

Geochemical Evolution of Radon Gas in Urban Environment

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Abstract

Natural background radiation is the major source of radiation exposure to humans, with radon (^{222}Rn) and thoron (^{220}Rn) contributing significantly to inhalation doses. These radioactive gases originate from the decay of uranium and thorium present in soils, rocks, and building materials. Radon and thoron decay products attach to airborne particles and, when inhaled, can deposit in the respiratory tract, increasing the risk of lung diseases. While radon has been extensively studied, thoron is often neglected due to its short half-life. However, recent studies indicate that thoron may contribute substantially to radiation exposure in certain environments. This study evaluates the concentrations of radon, thoron, and their progeny in various indoor environments and examines the influence of floor and wall covering materials. Special attention is given to coastal regions such as Chennai, where geological conditions may affect radionuclide levels. The findings provide valuable baseline data for environmental radiation monitoring, radiological impact assessment, and public health studies related to low-dose radiation exposure.

1. INTRODUCTION

Exposure to ionizing radiation originates from two major sources viz: naturally occurring and manmade sources. Naturally occurring radioactivity present on the earth's crust can be further classified into two distinct source categories such as virgin and modified natural sources. Virgin sources of radiation are of cosmogenic or primordial (terrestrial) origin and have existed on the earth since primordial times. Modified natural sources are mainly from activities like mining, usage of fossil fuel, production of fertilizers or usage of natural materials for building constructions. The latter is known as Technologically Enhanced Natural Radiation (TENR). Natural radiation is the largest contributor to the collective radiation dose to the world population. Relatively constant exposure to the population at a location is the distinctive characteristics of this radiation. The major contribution of dose from natural radiation in normal background regions arises due to inhalation of radon and its progeny and to a certain extent, due to thoron and its progeny (Porstendorfer, 1994; UNSCEAR, 2000).

Ever since studies on uranium miners established the presence of a positive risk coefficient for the occurrence of lung cancer in miners exposed to elevated levels of radon and its progeny, there has been a great upsurge of interest in programmes concerned with the measurement of radon in the environment.

This interest was accentuated by the observations of elevated radon levels in the indoor environment in many countries that led to the realization of residential radon as being a possible public health issue in the western world. It was also hoped that in conjunction with epidemiological studies, large scale indoor radon surveys might lead to quantitative understanding of the low dose effects of radon exposures. As a result of these, considerable amount of information is now available on the levels of radon gas and its progeny in the indoor environment across the globe (UNSCEAR, 2000).

In contrast, there exist only a few studies relating to measurements of thoron in the environment (Doi and Kobayashi, 1994; Doi *et al.*, 1994) since it is assumed that the inhalation dose to the general population from thoron and its progeny is only about 10% of the inhalation dose due to radon (UNSCEAR, 2000). But, recent studies in many countries have revealed that this assumption may not be entirely correct (Steinhausler *et al.*, 1994). In general, such studies are important

in two ways. Firstly, any radiological impact assessment of nuclear facilities, either existing or those to be set up in the future, requires information on the exposure due to natural radiation prevalent in their vicinity. Secondly, the radiation risk coefficients are fairly well established at high doses and high dose rates, whereas little is known about the effects of radiation at low dose rates. Several epidemiological study programmes in different countries are in progress to estimate the population exposures due to natural radiation with a view to obtain the radiation risk coefficients at low dose rate levels. In this regard, radiation surveys in high background areas (HBRAs) can provide excellent settings for epidemiological studies relating to the effects of low doses of radiation. In view of these, a comprehensive estimate of the natural inhalation dose requires both radon and thoron levels in the indoor and outdoor atmosphere.

Radio nuclide's such as ^{222}Rn and ^{220}Rn , from the uranium and thorium decay chains are noble gases produced by the decay of their immediate respective parent nuclides, ^{226}Ra and ^{234}Th , present in natural rocks, uranium ores and soils. The decay products of ^{222}Rn and ^{220}Rn are the radioactive isotopes of polonium, bismuth, lead and thallium. The ^{222}Rn decay products are divided into two groups; the short-lived ^{222}Rn daughters such as ^{218}Po (RaA), ^{214}Pb (RaB), ^{214}Bi (RaC) and ^{214}Po (RaC') with half-lives below 30 min, and long-lived ^{222}Rn decay products such as ^{210}Pb (RaD), ^{210}Bi (RaE) and ^{210}Po (RaF). However, ^{220}Rn progeny has no long-lived group. Most important radionuclide in this chain is the lead isotope ^{212}Pb with a half-life of 10.6 h. These decay products, being the isotopes of heavy metals, get attached to the existing aerosols, suspended particulate matters, in the atmosphere.

Historically ^{222}Rn and ^{220}Rn are called as radon and thoron, respectively. ^{222}Rn decays with a half-life of 3.83 days by alpha emission to a series of particulate progeny. These particulate progeny (of ^{222}Rn) are also radioactive and decay through a series of alpha and beta emissions. ^{220}Rn also decays by alpha emission with a half-life of 54.6 s to a series of particulate progeny having similar but different half-lives and emissions than the progeny of ^{222}Rn . Although the decay products of ^{222}Rn are the dominant source of radiation exposure. Evidence indicates that the equivalent radiation dose from thoron (^{220}Rn) and its progeny is about 5%-30% of that due to ^{222}Rn and its progeny. The distribution of excessive concentration of radon also depends on the geology and geography of the place, and exhibit significant variations across relatively short distances.

In most radon exposure studies, contribution of ^{220}Rn is usually neglected. The reasons which are attributed may include: Concentration of ^{220}Rn is generally much lower than the concentration of ^{222}Rn and ^{220}Rn has a relatively short Half-life than ^{222}Rn (54.6 s (^{220}Rn) vs. 3.83 d (^{222}Rn)). Hence ^{220}Rn might have decayed significantly before emanating from the soil. But in places such as marina beach (Chennai), the sand and have lower concentration of ^{222}Rn . Therefore it is inappropriate to neglect ^{220}Rn . Present studies on ^{222}Rn were made with a view to measure the radon. Radon and Thoron daughter progeny predicts from various indoor environments during different places and also to study the effect of floor and wall covering materials.

When the atoms of progeny are first produced they will be positive ions and they are very reactive and mostly attach themselves to water molecules and aerosols in air. In atmosphere we have radon progeny in excess and are present in attached and unattached forms. When inhaled both attached and unattached radon will be deposited in respiratory tracts. In the decay of the progeny, alpha particles are emitted which irradiate the cells of the lungs tissues. If radon gas present in the atmosphere inhaled it is largely breathed out. However, there is small probability of radon decay before it is exhaled. Therefore, the radioactive progeny, rather than radon itself, presents health hazards. Radon will be deposited in respiratory tracts. In the decay of the progeny, alpha particles are emitted which irradiate the cells of the lung's tissues. If radon gas present in the atmosphere inhaled it is largely breathed out. However, there is small probability of radon decay before it is exhaled. Therefore, the radioactive progeny, rather than radon itself, presents health hazards. The proposed research work envisages the environmental radioactivity in Chennai city with the specific attention to the measurements of indoor radon, thoron and their progeny levels in dwellings of Chennai city and their impact on health. The major objectives of the present research work are:

a) To study the background radiation for the environment of Chennai, b) To study the concentration of indoor radon and thoron levels, c) To study the variations of radon, thoron in dwellings of different features and d) To study the correlation between ^{226}Ra , ^{232}Th and ^{222}Rn , ^{220}Rn

To achieve the objectives of the study, field investigations were conducted. The study focused on measuring indoor radon, thoron, and their progeny concentrations in different types of rooms within Chennai City. Sampling locations

included rooms with varying flooring materials, ventilation conditions, room volumes, and wall constructions to evaluate the factors influencing indoor radioactivity levels. In addition, groundwater samples were collected from both coastal and inland regions of Chennai, including open wells and bore wells, to determine the concentrations of dissolved radon and thoron progeny. The spatial distribution of the sampling locations was recorded using a Global Positioning System (GPS), and the latitude and longitude coordinates of the study sites are presented in Table 1.

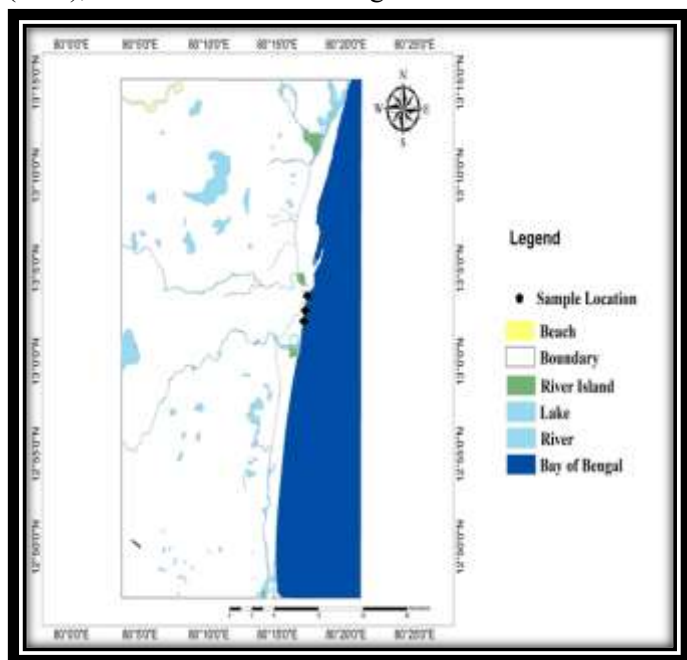


Fig 1: Map showing sand sample locations along Chennai coast.

SAMPLE LOCATION	LATTITUDE	LONGITUDE
SANTHOME CHURCH(BACK SHORE SAMPLE)	13°03' 26.04" N	80°17'05.26"E
SANTHOME CHURCH(SHORE LINE SAMPLE)	13°03'25.34"N	80°17'09.01"E
KANNAGI STATUE(BACK SHORE SAMPLE)	13°03'55.07"N	80°17'19.26"E
KANNAGI STATUE(SHORE LINE SAMPLE)	13°03'54.50"N	80°17'21.09"E
ANNA MEMORIEL(BACK SHORE SAMPLE)	13°01'47.11"N	80°16'46.44"E
ANNA MEMORIEL(SHORE LINE SAMPLE)	13°01'46.95"N	80°16'47.59"E

Table 1: Table shows latitude and longitude of samples taken in study area



Fig.2: Map showing groundwater sample locations along the Chennai coast.

2. STUDY AREA

The Chennai is 12°9' and 13°9' north latitude and 80°12' and 19' south longitude. Chennai is situated to the south eastern coast of India on a flat coastal plain. The district is surrounded by other district in the state like the Chengalpattu and Thiruvallur districts, while the Bay of Bengal lies to the east of the city. The coast stretches around 25.60kms. Chennai is spread over an area of 200 square kilometres and still growing. The city was known by the name of madras and has changed to Chennai. After independence, the city became the capital of Tamil Nadu, formerly known as madras state.

3. MATERIALS AND METHODS

A comprehensive field and laboratory investigation was conducted to assess radon distribution and associated environmental radioactivity along the Chennai coastal region. Surface and subsurface beach sand samples were collected from twelve locations using grab sampling techniques, georeferenced with a handheld GPS, and processed through oven drying (50°C) followed by particle-size analysis using standard ASTM sieves. The fine fraction (<63 µm) was subjected to heavy mineral separation using the gravity method with bromoform (specific gravity 2.9), and the percentage of heavy minerals was determined gravimetrically. Ambient gamma radiation levels at each sampling site were measured using a portable scintillometer (Ludlum Model 19), while geographical coordinates were recorded for spatial analysis. Indoor and outdoor air samples were collected from eleven locations using a low-volume air sampler equipped with glass-fiber filter papers. Airborne radon and thoron progeny were deposited on the filters and quantified using a ZnS(Ag)-based alpha scintillation counting system, from which working-level concentrations were calculated using standard decay correction factors. Groundwater samples were collected from coastal and inland wells, including both open and bore wells, and analyzed for dissolved ²²²Rn concentrations using the radon emanometry (bubbler) method. Radon extracted from water samples was transferred to pre-evacuated scintillation cells, allowed to attain radioactive equilibrium with its progeny, and subsequently measured using an alpha scintillation counting system. Appropriate decay corrections, detector efficiencies, and sample volumes were incorporated in the calculation of radon concentrations. The integrated dataset of sediment characteristics, heavy mineral content, ambient radiation, airborne radon progeny, and groundwater radon concentrations was used to evaluate the spatial distribution and environmental implications of natural radioactivity in the Chennai coastal environment. To quantify radon gas in coastal environment

of Chennai and to estimate the exhalation rate of radon gas from the beach sand and air and ground water of Chennai and its possible impact on the environment.

3.1 FIELD WORK:

To accomplish the objectives put forward 12 grab samples have been collected from the surface and subsurface of marina beach (Chennai). The sand samples were scooped and placed in polythene bags and sealed, and they were labeled according to the sampling locations with the help of a hand held GPS and marked in the study area map. All surface sediment samples were collected using grab sampler.

3.1.1 SAND SAMPLE COLLECTION:



Fig 3. showing the both back shore and shore line surface and sub-surface samples.

3.1.2 SAMPLE PROCESSING:

The collected sediment samples were first oven-dried at 50°C to remove moisture before laboratory analysis. Particle size distribution was then determined using a standard set of ASTM sieves (18, 25, 35, 45, 60, 80, 120, 170, and 230 mesh). Based on the sieve analysis results, the fine-grained fraction passing through the 120-mesh sieve (63 μm) was selected for heavy mineral separation. The separation of heavy minerals from the sediment samples was subsequently carried out using bromoform as a heavy liquid medium.

3.1.3. HEAVY MINERAL SEPARATION:

Heavy minerals were separated from the lighter mineral fraction using the gravity separation method. This technique is based on the difference in specific gravity between heavy and light minerals. The fine-grained sediment fraction was treated with bromoform, a heavy liquid with a specific gravity of 2.9, which allowed the denser heavy minerals to settle while the lighter minerals remained suspended. The light mineral fraction was subsequently cleaned and separated using acetone. This method enabled the effective concentration and recovery of heavy minerals for further analysis.

3.1.4. RADIATION MEASURED BY SCINTILLOMETER

Ambient radiation measurements were carried out using a portable scintillometer, an instrument designed to detect variations in electromagnetic radiation caused by atmospheric and environmental conditions. The device operates by measuring fluctuations in radiation intensity resulting from changes in atmospheric temperature, moisture, and pressure. A scintillometer typically consists of a transmitter and a receiver, which together detect and record radiation variations over a specified distance. In the present study, the instrument was employed to measure ambient radiation levels at the sampling locations, providing valuable information on the spatial distribution of natural radioactivity in the coastal

environment. The recorded measurements were subsequently used to assess the radiation characteristics of the study area and their relationship with sediment composition and heavy mineral concentrations.



Fig. 4 Scintillometer

Air samples were collected from eleven locations within Anna University, including both naturally ventilated rooms and air-conditioned indoor environments. Sampling was carried out using glass-fiber filter papers to capture airborne radon and thoron progeny. After collection, the filter papers were carefully transferred to an alpha counting system, where the deposited radioactive progeny were measured. The recorded alpha activity was subsequently used to determine the concentration of radon and thoron decay products present in the indoor air.



Fig 5 showing the set up of the air flow meter and alpha counter

4. RESULTS AND DISCUSSION

Sieve analysis was carried out to determine the particle size distribution of beach sediments collected from the study area. A total of twelve sand samples were collected from different locations along Marina Beach, Chennai. The samples were analyzed using a mechanical sieve shaker with a standard set of ASTM sieves (18, 25, 35, 45, 60, 80, 120, 170, and 230 mesh). The weight of sediment retained on each sieve was measured and recorded, and the resulting data were used to evaluate the grain-size characteristics of the beach sediments. The particle size distribution obtained from the analysis provides important information on sediment texture, depositional environment, and coastal sediment transport processes. The below table 2 and 3 shows that Heavy Mineral Percentage and In-Situ Gamma Radiation and areawise mean value of ^{222}Rn for coastal area using Radon Emanometry method.

STATION	Heavy Mineral (%)	Light Mineral (%)	In-situ Gamma Radiation Micro R/hr
SANTHOM SAMPLE 1	8.24	91.76	7.1
SANTHOM SAMPLE 2	9	91	7.4
SANTHOM SAMPLE 3	1	99	6.1
SANTHOM SAMPLE 4	1.7	98.3	6.0
KANNAGI STATUE SAMPLE 5	2.7	97.3	6.2
KANNAGI STATUE SAMPLE 6	5.7	94.3	6.4
KANNAGI STATUE SAMPLE 7	12.5	87.5	7.5
KANNAGI STATUE SAMPLE 8	1.6	98.4	6.0
ANNA MEMORIAL SAMPLE 9	0.4	99.6	5.9
ANNA MEMORIAL SAMPLE 10	2	98	5.6
ANNA MEMORIAL SAMPLE 11	1.2	98.8	6.1
ANNA MEMORIAL SAMPLE 12	0.7	99.3	5.8

Table2. Show Heavy Mineral Percentage and In-Situ Gamma Radiation

Areawise mean value of ^{222}Rn for coastal area using radon emanometry method :

S.NO	LOCATION	RADON RANGE IN WATER(Bq/lit)	RADON MEAN VALUE IN WATER(Bq/lit)
1	KOVALAM	3.2-7(CLOSED)&1.5-2(OPEN)	5.3
2	SHOLLINGANALLUR	4.6-31.8(CLOSED)2.5-3(OPEN)	15.9
3	KARAPAKKAM	2.0-2.5(CLOSED)1.2-1.5	2.1
4	PALAVAKKAM	4-4.5(CLOSED)	3.5
5	KOTTIVAKKAM	3.2-3.6(CLOSED)	4.3
6	THIRUVANMIYUR	1.6-5.3(CLOSED)	3.2
7	ROYAPURAM	2.8-4.1(CLOSED)	3.5

8	CHENNAI BEACH	3.0-6.3(CLOSED)	4.3
9	CHEPAUK	1.0-3.3(CLOSED)	2.3
10	ADYAR	1.5-3.6(CLOSED)	3.2

Table 3. Show Area Wise Mean Value Of Radon Concentration In Coastal Area.

Ground water samples were collected from the coastal area of Chennai particularly ennur to kottivakkam totally 10 locations were selected for each location 6-10 water samples were collected for determining the average mean value of radon. Ground water sample containing both open and bore well samples was collected by plastic bottles. The samples which collected from the coastal aquifers will give the low radon concentration comparing to the inland ground water. The average mean value of radon in coastal aquifers is range from 2.1 – 5.3 but steady area of shollinganallur will show high efficiency of radon concentration typically the bore well will give the high radon concentration. In the case of closed well emission of radon cannot escape to the atmosphere so it will concentrate into the ground water. Shollinganallur area gives radon concentration of 15.9 Bq/Lit high value of radon concentration in shollinganallur was shown below. (Fig. 6)

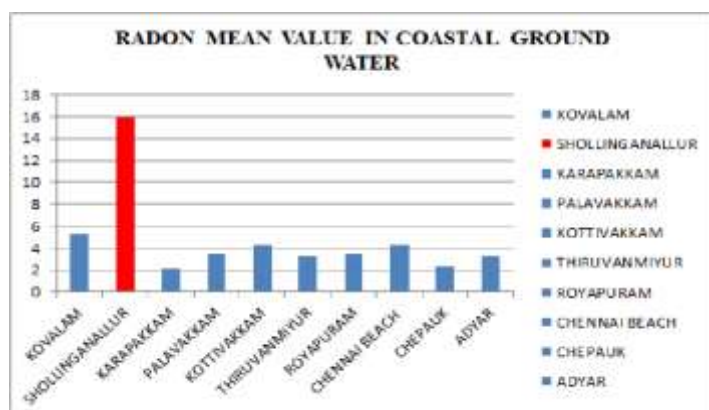


Fig. 6 Schematic Show Radon Mean Value In Coastal Ground Water.

Areawise mean value of ²²²Rn for inland area

S.NO	LOCATION	RADON RANGE IN WATER(Bq/lit)	RADON MEAN VALUE IN WATER(Bq/lit)
1	EKKATUTHANGAL	3.2-41.2(CLOSED)	28.4
2	ADHAMBakkam	6.6-14.0(CLOSED)	11.68

Table 4. Show Radon Mean Values For Inland Area.

Inland ground water sample were collected only two places ekkatuthangal and adhambakkam areas. These two inland areas will give high radon concentration both areas samples are collected from bore well. Bore well ground water will show always high efficiency of radon concentration in ekkatuthangal and adhambakkam respectively 28.4, 11.68 Bq/Lit. Graphical representation of radon average mean value for inland bore well water shown in (Fig 7) and the Schematic Show Graphical Representation Of Radon Concentration In Ground Water (Open And Bore Wells) And Metro Water is represented in fig. 8.

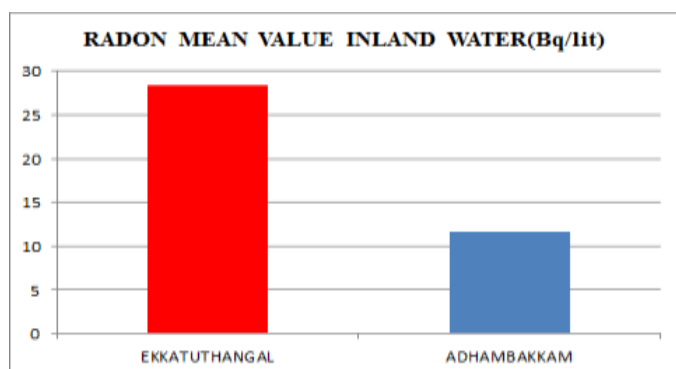


Fig 7. Schematic Show Graphical Representation Of Radon Mean Value Inland Ground Water

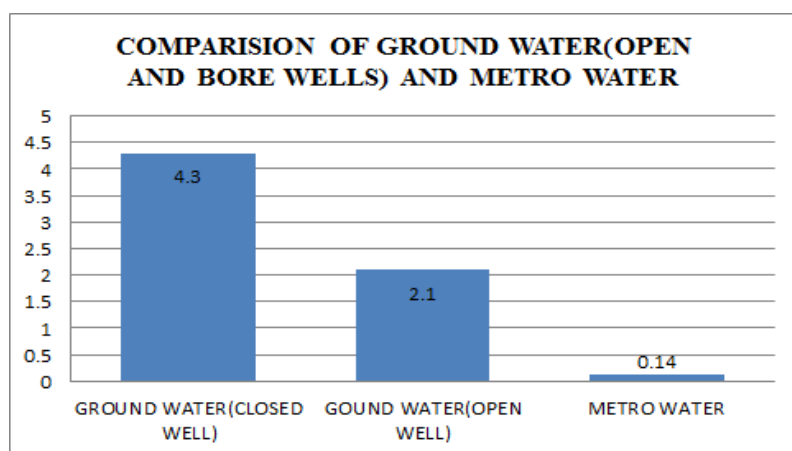


Fig. 8 Schematic Show Graphical Representation Of Radon Concentration In Ground Water (Open And Bore Wells) And Metro Water.

Radon concentration will high in inland ground water because of the bed rock of Chornockites. Also the inland ground water bore well will gives high radon concentration of 4.3 Bq/Lit and low level radon concentration of 2.1 Bq/Lit in open well.

In the case of metro water will give the very low radon concentration of 0.14 Bq/Lit. Metro water comes from lake of chembarambakkam, puzhal, veeranam lake vadavar canal beside rainwater from its own catchment area. Lake and river water have enough evaporation in respiration contact with atmosphere, radon concentration will low in metro water. The below gives the comparison of inland and coastal area of the Chennai city in fig 9.

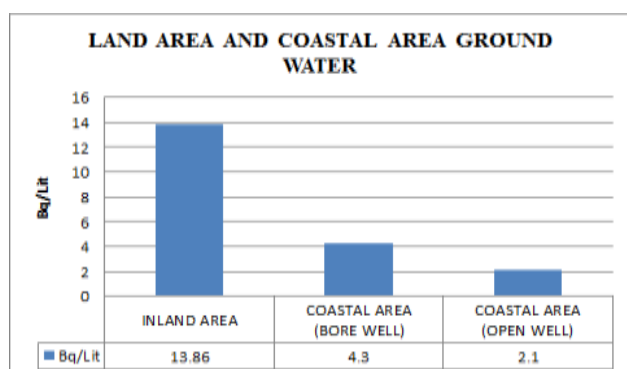


Fig. 9 Schematic Show Graphical Representation Of Radon Concentration In coastal and inland Ground Water (Open And Bore Wells)

Radon concentration in inland well is 13.86 Bq/Lit and coastal open and bore well respectively 2.1, 4.3 Bq/Lit. inland area of Chennai consist bed rock of Charnockites, water above the Charnockites rock bed will be concentrated by high amount of radon shown in the Fig. 10

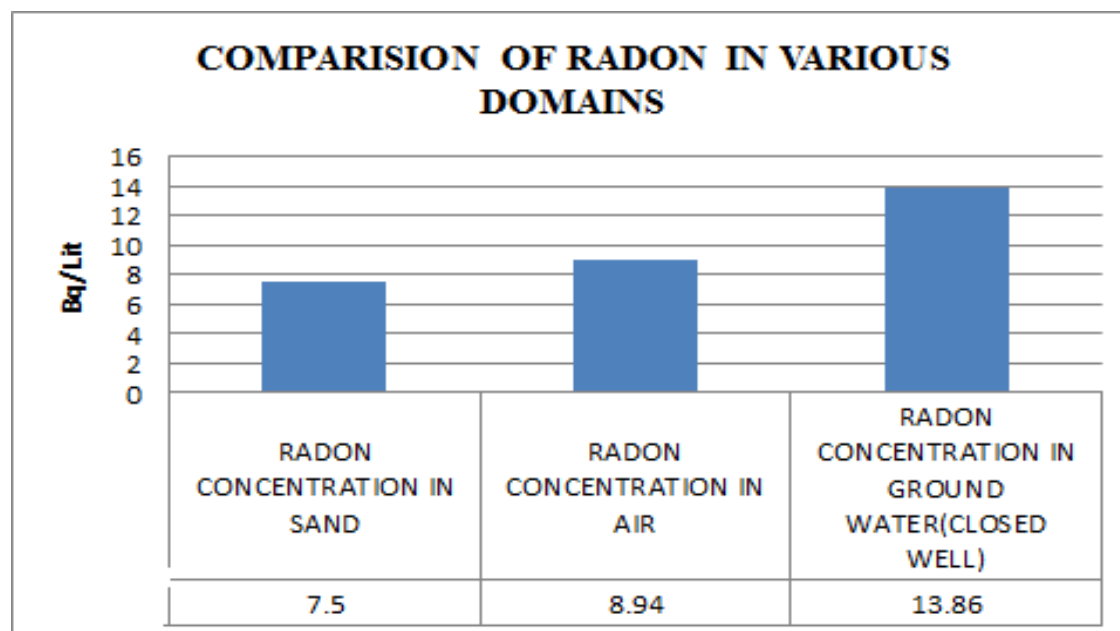


Fig. 10 Schematic Show Graphical Representation And Concentration Of Radon In Sand, Air And Ground Water (Closed Well).

Radon concentration sand, air and ground water were deducted by various methods and formulas. Radon cannot accumulate into the sand particles emission of radon progeny's can easily come out through the pore spaces of sand. Radiation in sand shows 7.5 Micro R/hr. Radon can attach to airborne particles, in the case of open rooms have ventilation so radon progeny's cannot accumulated in open rooms but the closed rooms radon can accumulate and it will produce the radon progenies. Inland ground waters are has high concentration of radon particularly in the bore waters will have more efficiencies of radon 13.86 Bq/Lit. A place which has charnockite and granite host rocks will concentrate by radon.

CONCLUSION

The in-situ gamma radiation levels measured in the coastal sediments of Chennai ranged from 5.6 to 7.5 $\mu\text{R h}^{-1}$, which are considerably lower than the background radiation levels reported from several other coastal regions of Tamil Nadu. This observation suggests that the concentration of naturally occurring radioactive minerals in the Chennai coastal sediments is relatively low compared to other parts of the state's coastline.

Airborne radon and thoron concentrations were evaluated to assess the emanation of radioactive gases from geological materials and indoor environments. Radon concentrations ranged from 0.36 to 8.94 Bq m^{-3} , while thoron concentrations varied between 0.12 and 2.90 Bq m^{-3} . Higher concentrations were observed in closed and air-conditioned rooms compared to naturally ventilated spaces, indicating the accumulation of these gases under restricted ventilation conditions. Nevertheless, all measured values remained within the limits recommended by the World Health Organization (WHO).

Groundwater radon concentrations were found to be strongly influenced by the geological characteristics of the host rocks. Bore wells located in charnockite formations exhibited relatively higher radon concentrations, reflecting the presence of radioactive minerals within the bedrock. In contrast, coastal aquifers showed comparatively lower radon levels. Open wells generally recorded lower radon concentrations than bore wells, as dissolved radon can readily escape into the atmosphere from open water surfaces, whereas it tends to accumulate in confined groundwater systems.

The measured radon concentration in groundwater along the Chennai coastal region ranged from 2.1 to 28.4 Bq L⁻¹. Inland groundwater sources generally exhibited higher radon concentrations than coastal aquifers, with values ranging from 2.1 to 13.86 Bq L⁻¹. These variations highlight the significant role of lithology, groundwater circulation, and well type in controlling radon distribution within the study area. Overall, the results indicate that the levels of gamma radiation, airborne radon, thoron, and groundwater radon in the Chennai coastal environment remain within acceptable safety limits and do not pose significant radiological risks to the local population.

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Conflict of Interest

The authors declare that there is no conflict of interest regarding the publication of this manuscript

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