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REVIEW

# A Review on Natural Gamma Radiation Dose Levels and its Health Effects

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**Abstract**

**Exposure to the natural background gamma radiations in both indoor and outdoor environments is inevitable. The long-term exposure to such radiations could result in lung cancer (sometimes leukaemia, CNS tumours); and hence it must be constantly monitored. In this paper, an attempt is made to review the background natural gamma radiation doses reported at various locations for the south Indian environment and it was found that the gamma levels in coastal regions were relatively higher than those in sub continental locations but in most of the locations the annual effective dose rate was within the permissible limits as per UNSCEAR.**

*Keywords:* Annual effect dose, Gamma radiation exposure, Health effects, Radon progenies

**Key Messages**

The monitoring of natural background nuclear radiations is very essential to understand its levels and possible health effects on the human beings. Hence an attempt is made to review the ambient gamma radiation dose levels in water, air, soil and construction materials for different sites of south Indian environment.

## 1. Introduction

Due to the severe impacts on human health, ambient background nuclear radiation levels have become increasingly important in recent decades, and this interest is spreading over the world. The overall human exposure from natural sources is mainly due to internal exposure, which is primarily due to Radon ($^{222}Rn$) and its isotopes (51%), with the remainder coming from other sources, as shown in Table 1 [1].

In medium to high doses, ionising radiation raises the risk of cancer. Gamma radiations can cause harm to the cell structure and DNA. Radiation dose is defined as the amount of energy absorbed per unit body tissue by gamma rays, while gamma dose is defined by the quantity of radiation dosage (measured in terms Sievert − Sv) absorbed by the body per unit time. When it comes to certain categories of cancer the possibility of increase in risk is higher in youth (0−16 years) than in middle aged public. These include leukaemia (Radon gas can easily disseminated into Red bone marrow) and CNS tumours, which are the most prevalent childhood cancers. Leukaemia is highly susceptible to radiation-induced induction, and disease development might occur after a two-year latent period [2,3].

Expose to the lower dose radiation by the common population, such as from surrounding radiation or diagnostic radiology, can increase the risk of childhood disease especially leukaemia [4,5]. Due to sample range constraints and the difficulty of effective dosimetry for large samples, direct epidemiological indication of the danger associated with lower

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*Table 1. Annual effective dose and its contributors.*

| Source | Annual effective dose (mSv) |
|---|---|
| *Extraterrestrial radiation* | |
| Cosmic rays | 0.39 (16.1%) |
| Cosmogenic radio nuclide | 0.01 (0.42%) |
| *Due to terrestrial radiation* | |
| External exposure | 0.46 (19.5%) |
| Internal exposure | 0.23 (9.77%) |
| *Radon and its progenies* | |
| Inhalation | 1.2 (51%) |
| Ingestion | 0.005 (0.21%) |
| *Thoron and its progenies* | |
| Inhalation | 0.07 (3%) |

dose rates (<100 mSv) is hard to produce. Scientific committees often presume that the hazards connected with low dose rates may be extrapolated from data from inhabitants exposed to moderate and high levels using linear quadratic non-threshold models (LNT) [1–3].

According to recent study, low-dose exposure raises the risk of leukaemia and CNS malignancies [5]. A collective study of nine cluster regions that included medically exposed people and survivors of atomic bomb revealed evidence of a positive dose–response connection between the risk of acute leukaemia and cumulative doses of 100 mSv at age 20 years [4]. It is observed that excess cancer risks linked with smaller-dose ionising radiation are usually to be modest, requiring huge model sizes to detect them. It is difficult to achieve the needed large model numbers in investigations based on discussion and measurements, and that kind of studies have previously been underpowered [6].

Hence the exposure to this unavoidable and inescapable radiation dose may pose serious threat to human health if exposed for long time. Hence the annual effective doses reported by several researchers for various sites in south Indian environments is reviewed in this paper, since revelation to background radiations varies greatly by location due to the unique geology and terrain of south Indian environment. The current review is based on a longer study period, a larger section size, and a thorough examination of the effective gamma dosage for various illnesses in order to comprehend the potential health impacts of external background radiation [7]. The detailed literature review has revealed that there exists a wide range of variability in respect of annual effective doses to the public for south Indian environments. Due to its complex geological structures the radiation levels vary from region to region. This has motivated us to review on the reported literatures and condense the results of AED for better understanding of its levels. It is well known that exposure to $^{222}$Rn and its progenies in inevitable and inescapable. Due to its chemical inertness and radioactive nature, activity of $^{222}$Rn in outdoor environments can be a potential candidate as a natural tracer.

Several researchers around the world have reported the major applications of monitoring the outdoor $^{222}$Rn towards understanding the lower atmospheric stability, dynamics of trace gases and pollutants, atmospheric air mass transport processes etc [8–16]. Hence, monitoring of $^{222}$Rn is not only important for its health effects but also to understand the lower atmospheric processes.

## 2. Discussion

The main objective behind this literature review is to provide the broad insight into the annual effective dose levels (gamma radiation levels) in different landscape reported for the south Indian environments, to cater the need for accessing the health effects of radiations. The monitoring of the radiation levels was primarily carried out by several researchers at dwellings in rural areas around Uranium sites, nuclear reactors, and mining sites. Throughout this review article the unit of annual effect dose/ambient gamma dose is expressed in Sievert/hour (Sv/h) or Sievert/year (Sv/y). Mahesh et al., 2001 [17] have studied the ground water (open well and bore well) samples from different sites of coastal Karnataka and Kaiga for $^{222}$Rn activities by emanometry method. The median value of concentration of $^{222}$Rn in the bore well water was 5.75 Bq/l. And for the open well water, the $^{222}$Rn was found to be 3.74 Bq/l. The effective dose for open well water consumers was found to vary from 0.09 to 204.2 μSv/y and for bore well water consumers it varied between 0.2 μSv/y to 1586.9 μSv/y. The results obtained in the present study were comparable with limits prescribed by UNSCEAR [1].

It is well reported that more than half of the total radiation dose is due to inhalation of $^{222}$Rn and its progenies to the general public. The simultaneous measurement of the levels of $^{222}$Rn concentration at different geological areas is of great importance, particularly in residential areas. Nagaraja et al., 2006 [18] have reported the inhalation dose rate because of inhalation of $^{222}$Rn and its progeny for the environment of Pune during 2006. For the Pune region, the dose rate by the population was different for different seasons and was 0.11, 0.09 and 0.28 mSv/y for summer, rainy and winter seasons are respectively. It was reported that the average annual effective dose from the inhalation of $^{222}$Rn for a person who lives in the environment of Pune is found to be 0.55 mSv. Shiva prasad et al., 2007 [19] have studied the $^{222}$Rn concentration in potable water of various locations of the Bangalore environment by the emanometry method. About 94 ground water samples were investigated and found that the mean value of 87 Bq/l. The frequency distribution of activity of $^{222}$Rn shows that large number of samples in the range of 0–50 Bq/l. It was found that a significant reduction in $^{222}$Rn activity was observed when water was boiled and the mean effective dose was found to be 705.5 μSv/y.

The ambient annual effective dose rate was studied by Sathish et al., 2009 [20] in houses at 10 locations in different parts of Bangalore, India using solid state nuclear track detectors. The population in the researched location experienced a dosage rate of 0.1–0.5 mSv/y due to $^{222}$Rn, $^{220}$Th, and its progenies. The geometric and arithmetic mean concentrations are respectively 0.2 and 0.2 ± 0.03 mSv/y. The findings demonstrate that there is no considerable radiation risk to Bangalore residents. The global average concentrations are 40 and 10 Bqm$^{-3}$, respectively. Shiva prasad et al., 2009 [21] have analysed the $^{222}$Rn data of potable water trials were collected from 35 different locations of Kanakapura region using emanometry method for dose calculations. The mean annual effective dose received was estimated to be 244.35 μSv/hour and it is well within the maximum permissible value of 500 μSv/hour as prescribed by Atomic Energy Regulatory Board (AERB) to the Indian environment.

Sathish et al., 2011 [22] have reported the continuous monitoring of radiation levels, indoor thoron and Radon for 10 different geographical locations carried out at Bengaluru with an intention to study the significance of exposure to occupants, particularly in living places. It was found that in all locations the effective dose rate received by the population during the study period varied between 0.1 and 0.5 mSv/y, with mean value of 0.2 ± 0.03 mSv/y. The result shows no significant radiological risk for the inhabitants. The majority of the observational confirmations for radiation-induced health impacts in humans come from short-term exposures to high levels of radiation. However, the potential health impacts of long-term low/average dose exposure to humans cannot be discounted, particularly in coastal belts where mineral-rich sand is abundant and thorium is abundant. One such study was carried out by Byju et al., 2012 [23] along the southwest coast line of the Kerala state of India which is one such region with higher levels of local radioactivity. The inhalation and external radiation doses to human beings were estimated using thermo luminescent dosimeters (TLDs) in over 500 dwellings in the region. The inhalation dose rate was found to vary between 0.1 and 3.53 mSv/y with an average of 1.15 mSv/y, which was within the limits prescribed by UNSCEAR [2].

Chandrashekara et al., 2012 [24] has systematically studied the groundwater and mud samples from different sites around Mysuru city (12.8°N and 76.8°E) for radiation dose levels. The mean ingestion as well as inhalation dose rates due to $^{222}$Rn in water were found to be 65.2 and 5.43, mSv/y, respectively. From the soil samples it was found that the ingestion ranged between 0.89 and 91.3 mSv/y with a mean of 5.43 mSv/y. Similarly the inhalation dose due to $^{222}$Rn ranged between 10.7 and 1095 mSv/y with a mean of 65.2 mSv/y and. The results reported for this region were significant and extensive to estimate the gamma dose levels for different locations in urban location Mysuru. Sathish et al., 2012 [25] have studied the thoron, radon and gamma dose levels at around 200 different geographical locations around Bengaluru region. During the study period the dose rate received by the population of Bangalore varied from 0.2 to 3.5 mSv/y with an arithmetic mean and the geometric mean of 1.14 ± 0.05 mSv/y and 1.06 mSv/y, respectively. Overall, the result does not show much significant radiological risk for the inhabitants and dose levels are well within the limits of global average as prescribed by UNSCEAR.

Ambient gamma radiation levels were studied at South Konkan region using thermo luminescent dosimeters (TLDs) by Dhawal et al., 2013 [26]. The annual effective doses (AEDs) received by the local inhabitants from the selected rural communities were found to be 0.31 and 0.09 mSv/y for indoor and outdoor locations, respectively. It was reported that the maximum AED was recorded in Mithgavane village of 0.12 mSv/y and the minimum by the Dale village as 0.04 mSv/y with an average of AED is found to be 0.08 mSv/y and is lower than the worldwide value 0.48 mSv/y [1]. A unique seasonal dependency of gamma dose rate was observed at the study location. For indoor conditions, during winter season the maximum dose rate was observed and during monsoon season minimum was observed. But for outdoor environments, the maximum dose rate was recorded during spring season and minimum was recorded during monsoon season. The soil samples of Ramanagara and Tumkur districts were collected for the study of the yearly effective gamma dose, activity concentration of primordial radionuclides, $^{226}$Ra, $^{232}$Th, and $^{40}$K by Srilatha et al., 2014 [27] using HPGe detector. The results reported shows that the outdoor annual effective dose rates vary between 0.08 and 0.14 mSv/y with a mean value of 0.11 mSv/y. Similarly for indoor annual effective dose rate changes from 0.48 to 0.98 mSv/y with a mean value of 0.75 mSv/y. The total yearly effective dose rate ranges from 0.56 to 1.1 mSv/y, with 0.87 mSv/y being the mean. Except for the outdoor annual effective dose, which was more than the world average of 0.07 mSv/y, the yearly effective dose was reported to be within the prescribed limit of 1 mSv/y as suggested by the International Commission on Radiological Protection [28].

Raghavendra et al., 2014 [29] has studied the dose received due to activity of atmospheric $^{222}$Rn, radiation and gamma absorbed dose rate by the members of community in the surrounding area of the proposed uranium mine area of Nalgonda district, Andhra Pradesh, India. The outdoor mean effective dosage due to $^{222}$Rn and its daughters was estimated to be 0.058 mSv/y, with an external gamma dose of 0.0017 mSv/y, both of which were lower than the global average effective dose of 0.07 mSv/y. The total yearly effective dose received by a member of the public in the proposed uranium mining area was calculated to be 0.23 mSv/y, which was within the ICRP's recommended limits [28]. Pillai et al., 2015 [30] studied the activity concentrations of $^{226}$Ra, $^{232}$Th and $^{40}$K in 91 soil samples collected from regions where dwelling construction was proposed in Tiruchirappalli district by making use of gamma ray spectrometer, $^{222}$Rn activity using SSNTD and ambient absorbed gamma dose using handheld scintilla meter. The average outdoor and indoor annual effective exposure rates for soil were 0.27 and 0.07 mSv/y, respectively, which were substantially under ICRP guidelines. The reported readings clearly indicated that the values are below the safe limit of 1 mSv/y.

The southern states of India namely Kerala, Karnataka and Goa are covered with high altitude dense ecosystem known as Western Ghats. Shimoga city of Karnataka state is part of these ghats and has wide variety of ecological and geophysical spread. Rangaswamy et al., 2015 [31] has studied the outdoor as well as indoor gamma dose levels within and around granite regions of Shimoga region using Dosimeter ER-709 detector. The indoor and outdoor AEDs were found to have a range of 0.559–1.631 mSv/y, with a mean value of 0.872 mSv/y and 0.106–0.339 mSv/y with a mean value of 0.235 mSv/y, respectively. The estimated indoor and outdoor AEDs were also found to be more than the global average. Similarly, the annual effective dose exposure from the 38 samples of drinking water around Shimoga region was reported by Rangaswamy et al., 2016 [32] using radioactivity data Emanometry technique. It was reported that as per WHO the annual effective dose received from consumption of water should be less than 0.1 mSv/y.

It was reported that the estimated ingestion and inhalation dose varied from 0.70 to 8.10 μSv/y with a mean value of 2.80 μSv/y and 7.90–96.90 μSv/y with a mean value of 34.20 μSv/y, respectively. And the estimated annual effective dose (total) due to $^{222}$Rn inhalation and ingestion were observed from 8.60 to 105.00 μSv/y with an average value of 37 μSv/y. The dose contribution from this source to the abdomen was calculated and is varied between 0.10 and 1.00 μSv/y with a mean value of 0.30 μSv/y and similarly the dose contribution from this source to the lung is calculated and is ranged between 0.90 and 11.60 μSv/y with a mean value of 4.10 μSv/y which are well within the limits prescribed by WHO. It was reported by Omori et al., 2016 [33] that the region named Chhatrapur placer over the south-eastern coast of India had higher levels of elevated background radiation region. The measurements were carried out in around 100 residences during 3 seasons (rainy, summer and autumn-winter) using SSNTD. The doses from thoron and radon inhalation have been reported to be 0.2–3.8 mSv/y and 0.1–1.6 mSv/y, respectively. The overall dosage varied between 0.8 and 4.6 mSv/y. Internal doses from thoron and radon inhalation was estimated to be 0.2–3.8 mSv/y and 0.1–1.6 mSv/y, respectively. As a result, thoron's contribution to a dose evaluation could not be over looked. The internal dose rate ranged from 0.8 to 4.6 mSv/y.

Balakrishnan et al., 2016 [34] have reported the outdoor and indoor gamma radiation levels for the industrial region of Eloor Island in Ernakulum District, Kerala state, India using TLDs and GM tube based survey meters. According to reports, the yearly effective dose corresponding to the island's population has been calculated and was observed to be 0.32 mSv/y for outdoor environments and 0.68 mSv/y for indoor environments. In comparison to the global average reported by UNSCEAR 2000, both the indoor and outdoor AED were relatively higher. Monica et al., 2016 [35] has reported the outdoor and indoor gamma dose rate levels for the coastal area of Kollam district, Kerala using portable gamma dosimeter. Aside from the above measurements, the residents' lifetime cancer risk was also evaluated. The mean indoor effective dose along the coast was found to be 7.56 mSv/y, which is higher than the global AED average of 4.83 mSv/y. It was reported that the excess lifetime estimated for cancer risk (ELCR) from indoor AED equivalent varies between 22.56–26.46 $\times$ $10^{-3}$ and ELCR from outdoor ranges from 14.95–16.65 $\times$ $10^{-3}$, which is higher compared with the resulting world average of 0.25 $\times$ $10^{-3}$.

Chandrashekara (2017a) [36] has studied the $^{222}$Rn concentration in ground water samples of Mysuru district was measured using a smart radon monitor employing emanometry technique. With a mean activity of 22.8 Bq/l, the ratio of maximum to minimum $^{222}$Rn concentration in ground water was estimated to be 58.44. The mean activity levels were determined to be within WHO acceptable limits and the mean total dosage attributable to inhalation were found to be 115.7 Sv/y. Chandrashekara (2017b) [37] have carried out systematic studies on natural radioactivity in bore well waters of Kodagu district, India using LED fluorimetric and $^{222}$Rn emanometry techniques. The concentration of $^{222}$Rn ranged from 6.38 to 30.69 Bq/l, with a mean value of 13.49 Bq/l, and the total dosage attributable to $^{222}$Rn was calculated to be 69.97 Sv/y. The average annual effective dosage owing to $^{222}$Rn concentrations in bore well water samples was determined to be below the EPA, WHO, and AERB MCL limit of 100 Sv/y, and calculated $^{222}$Rn concentrations were within permitted limits. Kumar et al., 2017a [38] have reported the activity of $^{222}$Rn and total AED in groundwater samples received from different villages of Tiptur and Sira taluks, Tumkur district, Karnataka using emanometry method. The total annual effective dose for infants, children, and adults was also estimated and was found to be 0.029, 0.017, 0.019 mSv/year in Tiptur taluk and 0.31, 0.18, 0.20 mSv/year in Sira taluk, respectively.

Kumar et al., 2017b [39] have studied the possible dose received by the public due to inhalation of $^{222}$Rn entering the atmosphere from the depth of soil surface for Bangalore University campus using RAD7. Annual Effective Dose (AED) was also calculated from the $^{222}$Rn activity near to the ground surface which was estimated to be varied between 0.03 and 0.07 mSv/y with a geometric mean of 0.04 mSv/y which was well within the prescribed limit set by UNSCEAR [1]. Many researchers have reported the radiation levels for south coastline of Kerala but very few reports are available for the neighbouring areas. Hence Monica et al., 2017 [40] have reported the in depth investigation in the shoreline of Alappuzha district situated north to the Kollam district where the well known high background radiation area exists using GM based gamma dose survey meter and TLD. The annual effective dose as reported using dose meter were $0.67 \pm 0.12$ mSv/y for outdoor environment and $2.18 \pm 0.47$ mSv/y for indoor environment. But the annual effective dose as recorded by TLD was $2.25 \pm 0.46$ mSv/y for indoor and $0.71 \pm 0.12$ mSv/y for outdoor environment. The mean AED from dose survey meter was reported as $2.86 \pm 0.77$mSv/y and from TLD was $2.96 \pm 0.48$ mSv/y. Both values were relatively larger than that of mean value of $0.44 \pm 0.13$ mSv/y for Indian environment. Shetty et al., 2017 [41] have reported the indoor and outdoor gamma dose rate levels in air using thermo luminescent dosimeters (TLDs) for different regions of Udupi district (south western coast), Karnataka, India. Indoor exposure AED ranged between 0.29 and 0.61 mSv with an average of 0.41 mSv, while outdoor exposure AED varied between 0.07 and 0.16 mSv with an average of 0.1 mSv. The resultant average AED for the Udupi district was 0.51 mSv, which was slightly higher than the global average.

Mahamood et al., 2018 [42] made an attempt to estimate AED using radon, thoron and their progeny concentration for various types of houses and outdoor measurements at Kalliasseri, Kannur district, Kerala. Indoor AED due to radon and its offspring received by occupants in houses ranged from 2.43 to 3.93 mSv, with a mean of $3.16 \pm 0.68$ mSv, and AED due to thoron and its progeny ranged from 1.58 to 5.58 mSv, with a mean of $3.26 \pm 1.72$ mSv. The yearly effective doses from indoor $^{220}$Rn and $^{222}$Rn were under the ICRP's recommended action threshold of 3–10 mSv/y. Kumar et al., 2018 [43] have made effort to study the contribution of $^{222}$Rn activity towards the dose rate received by the public for the environment of Bengaluru using RAD 7. The annual effective dose (AED) was estimated using $^{222}$Rn concentrations measured at the soil surface and ranged from 0.02 to 0.07 mSv/y, with a mean of 0.04 mSv/y. The AED due to inhalation is significantly below the global average, as published in UNSCEAR 2000, indicating that the outdoor $^{222}$Rn concentration in the research location poses no concern to humans. The radiation level monitoring for 52 locations of Balod district region, Chhattisgarh, India was carried out by Jindal et al., 2018 [44]. The detected gamma dose rates were $103.0 \pm 3.1$–$201 \pm 6.0$ nSv/h and $132.0 \pm 4.0$–$260.0 \pm 7.8$ nSv/h, respectively, which are slightly higher than the world population weighted average. The yearly mean of AED was determined to be 0.95 mSv/y for indoor environments and 0.18 mSv/y for outdoor conditions. As a result of this investigation, greater levels of AED were found in the Balod district of Chattisgarh as compared to the world average, and it served as the region's baseline data set. The higher levels may be attributed to the geological structures of the location and the detailed studies are necessary for arriving at any conclusion.

Srinivasa et al., 2019 [45] have measured $^{222}$Rn activity concentrations in drinking water samples collected from 31 different locations of the Chikmagalur city, Karnataka state, India (another city over Western ghats), using emanometry technique. The total yearly effective dosage assessed from three locations in the study area was found to be more than the WHO and EU Council recommended safe level of 0.1 mSv/y.

Sannappa et al., 2019 [46] has studied the $^{222}$Rn activity concentration and ambient gamma dose levels using Emanometry technique and micro R survey meter respectively in drinking water samples of different locations in coastal taluks of Uttara Kannada district. Annual effective doses vary from 0.39 to 0.82 mSv/y, with a GM of 0.55 mSv/y, which is slightly higher than the worldwide norm. Water consumption is significantly below the WHO and EC recommended action threshold of 100 mSv/y. But the results have also proved that the annual effective ingestion and inhalation dose rate values are slightly higher than the values prescribed by UNSCEAR [3]. The estimated mean values were 25 μSv/y for inhalation and 2 μSv/y for ingestion processes. But the annual average ingestion dose rate received from drinking water is well within the total indicative dose of 100 μSv/y. Srinivasreddy et al., 2020 [47] has reported the indoor and outdoor natural background gamma radiation levels for Devarakonda town, Telangana state, India using micro R-survey meter and TLDs. The regional distribution of estimated average gamma yearly effective dosage in air has been reported to be variable for different locales. This could be owing to the materials used in house construction. In the study region, the computed annual effective dose rate ranged from 1.10 to 2.13 mSv/y, with an average of 1.56 ± 0.33 mSv/y. According to the findings, the yearly effective dose rate in the research area is greater than the global average of 0.48 mSv/y.

Yashaswini et al., 2020 [48] have reported the concentration of $^{222}$Rn in ground and drinking water trials collected from different locations (36 samples) around Kabini River basin, Karnataka, India using Emanometry Technique. The western side of the river has greater radon values, which is attributable to the local geography of the study area, and the upstream water has a higher active concentration of $^{222}$Rn than the downstream water. The reported results clearly show that the annual effective doses for the samples were within the permissible limit of 0.1 μSv/y as per World Health Organization (WHO) [49]. While collecting the samples due care was taken by considering the percentage of consumption of water because in the study location, 20% population used river water, 70% user the water from underground sources and remaining from the small ponds, lakes. Suman et al., 2020 [50] has monitored the ambient background activity of gamma radiation in nearby villages of Meghavath Thanda (which was upcoming uranium mineralized site), Nalgonda district, Telangana state, India. The findings of the radioactive elements analysis of the collected soil samples of the area show that the activity of $^{238}$U and $^{232}$Th is greater than the global average, resulting in an average effective dosage of 1.47 ± 0.10 mSv/y in the study region due to gamma radiation.

Srinivasreddy et al., 2021 [51] have estimated the annual effective doses for northern districts of Telangana State, India situated on Deccan plateau. The Deccan plateau is the largest plateau in India, and it is located in the southern part of the country. This triangular-shaped plateau covers eight states in all. Massive granites carrying higher amounts of radionuclide have been found in Telangana, which is located on the eastern part of the Deccan plateau. The Micro R Survey meter was used for the dose measurements and the average annual effective dose in Peddapalli region was reported to be 0.94 mSv, Rajanna Sircilla region was 1.58 mSv, Jagtial region was 1.13 mSv, Karimnagar region was estimated to be 1.17 mSv. Suresh et al., 2021 [52] reported the gamma absorbed dose rates (GADR) in 88 locations within five different geological regions of Uttara Kannada district, Karnataka, India using UR-705 environmental radiation dosimeter. Outdoor AEDE estimates range from 0.06 to 0.19 mSv/y, with an average of 0.10 mSv/y, slightly higher than the global average of 0.07 mSv/y. The estimated indoor AED ranges from 0.24 to 1.19 mSv/y, with a mean of 0.44 mSv/y, significantly less than the globally established value of 0.48 mSv/y. The total AED estimation was between 0.3 and 1.38 mSv/y with a mean value of 0.53 mSv/y.

Kumar et al., 2021 [53] has performed the simultaneous measurements of meteorological parameters and ambient gamma dose levels at National Atmospheric Research Laboratory (NARL), Gadanki, India (13.459°N and 79.175°E) during November 2011 to May 2014 for the first time using GM tube inbuilt within AlphaGUARD PQ 2000 PRO. The results demonstrate that around 92 percent of ambient gamma dose levels fall between 150 and 200 nSv/h, with Gaussian fit having an adjusted R2 of 0.99 as the best possible fit as shown in Fig. 1. The ambient gamma radiation levels and selected meteorological data recorded over the site had a modest Pearson's correlation coefficient. There was no discernible seasonal trend in ambient gamma radiation levels, although there were significant seasonal fluctuations in temperature, relative humidity, and air pressure. During severe thunderstorm activity (Nilam cyclone), a significant increase in ambient gamma levels was detected, which could be attributable to an additional contribution of precipitation washed $^{222}$Rn progeny aerosols into the atmosphere. This study is the first to report an anomalous increase in gamma radiation during precipitation in an Indian climate. The monthly mean variations in ambient gamma dose levels for NARL is shown in Fig. 2 and

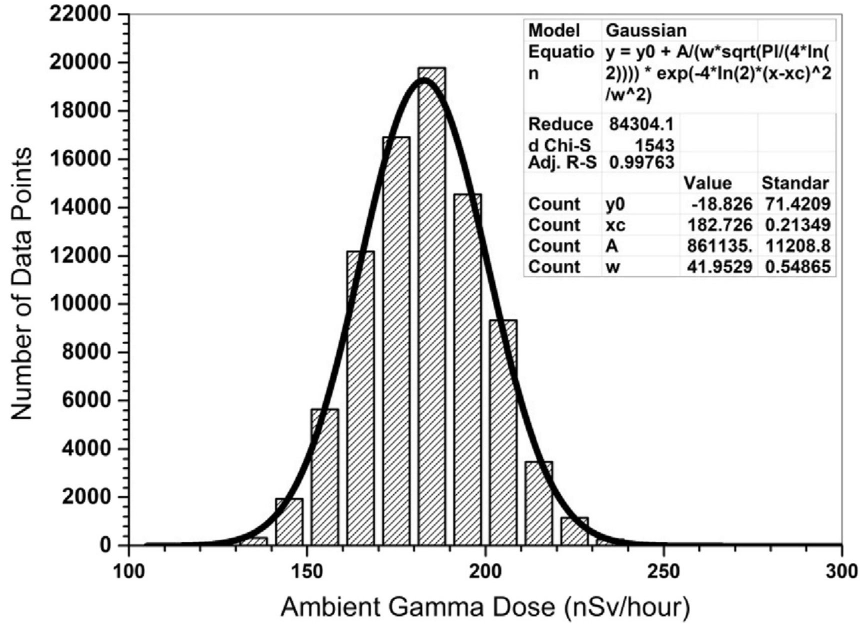


*Fig. 1. Guassian distribution fit for ambient gamma dose levels at NARL, Gadanki*

the mean ambient gamma dose over NARL was 186 ± 4.3 nSv/h which is within world average given by UNSCEAR [1]. The ambient gamma radiation levels around Bellary thermal power plant, Ballari (known as mine city of Karnataka state), India was estimated by Ujjinappa et al., 2021 [54] using Scintillometer of NaI (Tl) detector. The novel technique for determination of mass attenuation coefficient of x-rays employing NaI (Tl) detector system is discussed by Kaginelli et al., 2009 [55] and Gamma-ray spectroscopy is used to determine the activity of natural radionuclides found in the soil and building materials of some towns near the Bellary thermal power station.

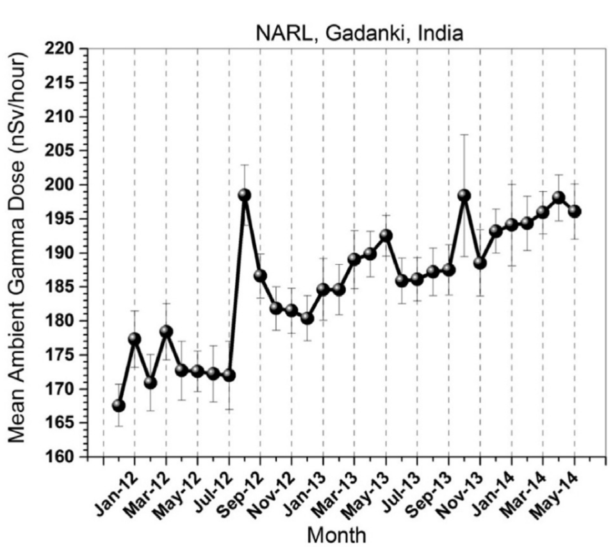


*Fig. 2. Monthly mean values of ambient gamma dose levels at NARL, Gadanki*

The total yearly effective dose rate ranged between 0.88 and 1.47 mSv/y, with a mean of 1.18 mSv/y. Except for fly ash bricks, which had a value greater than the safe level limit, all radiological indices measured in soil and construction materials were lower than the safe level limit. This could be due to the addition of fly ash from the thermal power station, which increases the level of radiation in adjacent settlements. The measured outdoor, indoor and total equivalent effective dose rates in this study was found to be 0.1–0.23 mSv/y with a mean value of 0.14 mSv/y, 0.71–1.26 mSv/y with a mean value of 0.98 mSv/y and 0.85–1.37 mSv/y with a mean value of 1.11 mSv/y, respectively.

Deepu Radhakrishnan et al., 2021 [56] has reported the long term outdoor radiation data collected during 2013–2018 in the premises of Department of Atomic energy site of Kalpakkam. It was reported that detectors usually measure the normal background dose levels due to exposure to $^{41}$Ar plume during normal operations at Madras Atomic Power Stations. The annual effective doses at the site boundary during the study period were reported to be 0.011 mSv–0.114 mSv which is well within the prescribed dose limit for public in outdoor environments.

## 3. Summary

An extensive literature review was carried out for understanding the gamma dose levels for different environments of south Indian sub continent. The discussion includes the estimated gamma dose due to water, air, soil etc at different locations with different measuring sensors (both active and passive). It was understood that the local geological structure play very important role in deciding the gamma radiation levels at a particular site. It is interesting to note that, at both south eastern and south western coastal regions the activity concentration of radionuclide and gamma radiation levels are relatively higher as compared to average value for Indian environment. This may be due to elevated levels of thorium content and mineral rich sand at coastal regions. But in most of the locations the gamma radiation levels are within the permissible limits as set by international agencies such as WHO, UNSCEAR, ICAE. From the literature review it was also pointed out that due to increased excavations works such as mining and alarming human interference with nature is leading to possible changes in geological properties which intern causes higher exposure to the background radiation and radionuclide especially Radon (a ghost gas!!), its progenies. Hence, the constant monitoring of the naturally occurring radionuclide and ambient gamma dose levels are very important in environmental radioactivity research.

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## Conflict of interest

None.

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