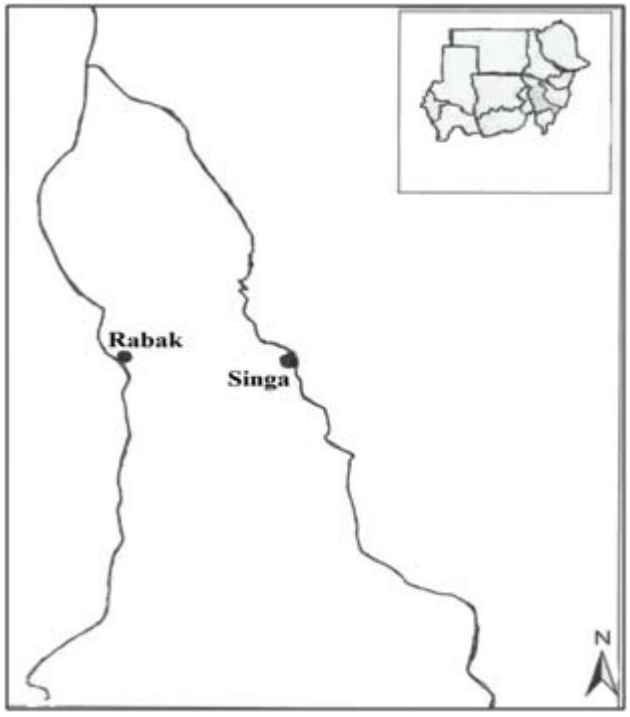

Figure 1: The map of Singa and Rabak towns, Sudan

2. Measurement Technique

The can technique [14–16] was employed for the measurement of radium concentration, radon concentration and radon exhalation rates in soil samples from 10 different locations of Singa and Rabak towns in Sudan (Figure 1). An amount of 4 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 [4]. A passive method (can-technique) using SSNTDs for measurements of radon exhalation rate was used [1, 4, 18, 19].

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 ± 0.10)°C for a period of 9 hours. The resulting α tracks were counted under an optical microscope of magnification 400X.

The track density was determined and converted into activity concentration C_{Rn} (Bq.m^{-3}) by using Eq (1) [4, 17, 20]:

$$C_{Rn} = \frac{\rho}{K\,t} \qquad \text{.....(1)}$$

where ρ is the track density (tracks per cm^2), 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}/Bq.m^{-3} [4].

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 (mBqm^{-2}h^{-1}) is calculated by using Eq (2), as: [4, 20]:

$$E_x = \frac{\lambda VC}{A[t + \lambda^{-1}(exp(-\lambda t) - 1)]} \qquad \text{.....(2)}$$

Moreover, the radon exhalation rate in terms of mass E_M (Bqkg^{-1}h^{-1}) is determined by Eq (3): [4,20]:

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

The radium concentration in soil was calculated using the relation: [1, 17, 20]:

$$C_{Radium} = \frac{\rho hA}{KT_eM} \qquad \text{.....(4)}$$

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

Te is the effective exposure time, which is related to the actual exposure time T by the relation [21].

$$T_e = T - 1/\lambda(1 - e^{-\lambda T}) \qquad \text{.....(5)}$$

3. Results and Discussion

In the present work, the values of radon, radium concentrations and radon exhalation rates are determined in a number of 120 soil samples collected from different locations of Singa and Rabak towns in Sudan. Table 1. represents the radon, radium concentration values and the radon exhalation rates for soil samples in Singa town. Figures 2-4. Presents the radon concentration, radium concentration vs surface and mass exhalation rates of radon for Singa town areas.

The maximum and minimum radon concentration values were found to be 22.8 and 16.0 kBqm^{-3} respectively. The radon, radium concentrations, surface and mass radon exhalation rates were found to be (19.9 ± 2.0)kBqm^{-3}, (82 ± 8) Bqkg^{-1} and (17.6 ± 1.8) Bqm^{-2}h^{-1}, (354 ± 36) Bqkg^{-1}h^{-1}, in Singa towns, respectively. The distribution of the measured values through the town inner areas are 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 Singa town may be due to that, Singa town is located 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 [22, 23]. The water takes away soil and sand from high altitude through the tributaries falling through the foothills of present mountains from highlands in Ethiopia.

Figure 2. present the radon concentration through Singa town areas. Southern singa recorded the maximum value this maybe due to that this area is nearer to the banks of the river this may maximize the concentration value [11]. The minimum value of concentration was measured in the eastern region of the town, this region is noticed to be far from the river and with some grasses and trees, the soil is partly moist and sandy, this may minimize the concentration values [4, 11].

Figures 3 and 4. 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).

Table 2. shows the radon, radium concentration values and the radon exhalation rates for soil samples in Rabak town, while figures 5-7. presents the radon concentration, radium concentration vs surface and mass exhalation rates of radon for Rabak town areas.

The maximum and minimum soil gas radon concentrations were recorded to be 10.7 and 5.1 $kBqm^{-3}$ respectively. The radon, radium concentrations, surface and mass radon exhalation rates were (8.2 ± 0.8) $kBqm^{-3}$, (34 ± 3) $Bqkg^{-1}$ and (7.2 ± 0.7) $Bqm^{-2}h^{-1}$, (145 ± 15) $Bqkg^{-1}h^{-1}$, in Rabak town. The distribution of the measured values through the town inner areas is found to be recording the minimum values throughout this study if we compare with Singa town for all concentrations and exhalation rates in this survey.

The lower recorded values for Rabak town may be due to that, Rabak town is located on the eastern bank of the White Nile. The white Nile is originate from Victoria lake in Uganda, the river is long, the velocity of the water in the stream is slow as compared with Blue Nile. Due to this reason, the most appeared property of the soil is sandy, moist in large regions of the town, this may giving the minimum value of measurements as we compare with Singa town.

Figures 5. present the radon concentration through Rabak town areas. Northern, middle and southern areas of Rabak recorded the same lightly higher value than of the eastern and western regions of the town. All these values maybe due to that the soil is seen to be sandy and sometimes moist; this may minimize the concentration values.

Figures 6 and 7. Presents the Radium concentration vs. surface and mass exhalation rates for Singa town areas. The relationship in both figures are also found to be linear.

A comparison of our results with other results in Sudan and other Countries are shown in Table 3.

Table 1: Values of radon, radium concentrations, radon exhalation rates from soil samples of Singa town, Sudan.

Area	*No of samples*	*Min* $kBqm^{-3}$	*Max* $kBqm^{-3}$	*(C± S.D)* $kBqm^{-3}$	*(E_x± S.D)* $Bqm^{-2}h^{-1}$	*(E_M± S.D)* $mBqkg^{-2}h^{-1}$	*(C± S.D)* $Bqkg^{-1}$
Northern Singa	**12**	**18.35**	**20.5**	**19.5 ± 1.8**	**17.3 ± 1.6**	**347 ± 31**	**80 ± 7**
Southern Singa	**12**	**18.77**	**22.8**	**20.8 ± 2.4**	**18.4 ± 2.1**	**370 ± 43**	**86 ± 10**
Middle Singa	**12**	**18.77**	**21.6**	**20.1 ± 2.0**	**17.8 ± 1.7**	**357 ± 35**	**83 ± 8**
Western Singa	**12**	**18.39**	**21.6**	**20.4 ± 1.8**	**18.0 ± 1.6**	**362 ± 32**	**84 ± 7**
Eastern Singa	**12**	**16.01**	**21.4**	**18.8 ± 2.1**	**16.6 ± 1.9**	**335 ± 38**	**77 ± 9**
Average	**60**	**16.0**	**22.8**	**19.9 ± 2.0**	**17.6 ± 1.8**	**354 ± 36**	**82 ± 8**

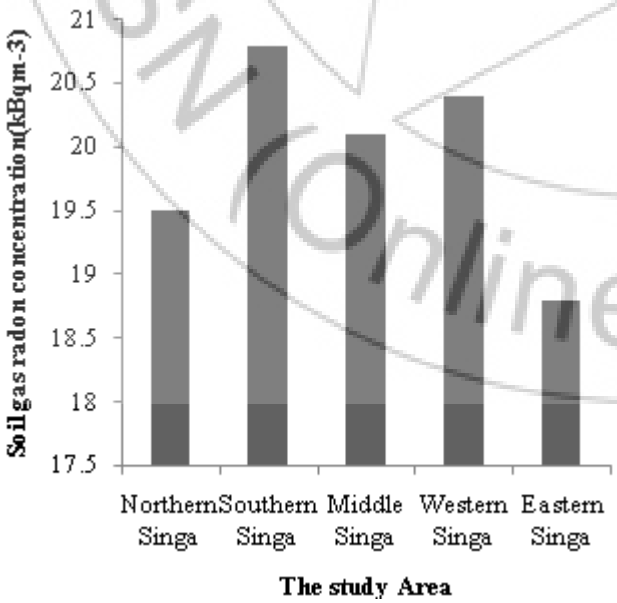

Figure 2: Radon concentration with respect to the study area in Singa town

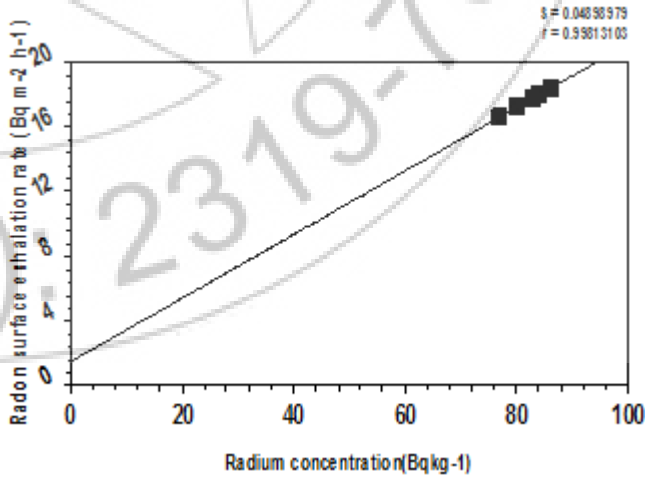

Figure 3: Surface exhalation rate vs. radium concentration for soil samples of Singa town.

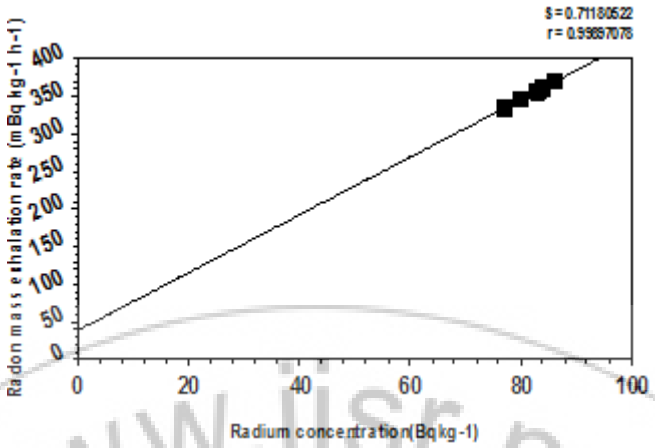

Figure 4: Mass exhalation rate vs. radium concentration for soil samples of Singa town

Table 2: Values of radon, radium concentrations, radon exhalation rates from soil samples of Rabak town, Sudan.

Area	*No of samples*	*Min* $kBqm^{-3}$	*Max* $kBqm^{-3}$	*(C± S.D)* $kBqm^{-3}$	*(E_x± S.D)* $Bq/m^{-2}h^{-1}$	*(E_M± S.D)* $Bqkg^{-2}h^{-1}$	*(C± S.D)* $Bqkg^{-1}$
Northern Rabak	12	7.4	10.7	8.6 ± 0.8	7.6 ± 0.7	153 ± 15	36 ± 3
Southern Rabak	12	6.5	10.2	8.9 ± 1.0	7.9 ± 0.9	159 ± 17	37 ± 4
Middle Rabak	12	7.3	10.2	8.6 ± 0.8	7.6 ± 0.7	153 ± 15	36 ± 3
Western Rabak	12	5.8	9.3	7.3 ± 0.8	6.4 ± 0.7	129 ± 13	30 ± 3
Eastern Rabak	12	5.1	8.4	7.3 ± 0.8	6.5 ± 0.7	130 ± 15	30 ± 3
Average	60	5.1	10.7	8.2 ± 0.8	7.2 ± 0.7	145 ± 15	34 ± 3

Figure 5: Radon concentration with respect to the study area in Rabak town.

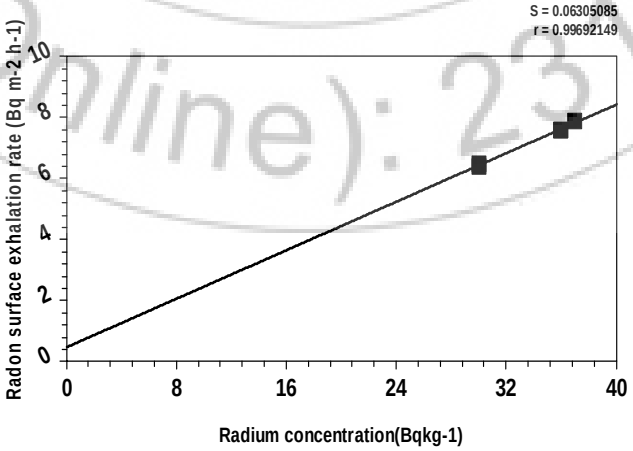

Figure 6. Surface exhalation rate vs. radium concentration for soil samples of Rabak town.

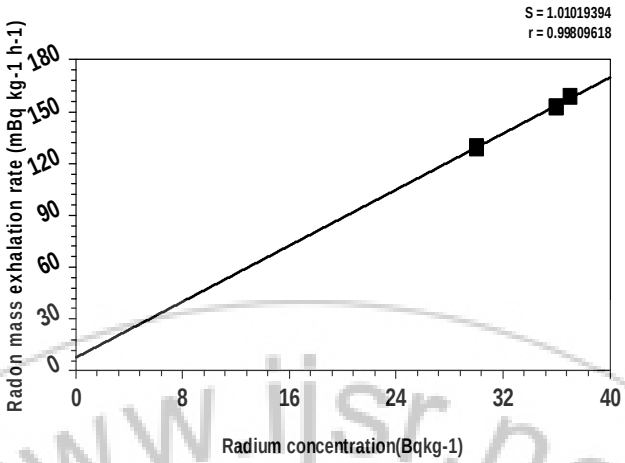

Figure 7. Mass exhalation rate vs. radium concentration for soil samples of Rabak town

Table 3: Values of concentration and exhalation rates of radon and radium concentration in different countries as compared with our study

Country	(C± S.D) $kBqm^{-3}$	(E_x± S.D) $Bqm^{-2}h^{-1}$	(E_M± S.D) $mBqkg^{-2}h^{-1}$	(C± S.D) $Bqkg^{-1}$	Reference
India	-	0.76	23	19.6	[24]
Saudi Arabia	6.71	8.4	251	33	[1]
Ethiopia	-	-	-	40.29	[25]
Egypt	4.35	-	-	-	[26]
Kassala, Sudan	2.63	-	-	-	[11]
Rabak Sudan	8.20	7.2	145	34	This study
Singa, Sudan	19.9	17.6	354	82	This study

4. Conclusions

The can technique containing CR-39 plastic track detectors have been used for the measurement of radon exhalation rate and radium concentration in soil samples collected from Singa and Rabak towns in Sudan. Radium concentration in soil samples varies from (82 ± 8) $Bq.kg^{-1}$ to (34 ± 3) $Bq.kg^{-1}$ for Singa and Rabak towns respectively. The radon exhalation rates in these samples has been found to vary from (19.9 ± 2.0) $kBq.m^{-3}$, (17.6 ± 1.8) $Bq.m^{-2}.h^{-1}$, (354 ± 36) $mBq.kg^{-1}.h^{-1}$ for Singa town, and (8.2 ± 0.8) $kBq.m^{-3}$, (7.2 ± 0.7) $mBq.m^{-2}.h^{-1}$, (145 ± 15) $mBq.kg^{-1}.h^{-1}$ for Rabak town.. The values of radium and radon exhalation rate in soil samples of the study areas are found to be linearly dependent with exhalation rates. The measured values were compared with others all over the world.

5. Acknowledgment

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