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Radon and Thoron Concentrations in Dwellings of Kanpur City, Uttar Pradesh: Assessment, Influencing Factors and Radiological Significance

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Abstract

Radon (^222Rn) and thoron (^220Rn) are naturally occurring radioactive noble gases generated in the uranium-238 and thorium-232 decay series, respectively. Because both gases can accumulate indoors, their short-lived radioactive progeny may contribute appreciably to radiation exposure of occupants. The present research paper reviews and evaluates the available evidence concerning indoor radon and thoron concentrations in residential dwellings of Kanpur City, Uttar Pradesh, with particular emphasis on measured radon concentrations, building characteristics, ventilation, floor level, dwelling type, equilibrium factors, and associated radiation-dose considerations. An important earlier investigation involving 120 dwellings in Kanpur reported mean radon concentrations of approximately 40 ± 10 Bq m^-3 in living rooms, 46 ± 6 Bq m^-3 in bedrooms, and 70 ± 5 Bq m^-3 in kitchens. The corresponding geometric means were approximately 25.3, 36.2 and 40 Bq m^-3, respectively. The study also reported an average radon equilibrium factor of 0.38 ± 0.26 and an estimated annual effective dose equivalent of approximately 1.0 mSv y^-1 for living-room exposure. Poorly ventilated dwellings showed substantially greater radon concentrations than well-ventilated dwellings, demonstrating the importance of indoor air exchange.

Although thoron is increasingly recognized as an important component of indoor natural radiation exposure, the published Kanpur-specific study cited here primarily quantified ^222Rn rather than providing a complete modern ^220Rn dataset. Therefore, thoron values reported for Central Uttar Pradesh should not be incorrectly presented as direct Kanpur measurements. The available regional evidence nevertheless establishes the scientific importance of simultaneous radon–thoron monitoring in Uttar Pradesh. Contemporary international guidance recommends that residential radon concentrations be kept as low as reasonably achievable, with WHO proposing a reference level of 100 Bq m^-3 where feasible and indicating that the selected national reference level should not exceed 300 Bq m^-3 when 100 Bq m^-3 cannot reasonably be achieved. The present review demonstrates that the historical Kanpur radon measurements were below these reference values, while still indicating measurable exposure and considerable variation between rooms and building conditions. A systematic city-wide survey using radon–thoron discriminating passive detectors, seasonal measurements and detailed building questionnaires would provide an updated exposure map for Kanpur.

Keywords: Radon; Thoron; ^222Rn; ^220Rn; Indoor air; Dwellings; Kanpur; Uttar Pradesh; SSNTD; CR-39; Radiation exposure; Radon progeny; Thoron progeny; Effective dose; Ventilation.

Introduction

Natural ionizing radiation is an unavoidable component of the human environment. It originates from cosmic radiation, naturally occurring radionuclides in rocks and soils, radioactive materials incorporated into construction materials, and radionuclides present in food and water. Among the naturally occurring radioactive substances, radon and its decay products are particularly important because radon is a radioactive gas capable of entering buildings and accumulating indoors. The two principal naturally occurring isotopes of environmental interest are radon-222 (^222Rn), commonly called radon, and radon-220 (^220Rn), commonly called thoron.

^222Rn is produced through the decay of radium-226 in the uranium-238 decay series, whereas ^220Rn originates from radium-224 in the thorium-232 decay series. Both isotopes are alpha-emitting noble gases. Their radioactive progeny can attach to aerosols and remain suspended in indoor air. When inhaled, these short-lived progeny can irradiate sensitive tissues of the respiratory tract. The World Health Organization identifies indoor radon as an important preventable environmental risk factor and recognizes radon exposure as a cause of lung cancer.

Radon concentrations are generally higher indoors than outdoors because buildings can restrict dilution and because soil gas can migrate into structures through cracks, joints, floor openings and other pathways. The concentration within a dwelling depends on geological conditions, soil permeability, foundation characteristics, building materials, ventilation, indoor pressure, floor level, weather and occupant behaviour. WHO notes that indoor radon concentrations can vary greatly between buildings and recommends reducing exposure wherever practicable.

Thoron deserves separate consideration because its physical behaviour differs significantly from that of ^222Rn. The half-life of ^220Rn is only about 55.6 seconds, compared with approximately 3.82 days for ^222Rn. Consequently, thoron is strongly influenced by the distance between its source and the indoor air volume, the characteristics of building materials, and air movement. Its short half-life means that thoron concentrations can change considerably within a building, while thoron progeny can still contribute to radiation exposure.

India provides an important setting for radon and thoron research because of its large geographical area, varied geology, diverse building practices and wide range of climatic conditions. Nationwide surveys have demonstrated substantial spatial variability in indoor radon concentrations. A major review of Indian measurements reported

^222Rn concentrations ranging from 4.6 to 147.3 Bq m^-3, with an overall geometric mean of approximately 23 Bq m^-3 for the locations included in that survey.

Kanpur is a major urban centre in northern India and is characterized by a wide variety of residential structures. The city contains older masonry houses, detached houses, multi-storey buildings, apartments and mixed-use structures. Differences in construction materials, foundation conditions, ventilation and occupancy patterns can therefore influence indoor radon concentrations.

One of the most relevant investigations for Kanpur was conducted by A. J. Khan and colleagues and published in Radiation Measurements. The study examined 300 dwellings in Lucknow and Kanpur, including 120 dwellings in Kanpur. Passive integrating solid-state nuclear track detectors were used to determine indoor ^222Rn concentrations, while information on house characteristics and ventilation was collected. The investigation found measurable radon concentrations in all major room categories and demonstrated the influence of ventilation and floor level on indoor concentration.

The present paper develops a comprehensive research-oriented assessment of radon and thoron in Kanpur dwellings by combining the Kanpur-specific evidence with established knowledge from Indian and international indoor-radon studies. Particular attention is given to the distinction between directly measured Kanpur data and regional thoron evidence. This distinction is scientifically important because regional or Central Uttar Pradesh thoron measurements cannot automatically be interpreted as measurements from Kanpur City.

Scientific Background of Radon and Thoron

Origin of radon

Radon-222 is generated through the radioactive decay of radium-226, which forms part of the uranium-238 decay series:

^238U → ^226Ra → ^222Rn → radioactive progeny → stable ^206Pb.

Because uranium and radium occur naturally in rocks and soils, radon generation is a widespread environmental phenomenon. Once produced in mineral grains, radon can escape through recoil and diffusion and subsequently migrate through pores and cracks in soil. Soil gas is therefore one of the most important sources of indoor radon.

The amount of radon entering a house depends not only on the amount generated in the surrounding soil but also on soil permeability, moisture, pressure gradients and the permeability of the building foundation. A house with cracks or gaps at the soil–building interface may permit greater radon entry.

Origin of thoron

Thoron, or ^220Rn, belongs to the thorium-232 decay series:

^232Th → ^228Ra → ^224Ra → ^220Rn → radioactive progeny → stable ^208Pb.

The major difference between radon and thoron is their half-lives. The short half-life of ^220Rn means that thoron generally cannot travel as far through soil as ^222Rn before decaying. Consequently, building materials containing thorium can be an important indoor source of thoron.

Bricks, cement, concrete, stone and other mineral-based construction materials can contain naturally occurring uranium and thorium. Their contribution to indoor radioactive-gas concentrations depends on radionuclide content, emanation characteristics, material porosity and surface area.

Radioactive progeny

The health significance of radon and thoron is largely associated with their short-lived decay products rather than the noble gases alone. The progeny emit alpha particles, and inhalation can result in deposition of radioactive particles within the respiratory tract.

The equilibrium between a radon gas concentration and the concentrations of its progeny is not complete in ordinary houses. Ventilation, aerosol concentration, deposition and attachment processes influence the equilibrium state. Consequently, a measured radon concentration alone does not completely characterize radiation dose.

Health Significance of Indoor Radon and Thoron

Radon is recognized internationally as an important environmental cause of lung cancer. WHO reports that radon contributes to a proportion of lung cancers at the population level, with the exact contribution depending on national radon concentrations and smoking prevalence.

The risk is associated principally with inhalation of short-lived radon progeny. Alpha particles emitted during radioactive decay can deposit energy in the respiratory system. Repeated exposure over long periods can increase the probability of radiation-induced biological damage.

Thoron also produces radioactive progeny capable of contributing to inhalation exposure. Historically, thoron received less attention than radon because of its very short half-life and measurement difficulties. Modern radon–thoron discriminating detectors have made simultaneous assessment more practical.

It is important, however, to interpret environmental measurements correctly. Detection of radon or thoron does not mean that an individual will necessarily experience a health effect. Radiation risk depends on concentration, exposure duration, equilibrium conditions, occupancy, smoking status and other factors. Environmental monitoring is therefore used to identify buildings where exposure reduction may be beneficial.

Study Area: Kanpur City, Uttar Pradesh

Kanpur is located in the central part of Uttar Pradesh and is one of the major urban centres of northern India. Its residential environment includes traditional masonry houses, independent houses, multi-storey residential buildings and apartment-type structures.

The city has experienced substantial urban growth, resulting in variation in building age and construction practices. Some residential structures are relatively old, while others are modern reinforced-concrete buildings. Such differences can affect indoor radon entry and retention.

For radon studies, the characteristics of the ground floor are particularly relevant because the underlying soil can provide a direct pathway for soil gas. Upper floors may receive less soil-derived radon but can still contain radon from building materials and indoor air transport.

Kanpur's climatic conditions also create seasonal variation in ventilation behaviour. During periods when doors and windows remain closed for longer durations, indoor air exchange can decrease. During warmer periods, increased ventilation can lower indoor radon concentration in naturally ventilated houses.

Review of Previous Research in Kanpur

A particularly important investigation was conducted in 300 dwellings distributed between Lucknow and Kanpur. Of these, 120 dwellings were located in Kanpur. Passive alpha-track detectors containing CR-39 were used for long-duration measurements. The detectors were exposed for approximately 120 days.

The Kanpur results demonstrated clear room-to-room differences. The reported arithmetic mean concentrations were approximately:

Room	Kanpur ^222Rn concentration
Living room	40 ± 10 Bq m^-3
Bedroom	46 ± 6 Bq m^-3
Kitchen	70 ± 5 Bq m^-3

The corresponding geometric means were approximately 25.3 Bq m^-3 for living rooms, 36.2 Bq m^-3 for bedrooms and 40 Bq m^-3 for kitchens.

These results show that the arithmetic mean concentration in kitchens was substantially greater than that in living rooms. Bedrooms also tended to have higher concentrations than living rooms. Such differences are consistent with differences in ventilation and occupancy patterns.

The same investigation reported an average equilibrium factor of approximately 0.38 ± 0.26 for Kanpur dwellings. The estimated annual effective dose equivalent for living-room exposure was approximately 1.0 mSv y^-1 under the assumptions used in the original study.

Radon Concentration According to Room Type

Living rooms

The average radon concentration in Kanpur living rooms was reported as approximately 40 ± 10 Bq m^-3. Living rooms often receive comparatively greater ventilation because doors and windows are opened more frequently. This can reduce accumulation of indoor radon.

The geometric mean was lower than the arithmetic mean, indicating a positively skewed distribution in which a smaller number of dwellings had comparatively higher concentrations. Such skewness is common in indoor radon datasets, which frequently approximate a log-normal distribution.

Bedrooms

The reported bedroom concentration was approximately 46 ± 6 Bq m^-3. The higher concentration relative to living rooms can plausibly be associated with longer occupancy periods and reduced ventilation during sleeping hours.

The bedroom result emphasizes that average concentration in a house does not necessarily represent exposure equally in every room. A person may spend many hours in a bedroom, making the concentration in that room relevant to cumulative exposure.

Kitchens

The highest reported concentration occurred in kitchens, at approximately 70 ± 5 Bq m^-3. The original study discussed possible contributions from ventilation patterns, fuel use and water-related radon release.

The kitchen result should not be interpreted as proof that cooking itself is necessarily the primary cause. Indoor radon concentration can be affected by several simultaneous variables, including ventilation, building location, water source, foundation characteristics and construction materials.

Influence of Ventilation

Ventilation is one of the most important controllable factors influencing indoor radon concentration. When indoor air is exchanged rapidly with outdoor air, accumulated radon is diluted. Conversely, low ventilation permits radon to accumulate.

The Kanpur study classified dwellings according to ventilation conditions and found increasing radon concentrations as ventilation became poorer. Approximately 35 dwellings classified as having good ventilation had a mean concentration near 30 ± 10 Bq m^-3, while approximately 70 dwellings with poor ventilation showed concentrations around 58 ± 12 Bq m^-3.

This pattern demonstrates that building ventilation is an important determinant of indoor exposure.

The implication is particularly relevant for urban housing. Energy conservation, air-conditioning, security considerations and weather conditions can lead occupants to keep doors and windows closed for extended periods. In naturally ventilated houses, such behaviour can reduce air exchange and potentially increase radon concentrations.

However, ventilation interventions should be designed carefully. Simply increasing ventilation without considering outdoor air quality may introduce pollutants such as particulate matter. An appropriate approach combines adequate air exchange with protection against outdoor pollution.

Influence of Floor Level

Radon entering from soil is generally expected to have a stronger influence on ground-level rooms than on upper floors. As vertical distance from the soil increases, direct soil-gas contribution tends to decrease.

The Kanpur investigation reported decreasing radon concentrations with increasing floor level. Approximate mean values reported for different levels were:

Floor level	Reported mean ^222Rn concentration
First floor	42 ± 6 Bq m^-3
Second floor	30 ± 8 Bq m^-3
Third floor	22 ± 5 Bq m^-3

This pattern supports the importance of soil as a radon source in ground-connected dwellings. Nevertheless, upper-floor concentrations do not necessarily become negligible because building materials and indoor air transport can contribute.

For future Kanpur surveys, measurements should therefore be stratified according to floor level. Ground-floor, first-floor and upper-floor measurements can provide valuable information about source pathways.

Influence of Dwelling Type and Construction

Building construction strongly influences indoor radon concentration. Houses in direct contact with the ground can receive soil gas through cracks and openings. Detached houses may have greater contact with surrounding soil, while multi-storey buildings may have less direct soil-gas contribution on upper floors.

The Kanpur investigation considered detached and multi-family dwellings and identified differences in concentration. The researchers suggested that both soil contact and ventilation characteristics contributed to these differences.

Common construction materials in northern Indian dwellings include fired clay bricks, concrete, cement, stone, tiles and other mineral-based products. Because uranium and thorium occur naturally in geological materials, construction materials can act as sources of radon and thoron.

For thoron specifically, building materials may be particularly significant because ^220Rn has a short half-life and therefore its concentration is strongly influenced by nearby sources.

Thoron in Uttar Pradesh and Its Relevance to Kanpur

A scientifically important distinction must be made between Kanpur-specific evidence and broader Central Uttar Pradesh measurements.

A study of dwellings in Central Uttar Pradesh using solid-state nuclear track detectors reported radon concentrations between approximately 21.17 and 43.04 Bq m^-3, with a mean of about 27.90 ± 1.03 Bq m^-3. The same study reported thoron concentrations between approximately 12.37 and 22.79 Bq m^-3, with a mean of approximately 16.75 ± 0.55 Bq m^-3.

These values provide useful regional context but should not automatically be labelled as measurements from Kanpur City. A rigorous Kanpur research paper should explicitly distinguish them from the published Kanpur ^222Rn measurements.

The distinction is important because thoron can vary greatly over short distances due to differences in construction materials and source distribution. Therefore, extrapolating a single regional thoron average to every Kanpur dwelling would introduce uncertainty.

A dedicated Kanpur survey should measure ^220Rn directly using a radon–thoron discriminating detector. This would allow identification of the relative contribution of thoron and its progeny to indoor radiation exposure.

Measurement Methodology for a Modern Kanpur Survey

A comprehensive follow-up study should employ passive solid-state nuclear track detectors or modern radon–thoron discriminating systems.

Detector principle

Solid-state nuclear track detectors such as CR-39 record damage tracks produced by alpha particles. After exposure, the detector is chemically etched so that latent tracks become visible and countable.

For radon-only measurements, a diffusion chamber can be designed to preferentially admit ^222Rn while excluding progeny. For simultaneous radon–thoron measurements, specialized discriminating dosimeters can distinguish the contributions of ^222Rn and ^220Rn according to diffusion and decay characteristics.

Sampling design

A representative Kanpur survey should include dwellings from different parts of the city. Sampling should consider:

- ground-floor and upper-floor houses;
- detached and multi-family dwellings;
- old and new buildings;
- different construction materials;
- different ventilation conditions;
- houses with basements, where present;
- rural–urban transition areas;
- houses using groundwater and municipal water;
- different socioeconomic and construction categories.

At least one detector should preferably be installed in the living room and another in the bedroom. Additional measurements in kitchens can help investigate the high concentrations previously observed there.

Exposure duration

Long-term measurements are preferable because indoor radon changes with weather and occupant behaviour. A measurement period of several months can reduce the influence of short-term fluctuations.

For a city-wide annual assessment, seasonal measurements should ideally cover summer, monsoon, autumn/winter and spring conditions.

Seasonal Variation

Indoor radon concentrations commonly vary seasonally because ventilation, atmospheric pressure, soil moisture and temperature change throughout the year.

During winter, windows and doors may remain closed for longer periods, decreasing ventilation. This can lead to higher indoor concentrations. During warmer periods, increased natural ventilation can lower indoor radon.

Monsoon conditions may produce a different response because soil moisture can affect radon transport. The relationship is complex and depends on local soil properties, rainfall and building conditions.

Recent Indian research demonstrates the importance of seasonal radon–thoron monitoring. For example, a 2026 study from the Malwa region of Punjab reported seasonal differences in both radon and thoron, with the reported order of concentration being rainy > winter > summer.

This result should not be directly transferred to Kanpur because local geological and meteorological conditions differ. It nevertheless demonstrates why a multi-season Kanpur study would be scientifically valuable.

Statistical Treatment of Data

Indoor radon concentrations generally show considerable variability. Therefore, both arithmetic and geometric statistics should be reported.

Important statistical parameters include:

- arithmetic mean;
- median;
- geometric mean;
- standard deviation;
- geometric standard deviation;
- minimum and maximum;
- percentile distribution;
- coefficient of variation.

The geometric mean is particularly useful because indoor radon distributions are often approximately log-normal. A small number of high-concentration dwellings can substantially increase the arithmetic mean while having a smaller effect on the geometric mean.

Correlation analysis can also be used to investigate relationships between radon/thoron concentrations and:

- floor level;
- house age;
- ventilation;
- room type;
- construction material;
- dwelling type;
- occupancy;
- season.

Multivariate statistical methods can provide additional insight by separating the influence of correlated building variables.

Dose Assessment

Radon concentration itself is not identical to radiation dose. Dose depends on radon progeny concentration, equilibrium factor, occupancy time and dose-conversion assumptions.

For the historical Kanpur investigation, an equilibrium factor of approximately 0.38 was reported. Using the assumptions adopted in that work, the estimated annual effective dose equivalent for living-room exposure was approximately 1.0 mSv y^{-1}.

The equilibrium factor can be represented as:

$$F = EEC_{Rn} / C_{Rn}$$

where:

- F = equilibrium factor,
- EEC_Rn = equilibrium-equivalent concentration of radon progeny,
- C_Rn = measured radon concentration.

Because equilibrium is affected by ventilation and aerosol conditions, the same radon concentration may not correspond to exactly the same progeny concentration in every building.

For thoron, dose assessment is more complicated because of the short half-life of ^220Rn and the spatial distribution of thoron progeny. Therefore, a modern study should preferably measure thoron progeny or equilibrium-equivalent thoron concentration where feasible.

Comparison with International Reference Values

WHO recommends a residential reference level of 100 Bq m^-3 where possible. If this level cannot be achieved under country-specific conditions, WHO indicates that the selected reference level should not exceed 300 Bq m^-3.

The IAEA framework also identifies 300 Bq m^-3 as a maximum reference level for homes in its relevant safety framework.

The published Kanpur living-room arithmetic mean of approximately 40 Bq m^-3 is below these reference values. The bedroom and kitchen means reported in the historical study were also below 100 Bq m^-3.

However, comparison with a reference level should not be interpreted as establishing a sharp boundary between safe and unsafe conditions. WHO explicitly emphasizes that a reference level is a level above which reduction is strongly recommended rather than a rigid threshold separating health and disease.

The objective of radon protection is therefore to reduce exposure as far as reasonably achievable.

Comparison with Indian Studies

India has a substantial body of research on indoor radon. Early surveys reported wide variations between geographical regions and dwelling types. A review of measurements from approximately 50 Indian locations reported a geometric mean of 67.1 Bq m^-3 in the dataset considered.

A nationwide review of indoor ^222Rn and ^220Rn measurements reported ^222Rn concentrations ranging from 4.6 to 147.3 Bq m^-3, with an overall geometric mean of about 23 Bq m^-3. The same review emphasized the importance of geological and building-related factors.

The historical Kanpur living-room value of approximately 40 Bq m^-3 therefore lies within the broad range observed in Indian dwellings.

The Central Uttar Pradesh study reporting average radon and thoron concentrations of approximately 27.90 and 16.75 Bq m^-3, respectively, provides additional regional context.

More recent Indian studies continue to demonstrate the need for simultaneous radon–thoron measurements. A 2026 study in Punjab, for example, found that annual average thoron concentrations could be substantial even where radon remained well below 300 Bq m^-3.

Discussion

The available evidence indicates that indoor radon is measurable throughout Kanpur dwellings and that concentration varies according to room and building characteristics. The reported living-room average of approximately 40 Bq m^{-3} is not unusually high when compared with international and Indian datasets, but the room-to-room differences are important. The highest concentration in the historical dataset occurred in kitchens. Bedrooms also had higher concentrations than living rooms. This suggests that ventilation and occupancy patterns are important determinants of exposure.

The decline in radon concentration with increasing floor level is consistent with soil being an important source. Ground-connected rooms can experience greater soil-gas entry, whereas upper floors are less directly connected to the soil. Nevertheless, building materials can contribute to radon and thoron at all levels. Ventilation emerged as one of the most important modifiable factors. Poorly ventilated houses showed greater concentrations than well-ventilated houses. This finding is consistent with the general understanding that air exchange controls the removal of accumulated indoor radon.

The historical study also illustrates the importance of long-term measurements. A detector exposed for several months provides a more representative estimate than a single short-duration measurement because indoor radon fluctuates substantially. A major research gap concerns thoron. While Central Uttar Pradesh studies have reported measurable ^{220}Rn concentrations, the publicly available Kanpur-specific historical investigation was primarily a ^{222}Rn study. Therefore, a new Kanpur survey should not simply assign the regional thoron mean to Kanpur households.

Instead, a systematic survey should directly measure both isotopes. This is especially important because thoron can originate strongly from construction materials and can exhibit large spatial variation inside buildings.

Recommended Framework for a New Kanpur Survey

A scientifically robust future study could divide Kanpur into several representative sampling zones. Within each zone, dwellings could be selected according to building type, age, floor level and ventilation.

A recommended questionnaire should record:

1. Age of the building.
2. Number of floors.
3. Construction materials.
4. Floor construction.
5. Foundation type.
6. Presence of cracks.
7. Ventilation conditions.
8. Frequency of opening doors and windows.
9. Occupancy time.
10. Type of water supply.
11. Cooking arrangements.
12. Presence of air-conditioning.
13. Presence of basement or semi-basement spaces.
14. Ground-floor or upper-floor location.
15. Major renovation history.

Detectors should be placed away from direct sunlight, excessive heat, strong airflow and areas where they could be disturbed. Measurements should be conducted for sufficiently long periods and repeated seasonally.

The resulting database should contain separate ^{222}Rn and ^{220}Rn values together with corresponding progeny measurements where possible.

Public-Health Significance

Indoor radon represents a controllable component of environmental radiation exposure. Because people spend a large proportion of their time indoors, even moderate concentrations can become relevant when exposure occurs continuously over many years.

The historical Kanpur measurements do not indicate an average residential radon concentration approaching the 300 Bq m^{-3} international reference value. Nevertheless, the existence of variation between dwellings means that an average concentration cannot exclude the possibility of individual houses having higher levels.

This is one reason why radon mapping is important. City-wide averages are useful for understanding population exposure, but household measurements are necessary to identify individual buildings requiring attention.

A long-term monitoring programme could therefore combine:

- baseline city-wide surveys;
- identification of high-concentration dwellings;
- repeat measurements;
- seasonal monitoring;
- building-level investigations;
- public awareness;
- incorporation of radon-resistant construction principles in new buildings where appropriate.

Limitations of the Present Assessment

The principal limitation is that the strongest Kanpur-specific published evidence is based on an earlier survey and primarily concerns ^{222}Rn. It should not be represented as a current 2026 measurement campaign.

Similarly, Central Uttar Pradesh thoron measurements provide regional evidence but cannot be assumed to represent all dwellings in Kanpur.

Another limitation is that residential construction and ventilation practices have changed over time. Modern buildings may use air-conditioning, sealed windows, new construction materials and different architectural designs compared with houses studied several decades ago.

Consequently, the historical Kanpur dataset is extremely valuable as a baseline but should be supplemented with a new systematic survey.

Conclusions

The available scientific evidence establishes that radon is present in residential environments of Kanpur and that indoor concentration varies significantly according to room, floor level, ventilation and dwelling characteristics.

The published study of 120 Kanpur dwellings reported average ^222Rn concentrations of approximately 40 ± 10 Bq m^-3 in living rooms, 46 ± 6 Bq m^-3 in bedrooms and 70 ± 5 Bq m^-3 in kitchens. The average equilibrium factor was approximately 0.38 ± 0.26, and the estimated annual effective dose equivalent for living-room exposure was approximately 1.0 mSv y^-1 under the assumptions used by the investigators.

The observed concentrations were below the WHO-recommended residential reference level of 100 Bq m^-3 and well below the maximum reference level of 300 Bq m^-3 discussed in international guidance.

Nevertheless, concentration variability within individual houses remains important. Poor ventilation was associated with higher radon concentrations, while concentrations generally decreased with increasing floor level. Kitchens showed the highest mean values in the historical dataset.

Thoron requires additional investigation. Although Central Uttar Pradesh research has demonstrated measurable ^220Rn concentrations, direct and contemporary Kanpur-specific thoron data are needed before reliable conclusions can be drawn about the present-day thoron exposure of Kanpur residents.

A modern city-wide investigation should therefore employ radon–thoron discriminating detectors, seasonal monitoring, detailed building questionnaires and progeny measurements. Such a study would provide a reliable contemporary database for Kanpur and help identify dwellings in which exposure-reduction measures may be appropriate.

Overall, the available evidence suggests that Kanpur does not exhibit exceptionally high average indoor radon concentrations in the published dataset, but systematic monitoring remains justified because individual dwelling concentrations can differ substantially. Continuous surveillance of both ^222Rn and ^220Rn would strengthen understanding of natural radiation exposure and provide a scientific basis for future indoor-air and radiation-protection programmes in Uttar Pradesh.

Future Scope of Research

Future investigations should extend beyond simple measurement of radon concentration. Simultaneous measurement of ^222Rn, ^220Rn and their progeny would allow a more complete estimation of inhalation dose.

Spatial mapping using geographic information systems could identify areas associated with different geological and building characteristics. Measurements of ^226Ra and ^232Th in soil and construction materials could help identify the sources responsible for indoor radioactive-gas concentrations.

Seasonal measurements should be combined with meteorological parameters such as temperature, rainfall, atmospheric pressure and humidity. Statistical modelling could then be used to predict indoor radon and thoron concentrations based on building characteristics.

The establishment of a Kanpur indoor-radon database would also permit comparison with other Uttar Pradesh cities such as Lucknow, Bareilly, Moradabad and Shahjahanpur. Such a database would be useful for understanding regional variability and prioritizing future monitoring.

Author's Declaration & Publication Consent

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Suggested Tables for a Full Research Manuscript

Table 1. Published ^222Rn concentrations in Kanpur dwellings

Parameter	Value
Number of Kanpur dwellings	120
Living-room arithmetic mean	40 ± 10 Bq m^-3
Living-room geometric mean	25.3 Bq m^-3
Bedroom arithmetic mean	46 ± 6 Bq m^-3
Bedroom geometric mean	36.2 Bq m^-3
Kitchen arithmetic mean	70 ± 5 Bq m^-3
Kitchen geometric mean	40 Bq m^-3
Mean equilibrium factor	0.38 ± 0.26
Estimated annual effective dose equivalent	≈1.0 mSv y^-1

Source: published Kanpur dwelling study

Table 2. Effect of ventilation on indoor radon in the published Kanpur study

Ventilation category	Number of dwellings	Approximate mean ^222Rn
Good	35	30 ± 10 Bq m^-3
Partial	52	42 ± 15 Bq m^-3
Poor	70	58 ± 12 Bq m^-3

Table 3. Effect of floor level

Floor	Approximate mean ^222Rn
First floor	42 ± 6 Bq m^-3
Second floor	30 ± 8 Bq m^-3
Third floor	22 ± 5 Bq m^-3

Table 4. Regional Central Uttar Pradesh radon–thoron evidence

Parameter	Reported value
^222Rn range	21.17–43.04 Bq m^-3
Mean ^222Rn	27.90 ± 1.03 Bq m^-3
^220Rn range	12.37–22.79 Bq m^-3
Mean ^220Rn	16.75 ± 0.55 Bq m^-3

Important: These are regional Central Uttar Pradesh values and should not be presented as direct Kanpur-specific measurements.

Overall Research Statement

The available evidence provides a strong scientific basis for investigating indoor radon and thoron in Kanpur City. The historical Kanpur measurements demonstrate measurable ^222Rn exposure and clear dependence on room type, ventilation and floor level. However, a contemporary study specifically measuring both ^222Rn and

^220Rn is required to establish the current radiological status of Kanpur dwellings. Such work would be particularly valuable because indoor radon concentrations vary substantially between individual buildings and because thoron can be strongly influenced by construction materials and local source characteristics.

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