Research Article

Determining The Concentration Of Radon Gas In Clayey Soil Sediments Taken From The Depths of The Hasan River In The Shatt Al-Arab District Of Southern Iraq Using A Cr-39 Detector

Sajjad Ali Hassan[1], Jabbar Hafez Jabr[2], Nidal Saleh Fayyad[3]

[1,2,3] Department of Physics, College of Education for Pure Sciences, University of Basrah, Basrah, Iraq
[1]sajjad.hassan@uobasrah.edu.iq
[2]jabbar.hafez@yahoo.com
[3] nsalh5451@gmail.com

Abstract

The purpose of this study is to determine the radon concentration of clayey soil sediment samples taken from the Hasan River in Basra, Iraq using CR39 nuclear track detector. Sediment samples were collected from different locations along the river. Samples underwent an exposure of 90 days followed by chemical etching with 6.25N (NaOH) solution at 70˚ C for 7 hours. The results showed that radon concentration values in the sediment samples collected from different sampling points of Hasan River varied. Variation in radon concentration may be due to variation in the geological nature of the sediments and the environment. The presence of naturally occurring radioactive material was evident in the clayey soil sediments of the Hasan River. The findings of this study are very significant to the distribution of radon gas in the sediments of Hasan River. Furthermore, these findings will assist in determining the environmental radioactivity and radiological condition of the study area.

Keywords: radon concentration, clayey soil sediments, CR-39 nuclear track detector, Environmental radioactivity.

1. Introduction

Radon is an inert gas and forms part of the natural radioactive decay of uranium.

The uranium decay series, the protactinium series, is the source of this radioactivity. Backed by radioactive decay series on protoactinium. 316ฤษภ 2023 You would find radon in three radioactive isotopes 219Rn (actinon), 220Rn (thoron), and 222Rn (radon) with the half-life of 3.96 s, 56.65 s, and 3.82 d respectively [5]. In the USA, radon is considered as the second most important cause of lung cancer after smoking [6]. Soil natural radioactivity is essential indicator of radioactivity contamination. The principal source of natural radioactivity are primordial radionuclides. Moreover, natural radioactivity facilitates the fission of radionuclides into the environment and poses a radiation toxic threat to the health of a person. About 80 per cent of the radiation we encounter comes from Uranium, thorium and Radon. Evidence shows that over half of the annual radioactive dose of the people comes from breathing in and eating natural radioactive radon gas and its daughter products [7]. According to the International Commission on Radiological Protection, radon exposure increases a person's chance of lung cancer. According to epidemiological studies, and studies of uranium miner cohorts in European countries, the risk increased with long-term exposure. In particular, if a smoker is exposed to radon [8]. Some radon decay products also emit beta and gamma radiation, the radiological effect is lower than that of alpha radiation owing to the high ionizing power of alpha radiation [9]. The current study intends to estimate radon concentrations in soil samples collected from the Hassan River region in Basra Governorate, southern Iraq, in the Shatt Al-Arab area. The research uses CR-39 nuclear track detectors to measure the alpha particle emission rate due to radon gas which is reliable and economical. This method which is highly sensitive to detection of alpha particles is used in monitoring environmental radiations. The region being examined is typically uniform due to river sedimentation deposits.

2. Materials and Methods

2.1 Sample Collection and preparation

Twenty-eight sediment samples were obtained from different locations of the Hassan River in the Shatt al-Arab. Samples from the locations were taken at an approximate distance of 500 m. Table 1 represents the longitude and latitude of the samples . The samples were dried in air and cleaned from dirt, washed, and ground into a fine powder to obtain a homogeneous mixture. Around 300 grams of every sample were filled in a cylindrical plastic container whose diameter is 7.5 cm and height is 30 cm. To maintain a sediment depth of 5 cm, we tightly closed the containers to prevent the escape of radon gas and achieve equilibrium [20].

Table 1. represents the longitude and latitude of the samples

Sample number	Location coordinates	
	Latitude"N"	**Longitude"E"**
1	30.55019	47.824303
2	30.553587	47.821739
3	30.556286	47.818264
4	30.558884	47.814732
5	30.561951	47.811707
6	30.565311	47.809132
7	30.569023	47.80727
8	30.57272	47.805393
9	30.576649	47.804337
10	30.580681	47.804176
11	30.584703	47.803791
12	30.588654	47.802849
13	30.592445	47.801254
14	30.596004	47.799065
15	30.599176	47.796173
16	30.601711	47.792545
17	30.603308	47.788258
18	30.60545	47.784306
19	30.609169	47.782486
20	30.613203	47.78236
21	30.617214	47.782845
22	30.620871	47.780869
23	30.624247	47.778313
24	30.627769	47.776047
25	30.630312	47.772427
26	30.631577	47.769112
27	30.631775	47.765457
28	30.630953	47.760849

2.2 Experimental Technique

Radon levels were determined using CR-39 solid nuclear track detectors [20, 23]. Slices with dimensions of (1.5×1.5 cm^2) were made in the detectors which were fixed in the lids of container. The sealed-box technique, a standard method for measuring radon in soil and sediment samples [20, 22], was used. The samples were kept for 90 days. This exposure period allows for radon accumulation and radioactive equilibrium to be reached within the sealed system [20].

2.3 Chemical Etching Procedure

Chemical etching was performed using sodium hydroxide (NaOH) solution according to the standard CR-39 etching procedure [20, 21]. The reagents were etched at 70 °C for 7 hours under controlled laboratory conditions. During chemical etching, the affected areas resulting from alpha particle reactions dissolve at a faster rate than the unaffected areas, leading to visible traces on the reagent surface [20, 21]. The normality of the sodium hydroxide solution was calculated using the following equation:

$$\mathrm{N} = \frac{\mathrm{W} \times 1000}{\mathrm{V} \times \mathrm{M_w}}$$

Where:

N: normality
W: weight of NaOH
V: volume of distilled water
M_w: molecular weight of NaOH (40 g/mol)

3.Calculation of Radon Concentration and Related Parameters

Alpha-particle track density was determined by optical microscopy of the chemical etched CR-39 detectors. Radon concentration in sediment samples was calculated using measured track density. Furthermore, we calculated the surface exhalation rate, mass exhalation rate, and effective radium content using the standard equations provided in literature [5,15,20-22].

The track density was calculated using the following equation:

$$\rho = \frac{N_{av}}{A} \quad \text{……………………………………… (1)}$$

The uncertainty in track density was determined using the following equation:

$$\frac{\Delta\rho}{\rho} = \sqrt{\left(\frac{\Delta N_{av}}{N_{av}}\right)^2 + \left(\frac{\Delta A}{A}\right)^2} \quad \text{………………………………(2)}$$

The radon concentration in sediment samples was calculated according to the following equation:

$$C = \frac{\rho}{KT} \quad \text{………………………………(3)}$$

The effective exposure time was calculated using the following equation:

$$T_{eff} = t - \frac{1}{\lambda}(1 - e^{-\lambda t}) \quad \text{…………………(4)}$$

The surface exhalation rate of radon was determined using the following equation:

$$E_A = \frac{CV\lambda}{AT_{eff}} \quad \text{……………………………(5)}$$

The mass exhalation rate was calculated according to the following equation:

$$E_M = \frac{CV\lambda}{MT_{eff}} \quad \text{………………………(6)}$$

The relationship between radon concentration and effective radium content can be expressed as follows:

$$C_{Rn} = C_{Ra}(1 - e^{-\lambda t}) \quad \text{………………………(7)}$$

The effective radium content was calculated using the following equation:

$$C_{Ra} = \frac{\rho h A}{KMT_{eff}} \quad \text{……………………..(8)}$$

Where:

ρ = track density (track $/cm^2$)
C = radon concentration (Bq/m^3)
K = calibration factor
T = exposure time
E_A= surface exhalation rate (Bq/$m^2.h$)
E_M= mass exhalation rate (Bq/kg.h)
C_{Ra}= effective radium content (Bq/kg)
V= effective volume of the container
A= sample surface area
M= mass of sample
h = distance between detector and sample surface
λ= decay constant of radon

4.Results and Discussion

This chapter presents and discusses the results of the CR-39 nuclear particle trace detector technique. The concentration of radon, surface exhalation rate, mass exhalation rate and active radium content in sediment samples from various locations of Hasan river was determined using measured trace intensity of alpha particle. The resulting values were compared to determine the variation in natural radioactivity among the studied sites.

4.1 Track density and radon concentration

As observed in the Table 2 the track density corresponding to the sediment sample taken from the Hassan river and the calculated radon concentration. Measurements were performed using a CR-39 nuclear track detector after chemical treatment, according to the experimental conditions described in the methodology. The results obtained were used to evaluate the distribution of radon concentration among the studied sampling sites.

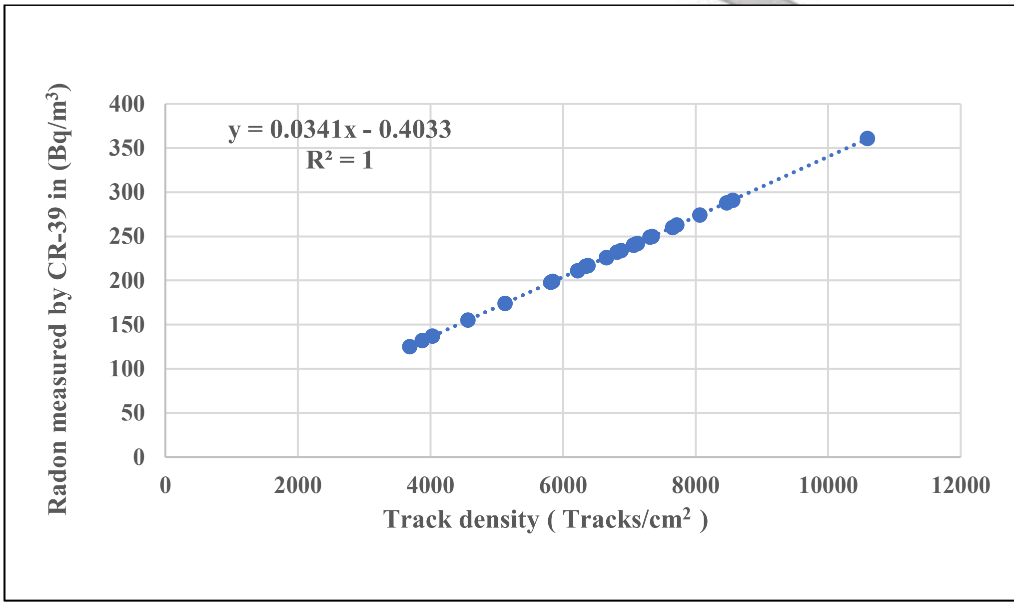
Table 2. Alpha-particle track density and radon concentration in sediment samples.

S.N	Track density $\rho \left(\frac{Tr}{cm^2}\right)$	C_{Rn} Passive $\left(\frac{Bq}{m^3}\right)$
S1	7125 ± 648	242 ± 31
S2	6656 ± 617	226 ± 29
S3	8468 ± 738	288 ± 36
S4	3875 ± 423	132 ± 18
S5	6343 ± 596	216 ± 28
S6	4031 ± 435	137 ± 19
S7	7343 ± 663	250 ± 31
S8	6813 ± 627	232 ± 29
S9	5844 ± 562	199 ± 26
S10	8063 ± 711	274 ± 34
S11	5125 ± 512	174 ± 23
S12	6375 ± 598	217 ± 28
S13	7063 ± 644	240 ± 30
S14	5813 ± 560	198 ± 26
S15	7719 ± 688	263 ± 33
S16	7656 ± 684	260 ± 33
S17	8563 ± 744	291 ± 36
S18	7063 ± 644	240 ± 30
S19	3688 ± 410	125 ± 17
S20	10594 ± 877	361 ± 44
S21	7063 ± 644	240 ± 30
S22	6375 ± 598	217 ± 28
S23	6656 ± 617	226 ± 29
S24	4563 ± 473	155 ± 21
S25	6219 ± 587	211 ± 27
S26	6875 ± 632	234 ± 30
S27	7094 ± 646	241 ± 30
S28	7313 ± 661	249 ± 31
Min.	**3688±410**	**125±17**
Max.	**10594±877**	**361±44**
Ave.	**6656±616**	**226±29**

As evident from table 2, the intensity of the alpha particles trails (the number of particles in 1.0 cm length) and the concentration of radon were found to be different in sediment samples under study. The average radon concentration is 226 Bq/m³ with the highest concentration being 361 Bq/m³. Sample S20 had the highest measurement and S19 had the lowest measurement. The sampling points from different locations show the variations in uranium and radium, rock composition of the samples, f grain size distribution and moisture content. Because of the continuous decay of radium-226 to radon, sediments richer in radioactive minerals produce a more intense and concentrated trails of alpha particles.

The CR-39 detector has been shown by others in concentrated studies of radon distribution in environmental samples [5, 15, 20, 21].

Figure 1. Relationship between track density and radon concentration in sediment samples.



As displayed in Figure 1, a relationship between track density and radon concentration in sediment samples from Hasan River is seen. The Coefficient of Determination ($R^2 = 1$) shows a strong positive linear relationship between both variables. The findings solidified the record of track density by CR-39 detector was directly proportional to radon concentration. Because alpha particles produced by radon and its decay products create latent tracks in the detector, if the concentration of radon increases, the number of tracks will increase. As a result, under the same experimental conditions, the track density, may be considered a good indicator for estimating radon concentration. This linear relationship corroborates the CR-39 detection principle and previously reported studies using solid-state nuclear track detectors for measuring radon in the environment [12, 20, 23]..

4.2 Radon Exhalation Rate

Radon exhalation rate is an important radiometric indicator since it reveals the amount of radon released out of sediments in the environment. In the present study, surface exhalation rate and mass exhalation rate were calculated from the recorded radon concentration by using the equations given in the method. Table 3 presents the resulting values as a function of the radial distance.

Table 3. Surface and mass exhalation rates of radon in sediment samples.

S.N	E_xA $\left(\frac{mBq}{m^2.h}\right)$	E_xM $\left(\frac{mBq}{kg.h}\right)$
S1	0.000468	0.090099
S2	0.000437	0.084172
S3	0.000556	0.107092
S4	0.000254	0.049001
S5	0.000416	0.080220
S6	0.000264	0.050977
S7	0.000483	0.092866
S8	0.000448	0.086154
S9	0.000384	0.073900
S10	0.000530	0.101961
S11	0.000337	0.064808
S12	0.000419	0.080615
S13	0.000464	0.089315
S14	0.000382	0.073508
S15	0.000507	0.097611

S16	0.000503	0.096814
S17	0.000563	0.108284
S18	0.000464	0.089315
S19	0.000242	0.046637
S20	0.000696	0.133967
S21	0.000464	0.089315
S22	0.000419	0.080615
S23	0.000437	0.084169
S24	0.000300	0.057702
S25	0.000409	0.078643
S26	0.000452	0.086938
S27	0.000466	0.089707
S28	0.000481	0.092477
Min.	**0.000242**	**0.046637**
Max.	**0.000696**	**0.133967**
Ave.	**0.000437**	**0.084174**

As shown in Table 3, a significant difference was observed in mass and surface radon exhalation rates among the sediment samples. The surface exhalation rates were between 0.000242 and 0.000696 (mBq.kg-2.h-1) while the mass exhalation rates were between 0.046637 and 0.133967. The highest exhalation rates are observed in sample S20 like the corresponding radon concentration change. The active radium content, sediment porosity and permeability, moisture content, and particle size are primarily responsible for the differences which affect radon diffusion and migration from sediment particles to surrounding air. The outcomes corroborate with earlier works which have established the direct association of radium concentration with radon exhalation rate [5, 20, 21].

Figure 2. Distribution of mass radon exhalation rate in sediment samples.

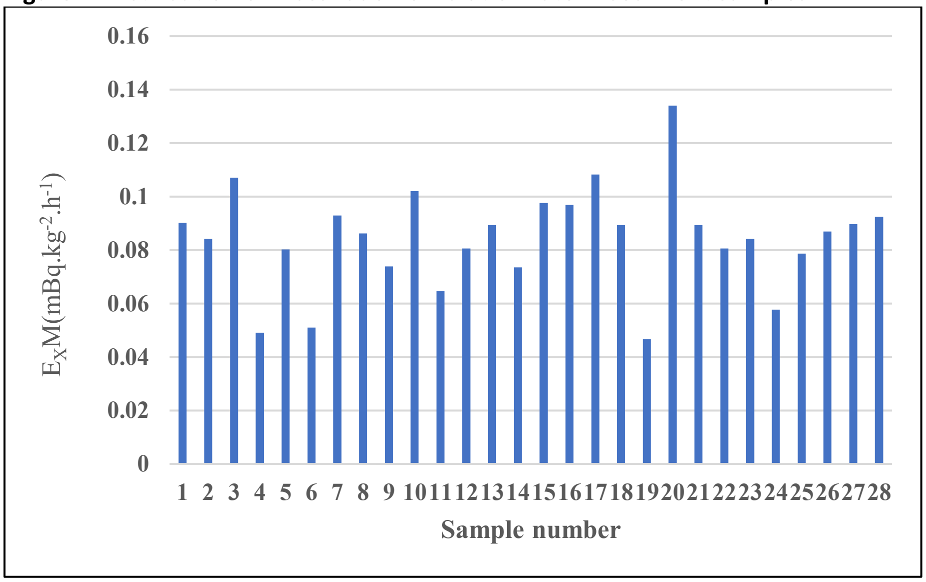
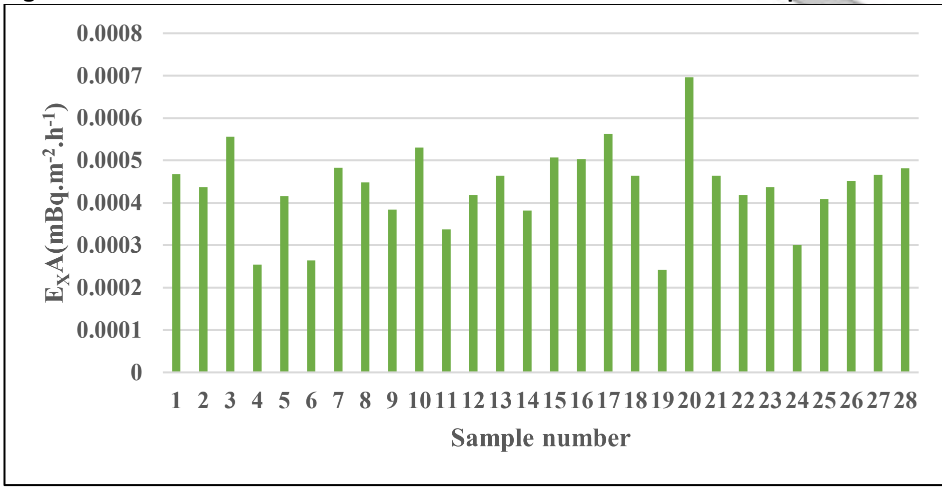


Table 3 shows presence of radon in sediment samples and specific activity and radon exhalation from soil. The measured values were computed as follows: from 0.046637 (mBq.kg-2.h-1) to 0.133967 (mBq.kg-2.h-1) with an average of 0.080615 (mBq.kg-2.h-1). Sample S20 recorded the highest E_xM, while sample S19 recorded the lowest as seen in this experiment. The disparity of E_xM in the samples is due to the differences in their effective radium contents, effective uranium concentrations, mineral compositions, porosity, grain size and moisture content of the sediments. Radon is continuously generated from radium-226 as it decays. Thus, samples with higher radium content exhale radon at a greater rate. The outcome obtained here is consistent with prior studies which similar behaviour of environmental sediment and soil samples using the CR-39 nuclear particle trace detector [5, 20, 21].

Figure 3. Distribution of surface radon exhalation rate in sediment samples.



As depicted in Figure 3, the distribution of surface radon emission rates (Ex) for 28 sediment samples, collected from various locations along the Hasan River was determined. The average and measured values were 0.000462 and the range was 0.000242-0.000696 (mBq.kg-2.h-1). The maximum surface emission rate was found in sample S20 and the minimum was found in sample S19. According to the samples, the variation in the radon exhalation rate is mainly due to the effective radium content of the uranium concentration, and mineral composition, porosity, grain size and moisture content of the sediments. All these factors affect radon emission from the sediment surface to the atmosphere.

Radium-rich samples typically displayed more elevated surface radon emission rates, results revealed. The obtained results agree with previous studies which measured the radon emission from soil and environmental sediment samples using the CR-39 nuclear track detector [5, 20, 21].

4.3. Effective Radium Content

The estimate of active radium content in the sediment samples was done to assess the quantity of radium-226 responsible for radon emission in the samples studied. Sediemnts' natural radioactivity and potential for radon gas generation may be inferred from this indicator's value. The values calculated are given in Table 3.

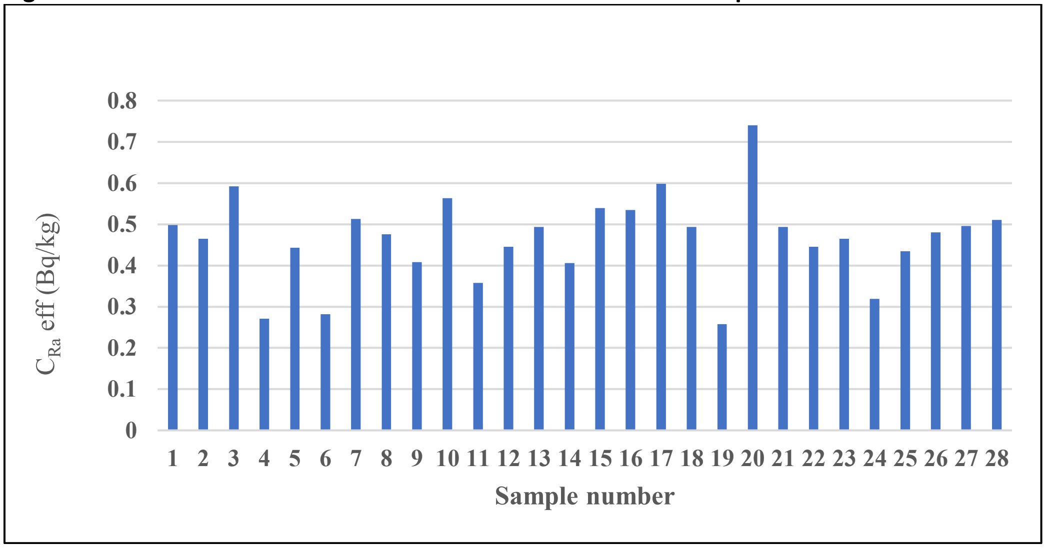
Table 4. Effective radium content in sediment samples.

S.N	Ra_{eff} $\left(\frac{Bq}{kg}\right)$
S1	0.497787
S2	0.465038
S3	0.591668
S4	0.270726
S5	0.443205
S6	0.281643
S7	0.513070
S8	0.475989
S9	0.408290
S10	0.563320
S11	0.358057
S12	0.445388
S13	0.493455
S14	0.406124
S15	0.539287
S16	0.534885

S17	0.598252
S18	0.493455
S19	0.257661
S20	0.740148
S21	0.493455
S22	0.445388
S23	0.465020
S24	0.318793
S25	0.434489
S26	0.480321
S27	0.495621
S28	0.510921
Max.	**0.740148**
Min.	**0.257661**
Ave.	**0.465052**

According to data presented in Table 4, the effective content of radium ranged from 0.257661 Bq/kg to 0.740148 Bq/kg with an average of 0.465052 Bq/kg. Sample S20 of the samples taken showed the highest effective radium content while S19 the lowest. The differences between the samples would be due to the natural distribution of the uranium-series radionuclides within the sediments from different locations on the Hasan River. Because radium-226 is the native radioactive isotope of radon-222, the samples with the highest effective radium content exhibited higher radon concentrations and higher emission rates. Overall, the values obtained indicate natural variations in environmental radioactivity and are consistent with results reported in previous studies using CR-39 nuclear trace detectors [4, 12, 20].

Figure 4. Distribution of effective radium content in sediment samples.



Sediment samples from different locations along Hasan River were analysed for their active radium (Cra) content. The analysis has been shown in **Fig. 4**. Active radium content was found to vary considerable among the samples and those values examined ranged from 0.257661 Bq/kg to 0.740148 Bq/kg with average 0.465052 Bq/kg.

The sample S20 had the highest active radium content while S19 had the lowest active radium content. The cause of these differences is found largely in the natural distributions of uranium-series radionuclides, mineral composition and the geological characteristics of the sediment sampling sites. As the native radioactive isotope of radon-222 is radium-226, so the samples with the more active (higher active radium content) radium also showed higher radon concentrations in the growth medium and a higher emission rate. The findings are in alignment with earlier research that found comparable variations in natural environmental samples using the CR-39 nuclear track detector [4,12,20].

Figure 5. Distribution of radon concentration in sediment samples.

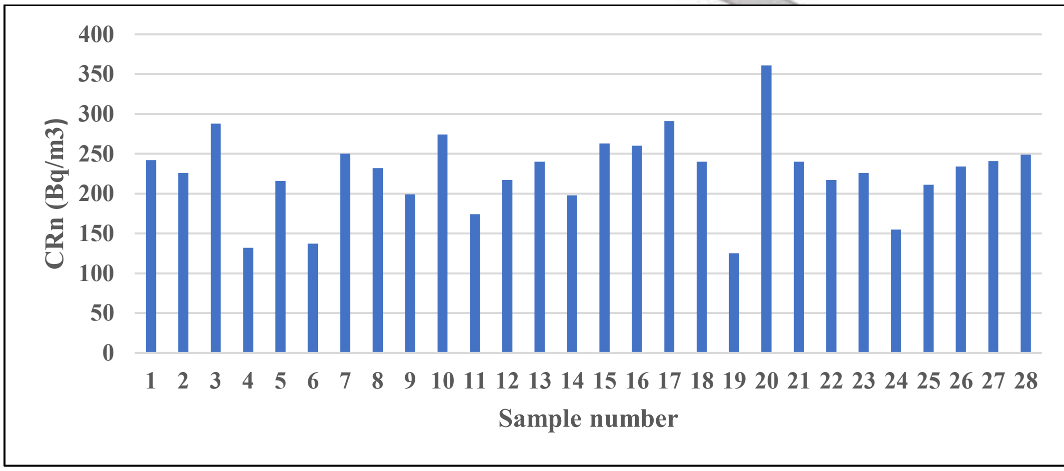
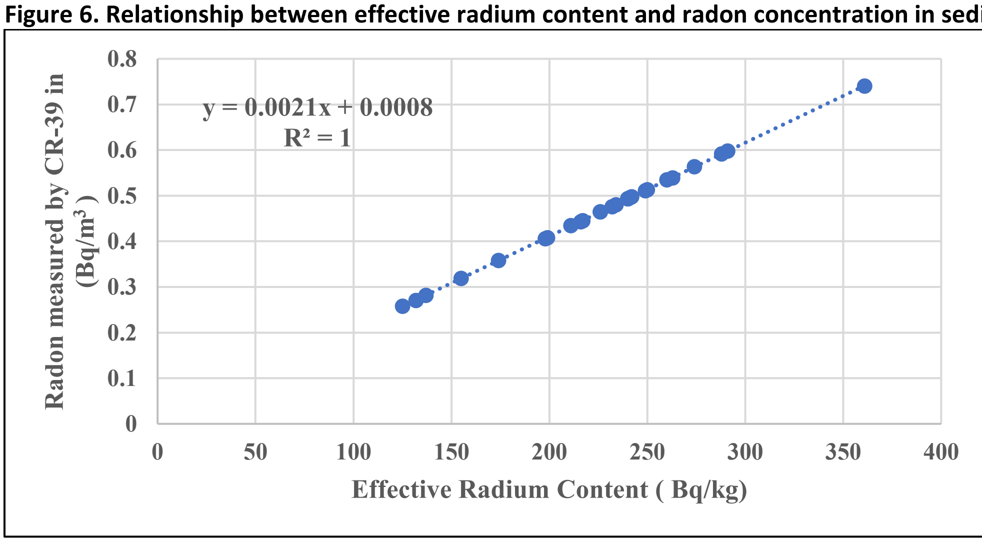


Figure 5 shows how radon concentration varied in sediment samples from different locations of Hasan River. Findings indicate a notable range of radon concentration in the samples studied, with values from 125 to 361 Bq/m³ and the average concentration of 226.36 Bq/m³. The maximum radon concentration was detected in sample S20 while the minimum was observed in sample S19. The most measured samples probably showed intermediate concentrations of radon which depicts natural distribution of radioactive elements within the river sediments. The differences in uranium and radium contents, mineral composition, grain size, moisture content, and geology of the sampling sites. According to the measured radon concentrations, it is concluded that the radioactivity is normal and is essentially consistent with other studies on environmental sediment samples conducted with the CR-39 detector [5 , 12 , 15 , 20].

Figure 6. Relationship between effective radium content and radon concentration in sediment samples.



The relationship between active radium content and radon concentration in sediment samples are shown in **figure 6**. The relationship between the two variables showed a strong positive linear correlation ($R^2 = 1$). The proportionality relationship suggests an increase in radon concentration with an increase in the active radium content. Due to radium-226 being the immediate native radioactive isotope of radon-222, greater radium concentration generates more radon. Therefore, radioactivity concentrations of radon are higher due to greater active concentration of radium in the samples. The resulting linear relationship confirms the efficacy of the CR-39 detector at estimating natural radioactivity in environmental samples and is corroborated by studies that established a direct relationship between radium content and radon concentration in soils and sediments [4, 12, 20, 21].

5.Conclusions

The study shows that the CR-39 nuclear particle trace detector is a consistent and efficient technique for measuring the radon gas concentration and the radioactive properties of sediment samples obtained from the Hasan River. The measured particle trace intensity exhibited a direct linear correlation with radon concentration, affirming the detector's appropriateness for environmental radiation evaluation. [12, 20, 23] Results indicated that the particle trace intensity, radon concentration, surface radon exhalation rate, mass radon exhalation rate and effective radium content varied significantly among sediment samples studied. These differences can be attributed to the geological characteristics of the sampling sites, uranium and radium concentrations, mineral compositions, grain size distributions, and moisture contents of sediments, which influence the generation and transport of radon .The effective radium contents were strongly correlated with radon concentrations and radon emission rates. Samples containing a higher content of active radium generally showed a higher concentration of radon and a higher exhalation rate. It confirms radium-226 is the main source of radon generation in the sediments studied. The radioactive decay series of uranium and the earlier works utilizing CR-39 nuclear trace detectors [4, 12, 20, 23] permit getting these results. According to the report, the measured radiological parameters were conforming to those reported for natural sediments, and there was no indication of abnormal accumulation of naturally occurring radionuclides. As per the details available, the sediments studied are unlikely to cause any radiological hazard to the environment under the conditions of the study. Nonetheless, future monitoring of the environment is recommended for detecting any changes due to natural processes or human activity [21, 24, 25]. In general, the study found useful baseline data on radon gas concentration, exhalation rates and active radium content of the sediments of Hasan River. The information may be useful in future environmental radiation monitoring efforts and can serve as a reference for changes to natural radioactivity in the studied area.

6.References

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