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Assessment of Natural Radioactivity and Radon-Induced Environmental and Health Risks in India

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ABSTRACT: Natural radioactivity and radon are among the major contributors to human exposure to ionizing radiation and have significant implications for environmental safety and public health. This study provides a comprehensive assessment of natural radioactivity and radon concentrations in environmental media, including soil, water, air, and building environments, with particular emphasis on their distribution and associated health risks in urban and rural areas. Published data obtained using advanced detection techniques, including RAD7 detectors, liquid scintillation counters, CR-39 detectors, and gamma-ray spectrometry, were systematically reviewed and analysed. The study evaluates the influence of geological characteristics, environmental conditions, and anthropogenic factors on radon distribution and annual effective dose (AED). The findings indicate considerable spatial variations in radon concentrations, primarily influenced by geological formations, groundwater characteristics, building materials, and ventilation conditions. Elevated radon exposure has been associated with an increased risk of lung cancer and other radiation-related health effects. The study highlights the importance of continuous environmental monitoring, effective radon mitigation strategies, and evidence-based public health policies to minimize radiation exposure and improve environmental safety. The findings provide valuable information for environmental management, radiation protection, and future research on natural radioactivity.

KEYWORDS: Natural Radioactivity; Radon; Environmental Radiation; Indoor Radon; Annual Effective Dose; Health Risk Assessment; Environmental Monitoring; Geological Factors.

I. INTRODUCTION

Natural background radiation represents the largest source of ionizing radiation exposure to humans and has become an important area of research in environmental science, radiation physics, and public health. Natural radiation originates primarily from cosmic rays and naturally occurring radionuclides present in rocks, soils, groundwater, and building materials. The distribution of these radionuclides varies considerably with geological formations, resulting in significant regional differences in environmental radiation levels.

Among naturally occurring radioactive gases, **radon (^{222}Rn)** is of particular concern because it is produced through the radioactive decay of uranium present in rocks and soils. Being a colourless, odourless, and chemically inert noble gas, radon can migrate through soil and accumulate in enclosed environments such as residential buildings, workplaces, and underground structures. Owing to its relatively high density compared with air, inadequate ventilation can lead to elevated indoor radon concentrations.

Radon and its short-lived decay products contribute approximately 50% of the average annual radiation dose received from natural background radiation. Long-term exposure to elevated radon concentrations has been identified as one of the leading environmental causes of lung cancer, particularly among non-smokers. The concentration of indoor radon is influenced by several factors, including geological formations, soil permeability, meteorological conditions, building construction materials, ventilation practices, and groundwater characteristics.

Consequently, continuous monitoring of radon concentrations in environmental media—including air, water, soil, rocks, and building materials—is essential for assessing radiation exposure and implementing appropriate mitigation measures.

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Reliable assessment of radon distribution contributes significantly to environmental protection, radiation safety, public health planning, and the development of evidence-based mitigation strategies.

Ionising radiation from naturally occurring radioactive elements

Ionising radiation is continuously emitted during the natural radioactive decay of unstable radionuclides present in the Earth's crust. The principal naturally occurring radioactive decay series include uranium-238 (^{238}U), thorium-232 (^{232}Th), and actinium-235 (^{235}U), together with naturally occurring potassium-40 (^{40}K). These radionuclides constitute the primary sources of terrestrial background radiation.

The distribution of natural radioactivity varies significantly with geological formations and mineral composition. Regions rich in uranium-, thorium-, or monazite-bearing minerals generally exhibit elevated radiation levels. Likewise, granite-rich geological formations have been reported to contain comparatively higher concentrations of naturally occurring radionuclides.

Thoron (^{220}Rn), a radioactive isotope of radon produced from the thorium decay series, possesses a relatively short half-life of approximately 55.6 seconds. Despite its short lifetime, thoron can contribute substantially to indoor radiation exposure, particularly in poorly ventilated environments where occupants remain in close proximity to walls containing thorium-bearing building materials. Consequently, accurate measurement of radon, thoron, and their progeny is essential for evaluating radiation exposure and implementing effective mitigation strategies. A comprehensive understanding of the behaviour of these radionuclides under varying environmental and geological conditions is fundamental for assessing potential health risks associated with natural radiation.

II. OBJECTIVES

The present study was undertaken with the following objectives:

1. **To evaluate indoor radon, thoron, and their progeny concentrations in Indian residential buildings and surrounding environments.**
2. **To assess the environmental and public health risks associated with radon exposure in indoor and outdoor environments.**
3. **To compare radon concentrations reported in water, buildings, soils, and rocks across different regions of India.**
4. **To examine the influence of geological, environmental, and structural factors on radon distribution and radiation exposure.**
5. **To identify suitable monitoring and mitigation strategies for reducing radon-induced health risks.**

III. REVIEW OF LITERATURE

Mousavi Aghdam et al. (2021)

Mousavi Aghdam et al. (2021) investigated natural radioactivity and radon/thoron exhalation in high-radon regions of southeastern Ireland. The study integrated indoor radon measurements, soil sampling, airborne radiometric surveys, and stream sediment geochemistry to evaluate radon and thoron exhalation rates. Soil classification was identified as a more reliable indicator of thoron exhalation than geological boundaries alone. The reported average annual effective dose was **0.84 mSv**, with several locations exceeding the recommended public exposure limit of **1 mSv per year**. The authors concluded that airborne radiometric surveys provide an efficient approach for identifying radon-prone areas and predicting radiation risk.

Anastasia Zlobina (2022)

Zlobina (2022) investigated natural radioactivity across four high-background radiation regions by analysing radionuclide concentrations in rocks and soils, ambient gamma radiation levels, radon exhalation rates, and indoor radon concentrations. The study demonstrated that regional geological and geochemical characteristics strongly influence radionuclide distribution and radon release into the environment. Variations in natural radioactivity were found to significantly affect radiation exposure among local populations. The findings highlight the importance of continuous environmental monitoring and geological assessment for identifying high-risk areas and developing effective radiation protection strategies.

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Anil Pawade (2020)
Pawade (2020) reported that radon is a naturally occurring radioactive gas generated from the decay of uranium present in rocks and soils. It enters buildings through cracks in foundations, walls, and construction joints, while groundwater also serves as an important source in many regions. Indoor radon concentrations vary considerably depending on geological conditions, seasonal changes, building design, and ventilation. The study emphasized that radon is the leading cause of lung cancer among non-smokers and recommended regular indoor radon monitoring, radon-resistant construction practices, and appropriate mitigation techniques to reduce long-term health risks.

L. M. Singh (2021)
Singh (2021) evaluated radon, thoron, and natural radioactivity associated with fly ash generated from coal-fired thermal power plants. Using radon exhalation measurements and gamma-ray spectroscopic analysis with a NaI(Tl) detector, the study assessed environmental radiation hazards from fly ash residues. The results indicated that radionuclide concentrations and radon/thoron exhalation rates remained within internationally accepted safety limits, with hazard indices below the recommended threshold. The study concluded that properly managed fly ash poses minimal radiological risk to nearby populations while highlighting the importance of routine environmental monitoring.

Rakmetkazhy I. Bersimbaev (2015)
Bersimbaev (2015) reviewed the health consequences of radon exposure in regions with naturally elevated background radiation, particularly uranium mining areas in Kazakhstan. The study emphasized that radon and its decay products are among the major contributors to natural radiation exposure and represent the second leading cause of lung cancer worldwide after smoking. The author highlighted the limited availability of epidemiological data on radon-related health effects in affected regions and recommended extensive population-based studies, regular indoor radon monitoring, and increased public awareness to reduce radiation-related health risks.

IV. RESEARCH METHODOLOGY

This study employed a **systematic literature review and comparative analysis** to assess natural radioactivity and radon concentrations in different environmental media across India. The review focused on radon occurrence in water, soil, rocks, residential buildings, and other indoor environments, together with the associated annual effective dose (AED) and potential radiological health risks.

Relevant published research articles, scientific reports, and reliable academic sources were identified through a structured literature search. The search was conducted using keywords such as **"radon concentration in India," "natural radioactivity," "indoor radon," "radon in groundwater," "radon in soil and rocks," "annual effective dose,"** and **"radon-related health risks."** Studies were selected based on their relevance to the objectives of the present research and the availability of quantitative data related to radon concentration, measurement methods, geographical location, and radiological dose assessment.

The selected studies were screened to ensure that they reported measurable radon concentrations in one or more environmental media. Studies with insufficient data, unclear measurement procedures, or information not directly related to radon occurrence and environmental exposure were excluded. The relevant information from the selected studies was extracted and organized according to the **study location, sample or building type, measurement technique, reported radon concentration, annual effective dose, and major environmental or geological factors** influencing radon distribution.

The collected data were classified into three major categories: **(i) radon concentration in water samples, (ii) indoor radon concentration in buildings and other occupied environments, and (iii) radon occurrence in soils and rocks.** The reported values were compiled into tables to facilitate systematic comparison among different geographical regions and environmental settings.

A comparative analysis was performed to identify variations in radon concentrations and associated radiation exposure across India. Particular attention was given to the influence of **geological formations, uranium- and thorium-bearing minerals, groundwater characteristics, soil properties, building materials, structural conditions, ventilation practices, and environmental factors.** Differences in measurement techniques and reported dose values were also considered during the interpretation of the findings.

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The results were interpreted with reference to the reported values and conclusions of the selected studies. Since the present research was based exclusively on previously published data, **no direct field sampling or experimental measurements were conducted.** The findings provide an integrated overview of radon distribution, environmental exposure, and potential radiological health risks and help identify areas requiring further investigation, continuous monitoring, and appropriate mitigation measures.

V. RESULTS AND DISCUSSION

Table 1: Radon Concentration in Water Samples and Associated Radiological Data

Location	Sample Type	Method	Radon Concentration (Bq/L)	AED (mSv/y)
Maharashtra, Pune	Borehole	Liquid Scintillation Counter	82.75	0.60
Maharashtra, Pune	Dug Well Water	Liquid Scintillation Counter	94.11	0.69
Karnataka, Bengaluru	HDW	RAD7 Radon Detector	13.33	–
Karnataka, Bengaluru University	HPB	RAD7 Radon Detector	27.40	–
Karnataka, Bengaluru University	MBH	RAD7 Radon Detector	7.40	–
West Bengal, Kolkata	Surface Water	RAD7 Active Electronic Detector	35.86	0.352
Maharashtra, Nagpur	Water	RAD7	1.86	0.02
Rajasthan, Jaipur	Groundwater	RAD7/RADH2O	78.51	0.00157
Odisha, Bhubaneswar	Bottled Water	RAD7 Detector	0.47	0.00018
Odisha, Bhubaneswar	Sachet Water	RAD7 Detector	0.25	0.00000051
Tamil Nadu, Chennai	Groundwater	RAD7 Detector	45.78	0.0594
Maharashtra, Nashik	Water	–	3.91	0.000051 (0.985)

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Location	Sample Type	Method	Radon Concentration (Bq/L)	AED (mSv/y)
Maharashtra, Mumbai	Boreholes/ Wells	Durridge RAD7	55.41–104.45	–
Maharashtra, Mumbai	Ponds/Streams	–	61.48–119.71	–
Maharashtra, Mumbai	Other Water Sources	–	47.31–111.90	–
Madhya Pradesh, Indore	Borehole	Tri-carb LSA 1000 Liquid Scintillation Detector	0.35–2.57	0.06–0.45
Madhya Pradesh, Indore	Wells Water	–	0.9–6.5	–
Odisha, Cuttack	Well Water	Tri-carb LSA 1000	17.25	4.10–6.87
Odisha, Bhubaneswar	Borehole	Liquid Scintillation Counter	28.01	0.20
Rajasthan, Udaipur	Well Water	–	25.34	–
Maharashtra, Nagpur	Groundwater	AlphaGUARD Radon Detector	1.23–18.11	0.020–0.25
Gujarat, Surat	Surface Water	RAD7	19.14	0.237

The compiled data demonstrate that radon concentrations in water vary considerably across different regions of India because of differences in geological formations, groundwater characteristics, uranium-bearing rocks, and hydrogeological conditions. Borehole water collected from Pune, Maharashtra, exhibited one of the highest radon concentrations (82.75–94.11 Bq/L), with corresponding annual effective doses ranging from 0.60 to 0.69 mSv/y. These observations indicate that groundwater drawn from deeper geological formations generally contains higher radon concentrations than surface water sources.

Measurements reported from Karnataka revealed moderate radon concentrations in university water supplies, ranging from 7.40 to 27.40 Bq/L. Surface water collected from Kolkata showed a concentration of 35.86 Bq/L, whereas groundwater samples from Jaipur reached 78.51 Bq/L, emphasizing the influence of local geological conditions on radon accumulation.

Considerable regional variations were also observed in Maharashtra. Groundwater collected from Mumbai exhibited concentrations between 55.41 and 104.45 Bq/L, while ponds and streams showed values ranging from 61.48 to 119.71 Bq/L. Similarly, groundwater samples from Nagpur varied between 1.23 and 18.11 Bq/L depending on sampling location and hydrogeological characteristics.

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Lower radon concentrations were reported for bottled and sachet water samples collected from Odisha, suggesting that water treatment and storage may reduce dissolved radon levels. In contrast, borehole and well-water samples from Madhya Pradesh and Rajasthan exhibited moderate concentrations, reflecting natural variations in uranium-bearing geological formations.

Overall, the reviewed studies indicate that groundwater sources generally contain higher radon concentrations than surface water. Although most reported values remain within internationally accepted reference levels, certain localized regions exhibit elevated concentrations that warrant continuous environmental monitoring. Regular surveillance, public awareness, and appropriate mitigation strategies are therefore essential to minimize long-term radiation exposure through drinking water and to protect public health.

Table 2: Radon Concentration and Radiological Data in Building Structures

Location	Building Type	Measurement Method	Radon Concentration (Bq/m^3)	AED (mSv/y)
Chennai, Tamil Nadu	Residential House	Digital Radon Detector	11.32	2.59
Chennai, Tamil Nadu	Buildings in Anna Nagar	Pocket-Sized Radon Detector	12.95	3.26
Chennai, Tamil Nadu	Buildings in T. Nagar	Not Reported	8.55	0.784
Coimbatore, Tamil Nadu	Buildings	Digital Radon Detector	10.65	0.64
Thiruvananthapuram, Kerala	Residential Buildings	Not Reported	12.25	0.74
Kochi, Kerala	Residential Buildings	Not Reported	13.32	0.81
Patna, Bihar	Low-Level Buildings	Not Reported	53.3 ± 13.3	1.469
Patna, Bihar	Medium-Level Buildings	Not Reported	223.3 ± 55.8	6.157
Patna, Bihar	High-Level Buildings	Not Reported	423.3 ± 105.8	11.673
Gandhinagar, Gujarat	Buildings	Not Reported	18.55	Not Reported
Vadodara, Gujarat	Buildings	Not Reported	19.78	Not Reported

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Location	Building Type	Measurement Method	Radon Concentration (Bq/m³)	AED (mSv/y)
Surat, Gujarat	Buildings	Not Reported	33.68	Not Reported
Rajkot, Gujarat	Buildings	Not Reported	59.46	Not Reported
Lucknow, Uttar Pradesh	Buildings	Durridge RAD7	19–160	Not Reported
Bengaluru, Karnataka	Buildings	Not Reported	16.9	Not Reported
Kolkata, West Bengal	Buildings	RAD7 Detector	Not Reported	Not Reported
Patiala, Punjab	Glass Buildings	Not Reported	14.96	0.377
Patiala, Punjab	Brick Buildings	Not Reported	10.74	0.271
Patiala, Punjab	Basement	Not Reported	144.61	3.644
Pune, Maharashtra	School Buildings	CR-39 Detectors	176.15	1.84
Coimbatore, Tamil Nadu	Buildings	CR-39 Detector	7.52	Not Reported
Varanasi, Uttar Pradesh	Basement	RAD7	23.0	0.0896
Bengaluru and Mangaluru, Karnataka	Buildings	RAD7	23.08–72.14	0.91–3.27
Indore, Madhya Pradesh	Hostel Buildings (Daytime)	Not Reported	23.0–36.0	Not Reported
Kanpur, Uttar Pradesh	Buildings	Pro3 Radon Gas Detector (Model HS71512)	19.3–34.2	Not Reported

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The reported indoor radon concentrations demonstrate considerable spatial variation among buildings in different regions of India. These variations may be influenced by local geology, building design, construction materials, foundation characteristics, ventilation conditions, occupancy patterns, and the measurement techniques used.

In Tamil Nadu, relatively low indoor radon concentrations were reported in residential and other buildings. The recorded concentrations were 11.32 Bq/m³ in Chennai residential houses, 12.95 Bq/m³ in buildings located in Anna Nagar, and 8.55 Bq/m³ in T. Nagar. In Coimbatore, concentrations of 10.65 Bq/m³ and 7.52 Bq/m³ were reported using digital radon and CR-39 detectors, respectively. The differences between these values may be associated with variations in building characteristics, environmental conditions, and measurement methods.

In Kerala, indoor radon concentrations of 12.25 Bq/m³ in Thiruvananthapuram and 13.32 Bq/m³ in Kochi were reported. These values indicate relatively low radon concentrations in the investigated buildings. However, continued monitoring is important because indoor radon levels may vary with seasonal changes, ventilation practices, and local geological conditions.

The highest concentrations in the reviewed Indian building data were reported in Patna, Bihar. Radon concentrations increased from 53.3 ± 13.3 Bq/m³ in low-level buildings to 223.3 ± 55.8 Bq/m³ in medium-level buildings and 423.3 ± 105.8 Bq/m³ in high-level buildings. The corresponding annual effective doses were 1.469, 6.157, and 11.673 mSv/y, respectively. These findings indicate substantial variation among building categories and emphasize the importance of detailed, site-specific investigations.

In Gujarat, radon concentrations ranged from 18.55 Bq/m³ in Gandhinagar to 59.46 Bq/m³ in Rajkot. Intermediate values of 19.78 Bq/m³ and 33.68 Bq/m³ were reported in Vadodara and Surat, respectively. In Lucknow, Uttar Pradesh, indoor radon concentrations ranged from 19 to 160 Bq/m³, indicating considerable variation among the investigated buildings.

The influence of building materials and structural characteristics was evident in the results reported from Patiala, Punjab. Radon concentrations were 14.96 Bq/m³ in glass buildings and 10.74 Bq/m³ in brick buildings, whereas a substantially higher concentration of 144.61 Bq/m³ was observed in basement environments. The increased concentration in basements may be associated with reduced ventilation and greater contact with radon-containing soil gas.

Relatively elevated concentrations were also reported in school buildings in Pune, Maharashtra, where the measured radon concentration was 176.15 Bq/m³, corresponding to an annual effective dose of 1.84 mSv/y. In Bengaluru and Mangaluru, Karnataka, indoor radon concentrations ranged from 23.08 to 72.14 Bq/m³, with corresponding annual effective doses of 0.91–3.27 mSv/y. In Indore, Madhya Pradesh, hostel buildings showed concentrations ranging from 23.0 to 36.0 Bq/m³. The reported values for buildings in Kanpur, Uttar Pradesh, ranged from 19.3 to 34.2 Bq/m³.

Overall, the reviewed data indicate substantial regional and building-specific variation in indoor radon concentrations across India. Most of the reported values were relatively low; however, elevated concentrations observed in certain buildings, particularly in Patna, Pune, and basement environments, indicate the need for regular monitoring and location-specific assessment. Improving ventilation, reducing the entry of soil gas through foundations, and adopting suitable radon-resistant building practices may help reduce indoor radon exposure. Further studies using standardized measurement methods and comparable exposure-assessment procedures are required to improve the understanding of indoor radon distribution and associated radiological risks across different regions of India.

Table 3: Radon Concentration and Radiological Data in Rocks and Soils

Location	Sample Type	Method	Radon Concentration (Bq/m³ or Bq/L)	AED (mSv/y)
Uttar Pradesh, Lucknow	Soil	RAD7 Solid-State Detector	1004–19250	–

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Location	Sample Type	Method	Radon Concentration (Bq/m³ or Bq/L)	AED (mSv/y)
India	Granite & Limestone Rocks	RAD7 Detector	237.5	5.99
Madhya Pradesh, Bhopal	Granite Grey & Mica Schist	RAD7 Electronic Radon Detector	3.5 kBq/m³	–
Odisha, Bhubaneswar	–	–	11.5	–
Odisha, Bhubaneswar	–	–	28.4	–
Karnataka, Mysuru	Wet Soil	Detectors	5.66	–
Karnataka, Mysuru	Dry Soil	–	6.98	–
India	Granite & Limestone Rocks	RAD7 Detector	585.16	14.80

The influence of local geology on radon emission levels is evident from the substantial spatial variation in radon concentrations reported across different geological settings in India. Soil samples collected from Lucknow, Uttar Pradesh, exhibited radon concentrations ranging from **1004 to 19,250 Bq/m³**, as measured using a **RAD7 solid-state detector**. These values indicate considerable radon exhalation from the soil in the study area.

Radon concentrations in granite and limestone rock samples analysed using the **RAD7 detector** were reported as **237.5 Bq/m³** and **585.16 Bq/m³**, with corresponding annual effective doses (AEDs) of **5.99 mSv/y** and **14.80 mSv/y**, respectively. The variation between these values may be attributed to differences in geological characteristics, mineral composition, and local environmental conditions.

In Bhopal, Madhya Pradesh, the radon concentration measured in granite, grey, and mica schist samples using a **RAD7 electronic radon detector** was **3.5 kBq/m³**. In Bhubaneswar, Odisha, radon concentrations of **11.5 Bq/m³** and **28.4 Bq/m³** were reported for the analysed samples. In Mysuru, Karnataka, radon concentrations of **5.66 Bq/m³** and **6.98 Bq/m³** were recorded in wet and dry soil samples, respectively.

Overall, these findings demonstrate that geological characteristics substantially influence radon occurrence and emission levels. Variations in rock type, mineral composition, soil properties, and local environmental conditions may contribute to the observed differences in radon concentrations. Therefore, continuous monitoring of regions exhibiting elevated radon levels is essential for assessing potential radiological health risks and developing appropriate mitigation strategies.

VI. CONCLUSION

This study provides a comprehensive assessment of natural radioactivity and radon occurrence in water, soils, rocks, and indoor environments, with particular emphasis on their potential environmental and radiological health implications in India. The reviewed data demonstrate considerable spatial variation in radon concentrations across different regions. These variations are primarily influenced by geological formations, uranium- and thorium-bearing minerals, soil properties, groundwater characteristics, building materials, construction practices, ventilation conditions, and local environmental factors.

The findings indicate that groundwater sources may contain higher radon concentrations than surface-water sources because radon can dissolve and accumulate during the movement of water through uranium-bearing rocks and geological formations. Similarly, indoor radon concentrations vary substantially among buildings owing to differences in building design, foundation characteristics, construction materials, ventilation rates, and the geological properties of the surrounding area. Elevated concentrations observed in certain locations highlight the need for location-specific monitoring and appropriate radiation-protection measures. Long-term exposure to elevated radon concentrations may increase the risk of adverse health effects, particularly lung cancer. Therefore, regular assessment of radon levels in residential buildings, workplaces, water sources, and other frequently occupied environments is essential. Continuous monitoring can help identify radon-prone areas, evaluate population exposure, and support the development of effective mitigation strategies.

Improving indoor ventilation, reducing the entry of soil gas through building foundations, sealing openings and cracks, and adopting suitable radon-resistant construction practices may help reduce indoor radon concentrations. The effectiveness of these measures depends on building characteristics, local geological conditions, and the magnitude of radon accumulation. Consequently, mitigation strategies should be selected on the basis of site-specific measurements and environmental conditions. Overall, the study emphasizes the importance of systematic radon monitoring, detailed geological assessment, public awareness, and evidence-based radiation-protection policies. Further region-specific investigations using standardized measurement methods are required to develop a more comprehensive understanding of radon distribution and associated exposure risks across India. Such studies will support effective environmental management, improve radiation safety, and contribute to the protection of public health.

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