

Spatial Variation of Radon Concentration Around a Coal-Fired Thermal Power Plant

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Abstract. Radon is a major contributor to natural radiation exposure, and its presence in residential areas near industrial facilities is a key concern in environmental radiation protection. This study assessed radon levels at different distances in the area surrounding the Simhadri National Thermal Power Corporation (NTPC) coal-fired plant in Paravada, Visakhapatnam, Andhra Pradesh, India. Radon levels were monitored using the Smart RnDuo system, which provides precise activity measurements along with relevant environmental parameters influencing radon transport. Measurements were taken at 120 locations distributed across nearby villages and categorised into high, medium, and low-proximity zones to examine spatial variation around the thermal power plant. The results showed measurable differences in radon concentration across the study region, indicating that distance from the plant affects radon dispersion and accumulation. Although all values remained within internationally accepted limits, the distribution pattern revealed that specific low-proximity locations recorded comparatively elevated concentrations. This suggests that the effects of local geological formations, soil permeability, and natural ventilation characteristics are more significant than those of industrial emissions alone. Variations in soil composition, ground moisture, and underlying rock structures likely contributed to the observed differences, highlighting the complexity of radon behaviour in heterogeneous terrains. The study further demonstrates the suitability of the Smart RnDuo system for field-level radon monitoring, offering stable performance and reliable data even under varying environmental conditions. The findings provide baseline information on outdoor radon levels around a major coal-fired installation and emphasise the importance of continued monitoring to better understand long-term environmental trends. By identifying distance-related variations in radon distribution, the study provides valuable insights for radiation protection planning in regions near large-scale industrial facilities.

Keywords: Radon concentration, Spatial Variation, Coal-Fired Thermal power plant, Smart RnDuo, Outdoor radon levels.

1 Introduction

Radon-222 is a naturally occurring radioactive element that forms in the Earth's crust when uranium and radium undergo radioactive decay in soils and rocks [1–3]. On formation, the noble gas permeates through the soil pores and finally reaches the atmospheric boundary

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layer. Radon concentration in the external environment is primarily determined by the lithology and pedology of the area, the permeability of the soils and rocks that comprise them, and the prevailing meteorological conditions that regulate the escape of radon into the atmosphere [4, 5]. Although radon levels are not high outside, there may be measurable spatial differences between locations, especially where the surface has been altered by specific geomorphological characteristics or human activity. In turn, this argument preconditions the investigation of outdoor radon near extensive industrial facilities, as these areas can influence radon movement in the lower atmosphere [6–8].

Although they do not directly emit radon, coal-fired thermal power stations may indirectly affect radon processes underground through their regular operations. Processes such as handling, deposition, and storage of coal ash, excavation and grading operations, mechanical compaction of surface soils, and changes in natural drainage paths alter soil permeability and gas diffusivity [9–11]. Such anthropogenic interventions can modify the vertical flux of radon, leading to spatial variations in radon concentrations at different distances from the plant. Comparing radon concentrations in concentric zones of proximity can help scientists understand the primary reasons for variations in the observed forms, as they may be due to either industrial perturbations or geological heterogeneity [12, 13].

In the current study, radon behaviour in the surroundings of the Simhadri NTPC plant located in Paravada, Visakhapatnam, Andhra Pradesh, was evaluated. One hundred and twenty-two outdoor monitoring sites were surveyed in the neighbouring villages, with each site allocated to one of three radial zone ranges: inside 2 km of the facility, 2 km to 3.5 km, and 3.5 km to 5.5 km. The Smart RnDuo continuous monitor was used to obtain measurements from a device that operates on a dual-chamber pulse ionisation detection principle, providing stable, high-precision readings even under changing environmental conditions [14–17]. This study aims to identify the distribution of outdoor radon around the thermal power plant, to determine spatial gradients in relation to proximity, and to assess whether observed variations are due to variability in industrially influenced soil modification.

2 Materials and Methods

2.1 Study Area

The Simhadri National Thermal Power Corporation (NTPC), a coal-fired plant, is located at 17°35'28" N latitude and 83°5'28" E longitude near Paravada village, Vishakhapatnam district, Andhra Pradesh, India, as shown in Figure 1.

According to the 2020 census, this plant occupies 3,384 acres of land, and more than 50,000 people live nearby [18]. In this study, 120 locations were identified in 50 villages, spread in all directions, within a 5.5 km radius of the plant. The area lies between 17°33' and 17°38' N latitude and 83°02' and 83°08' E longitude with a varied topography of residential houses and soil structures.

Fig. 1: Selected study locations in different proximity regions around the plant

The selected locations were divided into three proximity regions extending from the plant to determine radon level variation within a 5.5 km radius. They were classified into three regions as High Proximity Region (0-2 km, 40 selected locations), Medium Proximity Region (2-3.5 km, 39 selected locations), and Low Proximity Region (3.5-5.5 km, 41 selected locations). This zonal classification enabled the study of spatial variation in radon concentrations surrounding the plant, facilitating a distance-dependent varying interpretation of environmental variation.

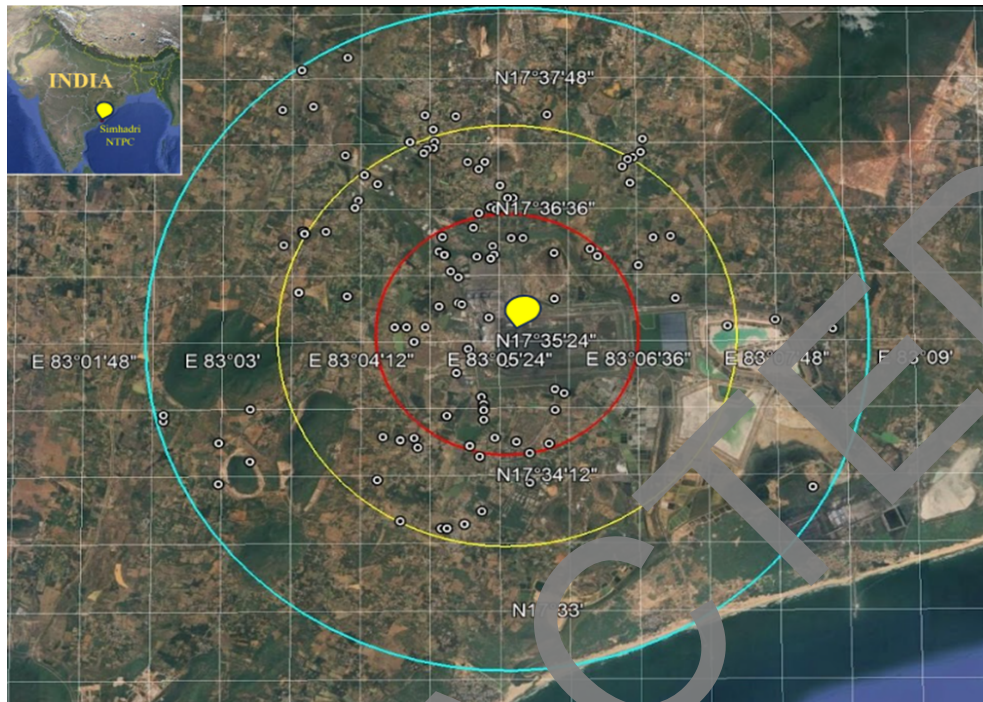


Figure 1. Selected study locations in different proximity regions around the plant

2.2 Smart RnDuo Radon Monitor

A continuous radon monitor, the Smart RnDuo, utilises a dual-chamber pulsed ionisation and semiconductor alpha detection principle. Radon gas diffuses into two separate measurement chambers, and solid-state sensors detect the emitted alpha particles of radon progeny. This device was designed to determine radon levels in outdoor environments. This design offers very sensitive performance, continuous measurement stability, and reduced background interference; hence, the instrument is well-suited for both short-term and long-term environmental monitoring. The monitor records radon concentrations every hour and accounts for fluctuations in temperature and humidity to ensure stable operating conditions. The equipment was factory-calibrated to international standards for radon measurement and tested before installation [19–21]. The instrument was allowed to stabilise before data recording. Background checks and post-measurement drift tests are performed to ensure the accuracy of the recorded data.

2.3 Measurement Protocol for Outdoor

Radon measurements were conducted at each selected location using a uniform procedure to ensure consistency across all proximity regions. The Smart RnDuo monitor was placed 1.0–1.5 meters above ground level and in shaded areas to minimise the effects of sunlight, rainfall, and surface heat reflection, ensuring that the readings accurately reflected natural atmospheric radon levels, which can all affect detectability. In this study, two consecutive one-hour measurements were carried out at each of the 120 locations. Given the limitations of short-term

measurements, all measurements were recorded at the same time of day to eliminate the effect of diurnal variability. This enabled consistent comparison of the sampling locations. The measured short-duration radon concentrations were normalised to make the values equivalent to whole-day readings. The use of this coefficient enabled a more accurate representation of the daily radon dynamics in the study area. Temporal normalisation was not done to translate these short-term measurements into daily or seasonal equivalent radon concentrations. The recorded short-term values were used to investigate relative spatial changes in radon levels across the high-, medium-, and low-proximity regions. This approach is in consonance with other studies of a similar kind [2–5, 11, 22, 23].

Because outdoor fields typically have low, fluctuating equilibrium conditions due to unrestricted airflow, the measured radon concentrations did not yield equilibrium factors. Environmental factors, such as temperature, humidity, and soil moisture, were recorded qualitatively during fieldwork to interpret spatial variability. Although these conditions were not directly included in the numerical analysis, they provided background information on the distribution of radon patterns, as discussed in other studies as well [5, 11]. A filtering process was applied to the entire recorded data, followed by rejection of readings influenced by warm-up effects, abrupt environmental disruptions, or incomplete sampling cycles [20, 24]. The final validated data considered acceptable and reliable were utilised for analysis.

To analyse the spatial gradient and determine the variability in terms of distance, various statistical measures, including minimum, maximum, mean, median, and standard deviation, were determined for each region. Since the present study is limited to radon distribution outdoors, the measurements were conducted to compare with international outdoor standards, thus placing the results within the international environmental context [23].

3 Results and Discussions

The statistical summary of the outdoor radon levels in various proximity areas surrounding the Simhadri NTPC coal-fired plant is represented in Table 1. At the high proximity region, the radon values were 11.50 to 39.10 Bq m⁻³ with a mean value of 20.16 Bq m⁻³ and a standard deviation of 5.93 Bq m⁻³.

Table 1. Statistics of Outdoor radon concentration in high, medium, and low proximity regions around the plant

Proximity Region	Number of Locations	Minimum (Bq m ⁻³)	Maximum (Bq m ⁻³)	Mean (Bq m ⁻³)	Median (Bq m ⁻³)	SD (Bq m ⁻³)
High (0-2 km)	40	11.50	39.10	20.16	20.70	5.92
Medium (2-5 km)	39	9.20	39.10	24.35	25.30	5.96
Low (5-15 km)	41	2.30	36.80	23.38	23.00	6.85

The proximity of the mean and median values indicates that radon concentrations in the area are relatively homogeneous. The radon concentrations in the medium proximity region were within the range of 9.20 to 39.10 Bq m⁻³, with a mean concentration of 24.35 Bq m⁻³ and a standard deviation of 5.96 Bq m⁻³. There was moderate spatial variability, with slightly higher average radon levels in this area than in the high proximity region. The mean was close to the median, indicating low skewness. The low proximity region had radon levels of 2.30–36.80 Bq m⁻³, with a mean of 23.38 Bq m⁻³ and a standard deviation of 6.85 Bq m⁻³. This region exhibits the greatest variability among the three regions, as indicated by its higher standard deviation. In all regions, the measured concentration of radon was far below the reference limits of radon levels in the outdoors [10, 15]. The distribution of radon concentrations is shown in Figure 2 for different proximity regions.

Fig. 2: Distribution of radon concentrations for high, medium, and low proximity regions

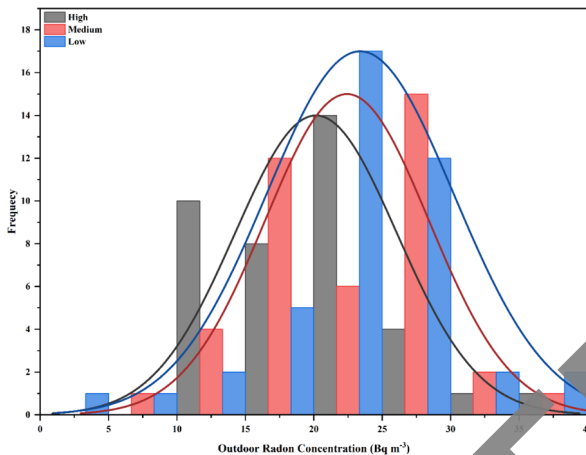


Figure 2. Distribution of radon concentrations for high, medium, and low proximity regions

This graph shows a less distributed representation in the high-proximity region than in the medium and low-proximity regions. Overall, the distribution suggests that radon concentrations in all regions remain within normal background levels.

The spatial variations in outdoor radon values across the three proximity areas are average, with no significant abnormalities in either high or low background levels. The high-proximity region, as presented in Table 1 and Figure 1, exhibits less variation than the medium- and low-proximity regions, which are more widely spread. This trend suggests that distance from the coal-fired thermal power plant is not sufficient to determine radon behaviour in the study area. With increased proximity to the plant, radon concentration variability decreased. This can be attributed to surface alterations, including compaction and levelling of the soil on which the industrial infrastructure is located, which may reduce soil-gas permeability and radon release [12, 13]. Moreover, the increased radon concentrations at greater distances are consistent with the major effects of natural geological and environmental conditions, such as soil texture, porosity, moisture content, and subsurface lithology [25–28]. These parameters are known to vary locally and have a substantial role in the distribution of radon outside.

The significant similarity in radon distribution across all proximity regions indicates that there is no exaggerated radiological effect attributable to the thermal power plant. Every measured concentration was significantly lower than the recommended reference levels for outdoor conditions as per international standards [1, 10, 15]. The same phenomenon has been observed in other studies on radon levels at coal-based power plants and other industrial installations, where outdoor radon was more strongly influenced by background environmental conditions than by industrial emissions [19, 21].

Although the current research provides valid data on outdoor radon levels in the area around the Simhadri NTPC plant, one of its most significant limitations is the limited time for outdoor radon measurements, as they were conducted for only two hours at each monitoring point. Outdoor radon concentrations are affected by diurnal and meteorological variability, and short-term measurements may not be sufficient in determining long-term or seasonal averages. Hence, the findings presented here must be treated as relative spatial variation of proximity regions rather than as absolute radon levels over a long period of time.

4 Conclusion

The research examined the spatial distribution of outdoor radon levels surrounding the Simhadri National Thermal Power Corporation (NTPC) coal-fired plant. Measurements taken at 120 locations revealed moderate variability across regions of high, medium, and low proximity, yet all recorded values remained within internationally accepted limits for outdoor exposure. The observed differences among these regions are largely linked to natural geological and environmental factors, such as soil permeability and subsurface conditions, rather than emissions from the plant itself. This pattern reflects a relatively uniform distribution close to the facility, with greater fluctuations detected at more distant locations. The smart RnDuo monitoring system proved reliable in capturing outdoor radon levels, consistently producing repeatable results in field conditions. Overall, the findings serve as a valuable reference for radiation monitoring in the region and provide a foundation for extended studies on radon behaviour near major industrial installations.

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