 26	13.55 ± 1.38	0.27 ± 0.03
5	W5	12	6.53 ± 0.83	225 ± 28	12.08 ± 1.53	0.24 ± 0.03
		60	7.22 ± 0.70	249 ± 14	13.35 ± 1.30	0.27 ± 0.03

- *W1, W2, W3, W4, and W5 are the regions of the study at Medani town.*

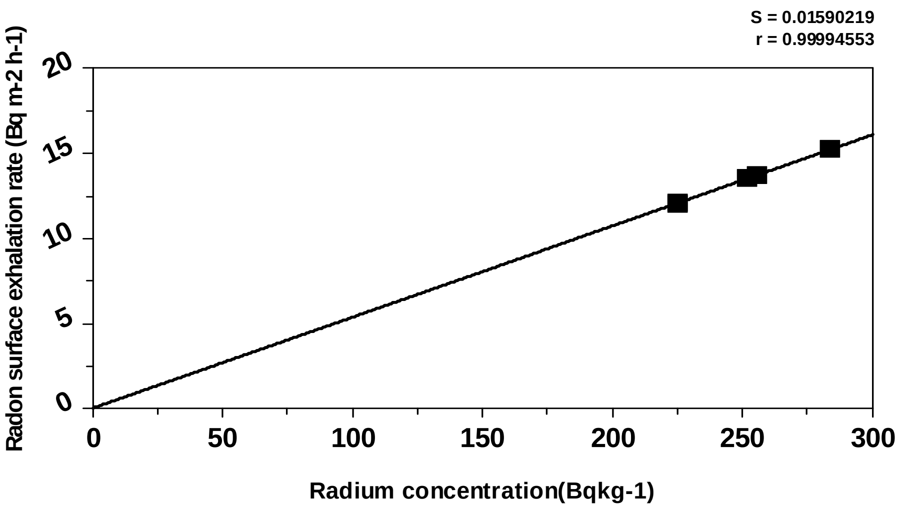


Fig. 6 The correlation between radium concentration and surface exhalation rate for Medani town

Table 3 present the radium concentration values which were found to be (225 ± 28) Bq.kg^{-1}to (284 ± 20) Bq.kg^{-1} with an average of (249 ± 14) Bq.kg^{-1}, the average values of surface and mass radon exhalation rates were found to be (13.35 ± 1.30) Bqm^{-2}h^{-1}, (0.27 ± 0.03) Bqkg^{-2} h^{-1}, in Medani town, respectively. The distribution of the measured values through the town inner areas is found to be in the same range, constituting the higher measured values for all concentrations and exhalation rates in this study.

The higher recorded values for Medani town may be due to its location along the west bank of the Blue Nile, its soil is classified as being belonged to river terrace soils. During its flowing period, the Blue Nile carries large amounts of suspended material (sedimentary deposits) which re-sediments as silt clay, sandy clay, and sand and gravel [24, 29, 30]. The water takes away soil and sand from high altitude through the tributaries falling through the foothills of present mountains from highlands in Ethiopia.

Figures 6 and 7. Presents the radium concentration vs. surface and mass exhalation rates, the relation in both figures are linear relationship between the concentration values of radium and the exhalation rates (surface and mass).

The values of radium concentration were found to be less than the permissible value of 370 $Bq.kg^{-1}$ as recommended by Organization for Economic Cooperation and Development (OECD)[31]. The observed values of radium activity in soil samples in the present study are larger than the global value 30 $Bq.kg^{-1}$ [32]. Table 4 show the comparison between our results in this study with other findings in various locations

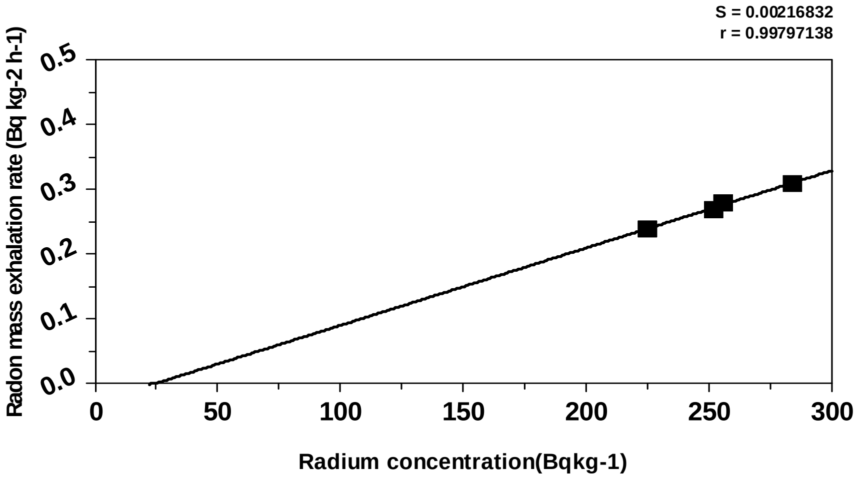


Figure 7. The correlation between radium concentration and mass exhalation rate for Medani town

Table 4. Values of concentration and exhalation rates of radon and radium concentration in different countries as compared with our study

Country	$CBq.kg^{-1}$	$E_aBq.m^{-2}h^{-1}$	$E_mBq.kg^{-2}h^{-1}$	Reference
India	19.6	0.76	0.02	[33]
Saudi Arabia	33	8.4	0.25	[2]
Ethiopia	40.29	-	-	[34]
Rabak Sudan	34	7.2	0.15	[24]
Singa, Sudan	82	17.6	0.35	[24]
El-Hosh, Sudan	91	4.86	0.10	This study
El-Managil, Sudan	182	9.77	0.20	This study
Medani, Sudan	249	13.35	0.27	This study

CONCLUSION

Radium concentration and radon exhalation rates (both the mass and surface exhalation rates) have been measured successfully using CR-39 plastic track detectors. The values radium concentration were found to be less than the permissible value of 370 $Bq.kg^{-1}$ as recommended by Organization for Economic Cooperation and Development (OECD) and larger than the global value 30 $Bqkg^{-1}$ as quoted by UNSCEAR.

Radon exhalation study is important for understanding the relative contribution of the material to the total radon concentration found inside the dwellings. The results of this study were compared with national and worldwide results.From this study, a positive correlation has been observed between radium concentration and area exhalation rate in soil of the study area.

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