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Understanding Groundwater Radon Contamination through Clustering and Structural Risk Models

Sebestyen Puissant*
Department of Respiratory, University of Florida, Gainesville, FL 32608, USA

Introduction

Radon, a naturally occurring radioactive gas, is a significant environmental health concern. It is a colorless, odorless and tasteless gas that arises from the decay of uranium and thorium, which are found in varying concentrations in soil, rock and groundwater. Groundwater contamination by radon is of particular concern because it is an important drinking water source for millions of people worldwide. Prolonged exposure to radon, whether through indoor air or drinking water, can result in serious health risks, primarily lung cancer and other respiratory illnesses. In recent years, understanding the pathways and mechanisms of groundwater radon contamination has become a critical area of research, especially as groundwater serves as a primary source of drinking water in many rural and suburban areas. Groundwater radon contamination is influenced by a range of factors, including geological formations, regional hydrology, human activities and environmental conditions. Predicting and mitigating the risk of radon contamination requires a robust understanding of the spatial and temporal distribution of radon concentrations in groundwater, along with the associated health risks [1].

Description

Radon is a gas that originates from the natural radioactive decay of uranium, thorium and radium found in soil, rock and groundwater. The process occurs when uranium and thorium, elements present in various geological materials, decay into radon gas, which then escapes into the atmosphere or groundwater. As radon moves through the soil, it can enter homes and buildings through cracks in foundations or water systems. Radon is classified as a health hazard because its radioactive properties can lead to long-term health issues when people are exposed to elevated levels. It is considered the second leading cause of lung cancer after smoking and its effects on human health are magnified when radon is inhaled. While radon exposure through the air is more common, contamination in groundwater is also a significant concern, particularly in regions where groundwater is the primary source of drinking water. The U.S. Environmental Protection Agency (EPA) has set a Maximum Contaminant Level (MCL) for radon in drinking water at 300 picocuries per liter (pCi/L). However, levels that exceed this threshold can present health risks and many regions have yet to identify areas where groundwater contamination by radon is prevalent. Understanding where and why these high concentrations of radon occur is essential for protecting public health [2].

Prolonged exposure to high concentrations of radon, particularly when inhaled over time, can lead to severe health consequences, including lung cancer. The inhalation of radon gas, when trapped inside buildings or homes, allows radioactive particles to enter the lungs, where they can cause damage to lung tissue. This damage increases the risk of developing lung cancer over the long term. While radon's health impacts are widely recognized in indoor air quality, the ingestion of radon-contaminated water may also contribute to health risks. However, studies indicate that the primary health risk from radon in drinking water comes from inhalation rather than ingestion. As water is exposed to air in showering, cooking and other activities, radon gas can be released and inhaled. Traditional approaches to monitoring radon levels in groundwater typically involve periodic sampling and analysis of water quality. Radon concentration is usually measured in Picocuries Per Liter (pCi/L) and water samples are analyzed using specialized equipment, such as liquid scintillation counters or alpha-track detectors. However, this method is labor-intensive, time-consuming and often limited to isolated sampling points [3].

Clustering is a statistical method used to group data points based on shared characteristics or similarities. In the context of groundwater radon contamination, clustering techniques can help identify patterns in the spatial distribution of radon levels and group regions with similar contamination profiles. This can help researchers and policymakers identify areas at greater risk of radon contamination and tailor intervention efforts accordingly. One of the most widely used clustering algorithms, K-means clustering divides a dataset into a pre-defined number of clusters. The algorithm assigns data points (e.g., radon concentrations) to the closest cluster center and iteratively refines the cluster boundaries to minimize the variance within each cluster. Hierarchical Clustering method builds a tree-like structure of clusters by progressively merging or splitting them based on similarity. Hierarchical clustering can be particularly useful when the number of clusters is unknown and can provide insights into the natural groupings of data points. Unlike K-means, which requires a pre-defined number of clusters, DBSCAN detects clusters based on the density of data points in a given region. This method is useful for identifying irregular clusters and outliers, which may be important for pinpointing areas with unusual radon concentrations [4,5].

Conclusion

Groundwater radon contamination is a pressing environmental health issue that affects millions of people worldwide. Understanding the factors that contribute to radon contamination, as well as the spatial and temporal dynamics of this contamination, is crucial for developing effective mitigation strategies. Clustering techniques and structural risk models are powerful tools that can help identify areas at high risk for radon contamination, predict future risks and inform public health policies. Clustering methods provide valuable insights into the geographic distribution of radon concentrations, while structural risk models help assess the likelihood of contamination under various environmental and human-related scenarios. Together, these methods can guide decision-making and enable targeted interventions to reduce radon exposure and protect public health. As the field of groundwater radon research continues to evolve, the integration of advanced computational techniques and data analytics will play an increasingly important role in understanding and managing radon contamination.

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***Address for Correspondence:** Sebestyen Puissant, Department of Respiratory, University of Florida, Gainesville, FL 32608, USA, E-mail: sbestyen.issantpu@ist.edu*

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Conflict of Interest

None.

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