iJRASET
International Journal For Research in Applied Science and Engineering Technology

INTERNATIONAL JOURNAL FOR RESEARCH
IN APPLIED SCIENCE & ENGINEERING TECHNOLOGY

Volume: 14 Issue: III Month of publication: March 2026

DOI: https://doi.org/10.22214/ijraset.2026.78747

International Journal for Research in Applied Science & Engineering Technology (IJRASET)
ISSN: 2321-9653; IC Value: 45.98; SJ Impact Factor: 7.538
Volume 14 Issue III Mar 2026- Available at www.ijraset.com

Non-Destructive Measurement of Soil Porosity and Attenuation Coefficient Using Gamma-Ray Technique in Jalgaon Region of Maharashtra

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Abstract: Soil porosity is an important parameter governing water holding, drying, and soil structure. In this work, a non-destructive gamma-ray attenuation technique was used to determine soil bulk density, porosity, and attenuation coefficients for soil samples collected from the Jalgaon district, Maharashtra, India. Gamma-ray measurements were carried out using sealed ^{137}Cs (661.657 keV) and ^{60}Co (1173.228 keV and 1332.492 keV) sources with a NaI(Tl) scintillation detector. Bulk density values ranged from 0.85 to 1.09 g cm^{-3}, while porosity varied between range of 45.5% and 57.5%. The result shows that the inverse relationship between bulk density and porosity was observed. Linear attenuation coefficients increased with soil density but decreased with increasing photon energy, whereas mass attenuation coefficients showed smaller variations. The results confirm that gamma-ray attenuation is a reliable and effective method for non-destructive soil characterization.
Keywords: Soil porosity; Gamma-ray attenuation; Linear attenuation coefficient; Mass attenuation coefficient; NaI(Tl) detector.

I. INTRODUCTION

Soil porosity (ϕ) refers to the ratio of empty spaces or pores within the total volume of soil. These pores may be filled with air or water and play a key role in the studies of soil behaviour. The typical range of porosity in natural soil is observed between 30% and 60%. Since pore spaces control the movement and storage of water and air, even small changes in porosity can significantly influence soil properties such as permeability, aeration, and water retention [1].

The porous structure of soil provides environmental importance in physical, chemical, and biological processes that occur. Root growth, microbial activity, gas exchange, and nutrient transport all depend on the size, distribution, and connectivity of soil pores. Soil with good structure enables smooth water infiltration and efficient gas exchange, both of which are essential for plant growth and soil health. However, soils with poorly connected pores tend to restrict water flow and air movement. In the literature survey, coarse-textured soils have larger pores but lower total pore volume, whereas fine-textured soils show higher porosity with smaller pore sizes [2].

Soil porosity is commonly measured using traditional gravimetric methods, such as determining water content at saturation or calculating porosity from bulk density and particle density values [3]. Although these methods are widely used, they are often time-consuming and may disturb the soil structure. To overcome these limitations, non-destructive nuclear techniques have gained increasing attention in soil studies.

Among them, gamma-ray spectroscopy (GRS) and computed tomography (CT) have proven to be effective tools for rapid measurement and accurate soil characterization [4], [5]. In particular, GRS is a reliable technique and has been widely used to measure soil bulk density (ρ_s), soil moisture content (θ), and mass attenuation coefficients (μ_m). Using these parameters, additional soil properties such as total porosity and elemental composition can also be estimated [6].

In this study, gamma-ray attenuation techniques are employed to determine the linear attenuation coefficient, mass attenuation coefficient, and soil porosity of selected soil samples from the North Maharashtra region, Jalgaon.

The gamma rays with an initial intensity I_0 pass through a soil sample of thickness x, transmitted intensity I decreases due to interactions between the photons and the soil material. This attenuation follows the Beer–Lambert law [7]:

$$I = I_0 e^{-\mu x} \tag{1}$$

where μ is the linear attenuation coefficient (cm^{-1}), representing the probability of gamma-ray interaction per unit length within the soil. μ can be represented as the sum of four individual photon interaction processes, that is, photoelectric absorption, Compton

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Volume 14 Issue III Mar 2026- Available at www.ijraset.com

scattering, Rayleigh scattering, and pair-production [8]. From Eq. (1), the mass attenuation coefficient μ_m ($cm^2\ g^{-1}$) can be calculated as:

$$\mu_m = \frac{1}{x \cdot \rho_s} \cdot \ln\left(\frac{I_0}{I}\right) \tag{2}$$

where ρ_s (g cm^{-3}) is the measured soil density of the material, x is the thickness of soil samples.

Total porosity obtained from the gamma-ray attenuation approach is based on the determination of ρ_s through Eq. (2), written for the case of a soil as a porous material [9], and substitution of its value in the traditional method [3] Eq. (3) in order to come up with Eq. (4).

$$\phi_1 = \left(1 - \frac{\rho_s}{\rho_p}\right) \tag{3}$$

$$\phi_2 = \left(1 - \frac{1}{x \cdot \mu_s \cdot \rho_p} \ln\left(\frac{I_0}{I}\right)\right) \tag{4}$$

This approach allows soil porosity to be estimated in a non-destructive manner, making gamma-ray attenuation a valuable tool for soil physical studies and environmental applications.

II. MATERIAL AND METHOD

The Agricultural soil samples were collected from the North Maharashtra region of Jalgaon district of Maharashtra, India. Agricultural soil samples were placed in a cylindrical plastic container with a diameter of 5 cm and a thickness of 3 cm. Radioactive gamma sources such as ^{60}Co and ^{137}Cs are commonly employed in soil physical studies due to their suitable photon energies and stability [10]. In the present work, sealed sources of ^{60}Co (0.074 µCi) and ^{137}Cs (1.59 µCi) were used. The experimental setup employed for gamma-ray attenuation measurements is shown schematically in Fig. 1. A narrow beam of gamma rays emitted from the source was directed toward the soil sample. The incident gamma-ray intensity (I_0) was measured before placing the sample in the beam path, while the transmitted or attenuated intensity (I) was recorded after the beam passed through the soil sample. The transmitted radiation was detected using a scintillation detector coupled to a multichannel analyzer.

Soil samples were placed in a cylindrical plastic container with an internal diameter of 5 cm and a height of 3 cm. The container was positioned between the radioactive source and the detector, maintaining a fixed distance of 5 cm between the soil sample and the detector. Initially, the empty container was placed in the beam path to measure the incident gamma-ray intensity (I_0) for a counting time of 1800 sec. Afterwards, the container filled with soil was placed in the beam path, and the transmitted intensity (I) was measured for the same counting time. Data acquisition and spectral analysis were carried out using CNSPEC [11] software.

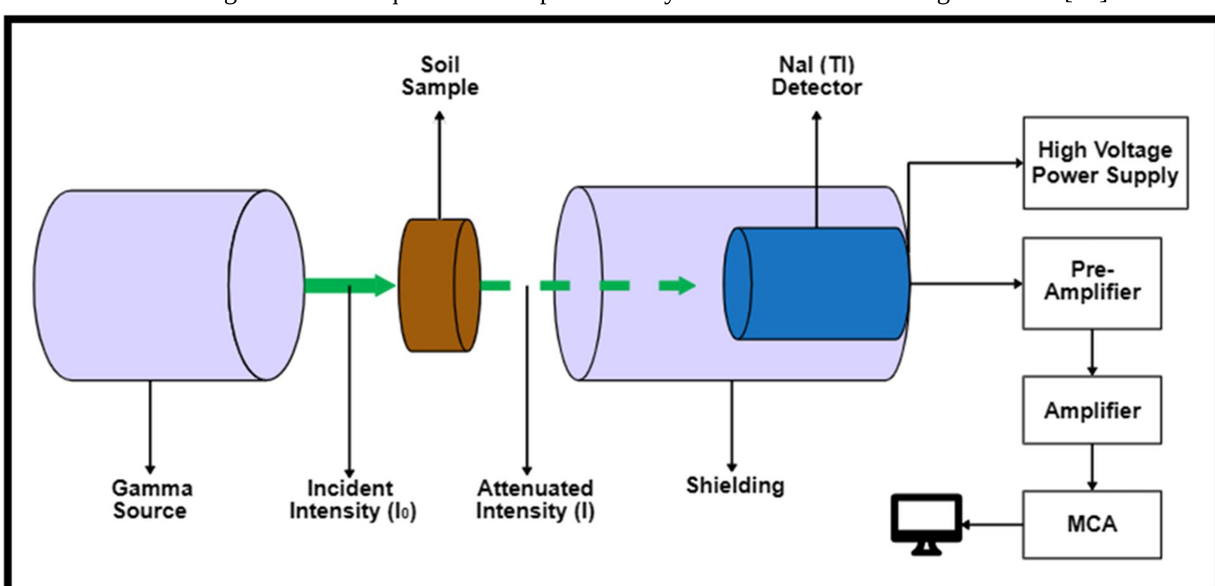


Fig. 1 The schematic of the NaI(Tl) detector and the soil sample experimental setup.

III.RESULTS AND DISCUSSION

The gamma-ray spectra obtained using ^{137}Cs and ^{60}Co sources are presented in Fig. 2–6. All spectra show a distinct photopeak at 661.657 keV for ^{137}Cs and 1173.228 keV and 1332.492 keV for ^{60}Co. The clear and stable peak positions in all spectra indicate good energy calibration and reliable performance of the NaI(Tl) detector system. Differences in peak heights among the spectra are mainly due to variations in gamma-ray attenuation caused by changes in soil bulk density and porosity.

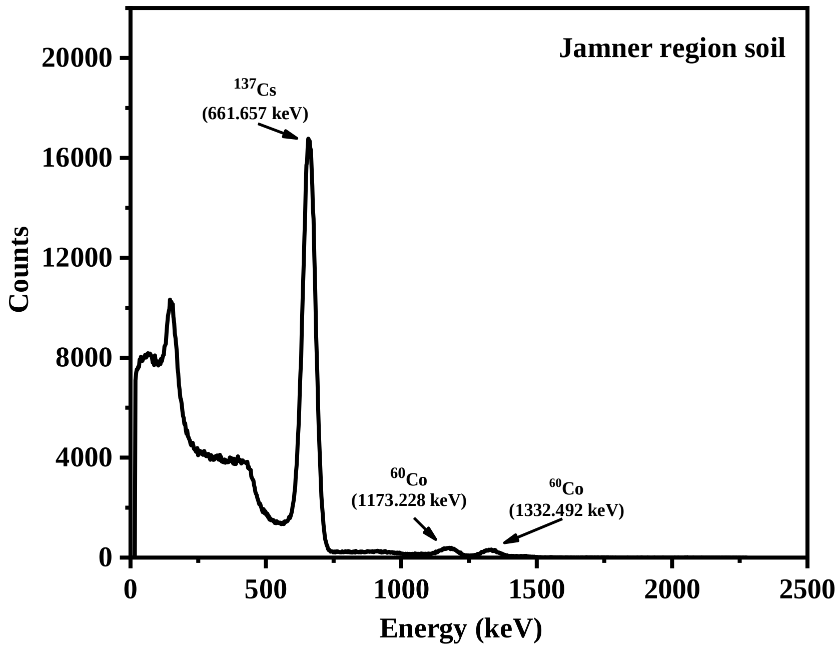


Fig. 2 Gamma-ray spectra of Jamner region soil sample after placing between the source and the NaI(Tl) detector.

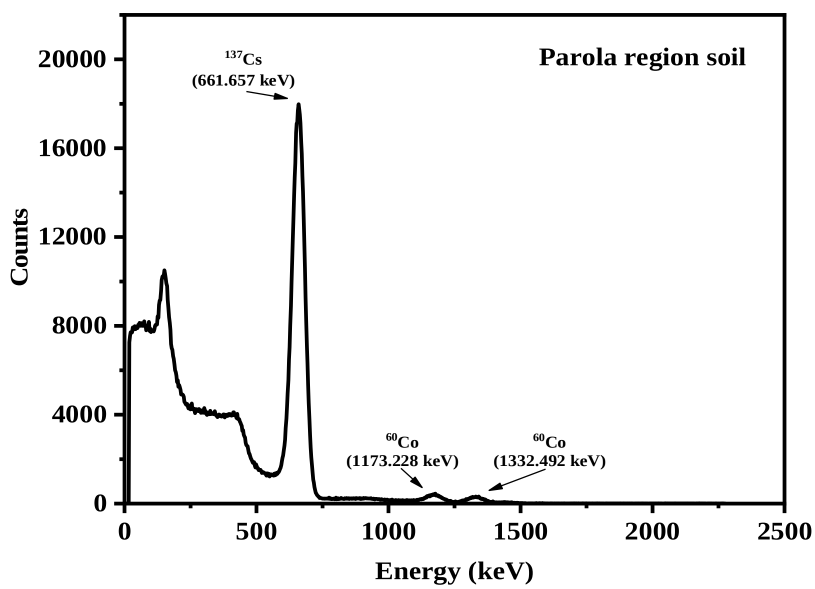


Fig. 3 Gamma-ray spectra of Parola region soil sample after placing between the source and the NaI(Tl) detector.

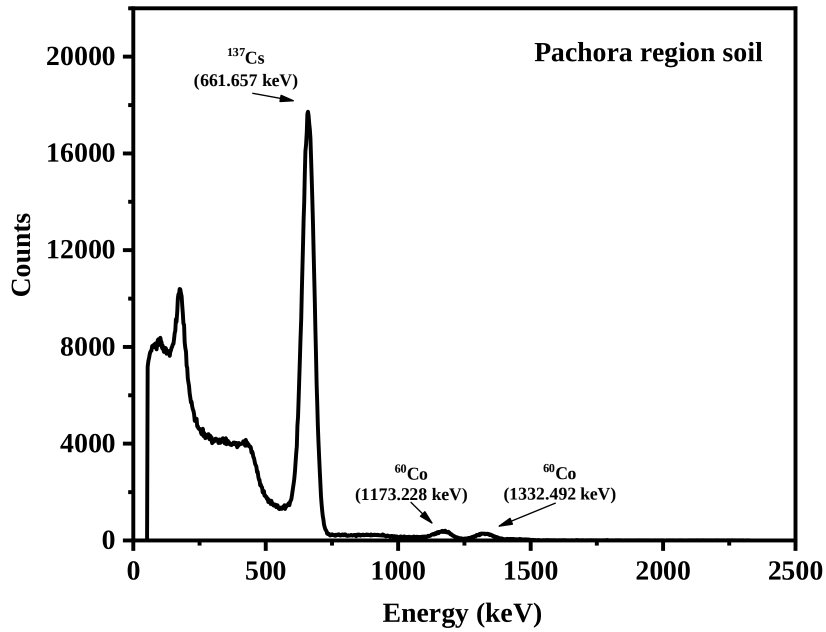


Fig. 4 Gamma-ray spectra of Pachora region soil sample after placing between the source and the NaI(Tl) detector.

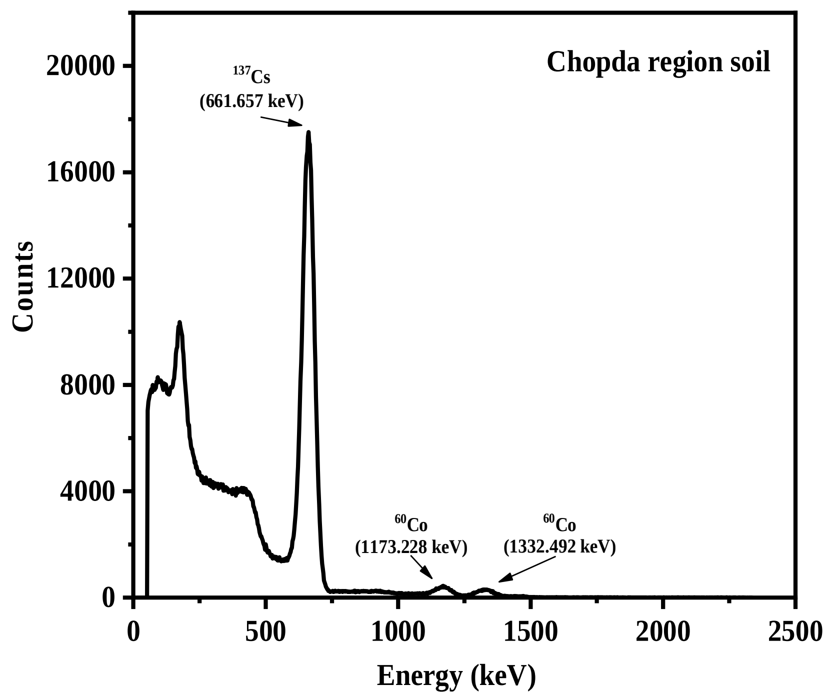


Fig. 5 Gamma-ray spectra of Chopda region soil sample after placing between the source and the NaI(Tl) detector.

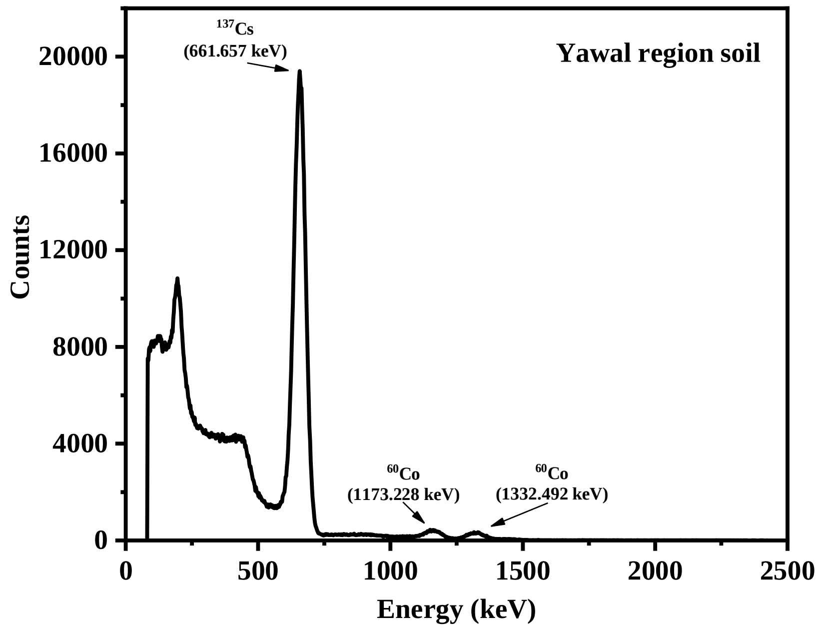


Fig. 6 Gamma-ray spectra of Yawal region soil sample after placing between the source and the NaI(Tl) detector.

The calculated values of linear and mass attenuation coefficients for all soil samples are listed in Table 1–3. For a fixed gamma-ray energy, the linear attenuation coefficient (μ) generally increases with bulk density. This happens because denser soils contain more atoms per unit volume, increasing the chance of gamma-ray interaction through absorption and scattering. Small deviations from this trend may result from differences in soil structure, particle arrangement, and pore distribution.

The attenuation coefficients also show a clear dependence on gamma-ray energy. The μ values obtained using ^{137}Cs (661.657 keV) are higher than those measured with ^{60}Co, as lower-energy photons interact more strongly with matter. At higher energies (1173.228 keV and 1332.492 keV), gamma rays penetrate the soil more easily, leading to lower attenuation coefficients, where Compton scattering is the dominant interaction process.

Compared to the linear attenuation coefficient (μ), the mass attenuation coefficient (μ_m) shows smaller variation for a given energy. This indicates that μ_m depends less on bulk density and more on the chemical composition of the soil. Minor changes in μ_m values suggest slight differences in elemental composition among the soil samples collected from different locations.

TABLE 1
ATTENUATION COEFFICIENT OF SOIL SAMPLES USING ^{137}CS OF ENERGY 661.657 KEV

Soil Sample	Bulk Density (ρ_s) gm/cm^3	Linear attenuation coeff. (μ) cm^{-1}	Mass attenuation coeff. (μ_m) cm^2/g
Yawal Region	0.850	0.106	0.125
Chopda Region	0.887	0.111	0.126
Pachora Region	0.989	0.134	0.136
Parola Region	1.077	0.120	0.111
Jamner Region	1.089	0.122	0.112

TABLE 2
Attenuation coefficient of soil samples using ^{60}Co of energy 1173.228 keV

Soil Sample	Bulk Density (ρ_s) gm/cm^3	Linear attenuation coeff. (μ) cm^{-1}	Mass attenuation coeff. (μ_m) cm^2/g
Yawal Region	0.850	0.053	0.062
Chopda Region	0.887	0.059	0.067
Pachora Region	0.989	0.082	0.082
Parola Region	1.077	0.095	0.088
Jamner Region	1.089	0.097	0.089

TABLE 3
ATTENUATION COEFFICIENT OF SOIL SAMPLES USING ^{60}CO OF ENERGY 1332.492 KEV

Soil Sample	Bulk Density (ρ_s) gm/cm3	Linear attenuation coeff. (μ) cm^{-1}	Mass attenuation coeff. (μ_m) cm^2/g
Yawal Region	0.850	0.080	0.094
Chopda Region	0.887	0.109	0.123
Pachora Region	0.989	0.128	0.129
Parola Region	1.077	0.134	0.124
Jamner Region	1.089	0.141	0.129

To examine the attenuation behaviour more clearly, a comparative plot of gamma-ray counts recorded without the sample (incident intensity, I_0) and with the sample (attenuated intensity, I) is presented in Fig. 7. In all cases, the counts measured with the soil sample are lower than those recorded without the sample over the entire energy range. This consistent reduction in counts confirms the attenuation of gamma rays within the soil medium.

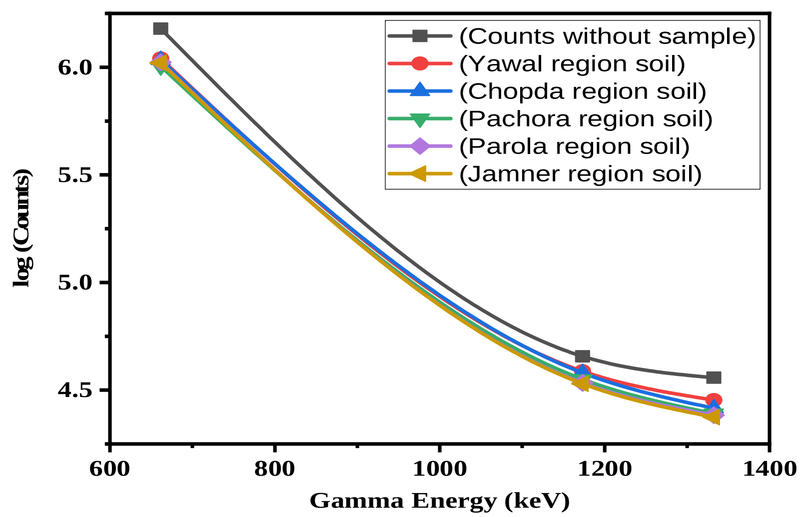


Fig. 7 Comparison of gamma-ray counts recorded without sample (incident intensity, I_0) and with soil samples (attenuated intensity, I)

The measured values of bulk density (ρ_s) and soil porosity (ϕ) for the studied soil samples are given in Table 4. The bulk density of the samples lies between 0.85 and 1.09 g cm^{-3}, while the porosity varies from about 45.54% to 57.58%.

TABLE 4
Bulk Density (P_s) And Porosity (Φ) Of Soil Samples Collected From Different Regions Of Jalgaon District, Maharashtra, India.

Sr. No.	Soil Sample	Bulk Density (ρ_s) gm/cm^3	Soil Porosity (ϕ) %
1	Yawal Region	0.850	57.488
2	Chopda Region	0.887	55.651
3	Pachora Region	0.989	50.550
4	Parola Region	1.077	46.127
5	Jamner Region	1.0891	45.541

The clear negative relationship between soil porosity and bulk density seen in **Fig. 8** confirms the reliability of the experimental results. Soil with lower bulk density has higher porosity, indicating more pore spaces. This behaviour is expected because soil compaction reduces the volume of pores and increases bulk density. The results confirm that gamma-ray attenuation measurements can be used effectively to estimate soil bulk density and porosity non-destructively.

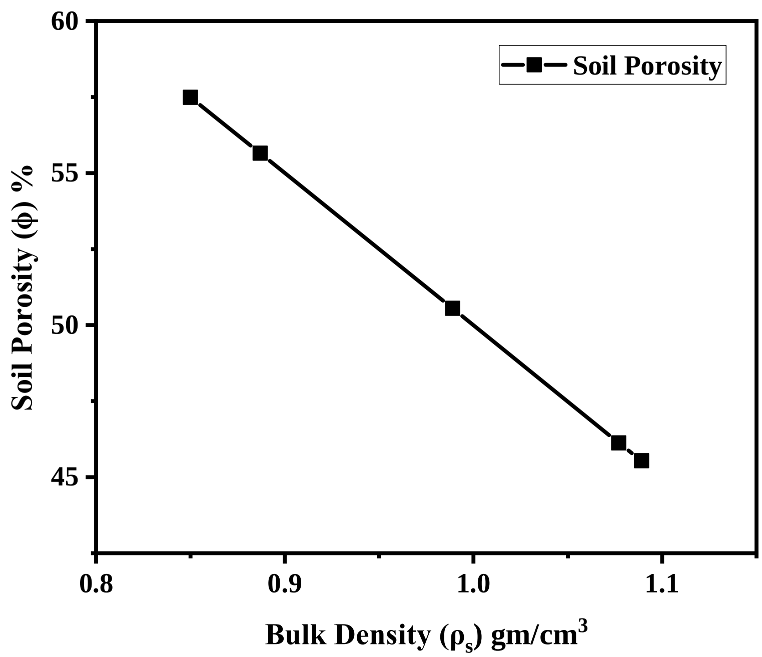


Fig. 8 Bulk Density vs Soil Porosity

IV. CONCLUSION

In this work, the gamma-ray attenuation technique was successfully applied to estimate soil porosity and attenuation coefficients in soil samples. The method proved to be non-destructive, reliable, and sensitive to variations in soil density and structure. Among the analyzed samples, the Yawal region soil exhibited the highest porosity (57.48%), while the Jamner region soil showed the lowest porosity (45.54%). The results confirm that soil porosity plays a significant role in determining the water-retention capability of soil. The linear attenuation coefficient (μ) was found to increase with increasing bulk density, as denser soils provide a greater number of atoms per unit volume for interaction. In contrast, the mass attenuation coefficient (μ_m) showed comparatively smaller variation among the samples, indicating its stronger dependence on soil composition rather than bulk density alone.

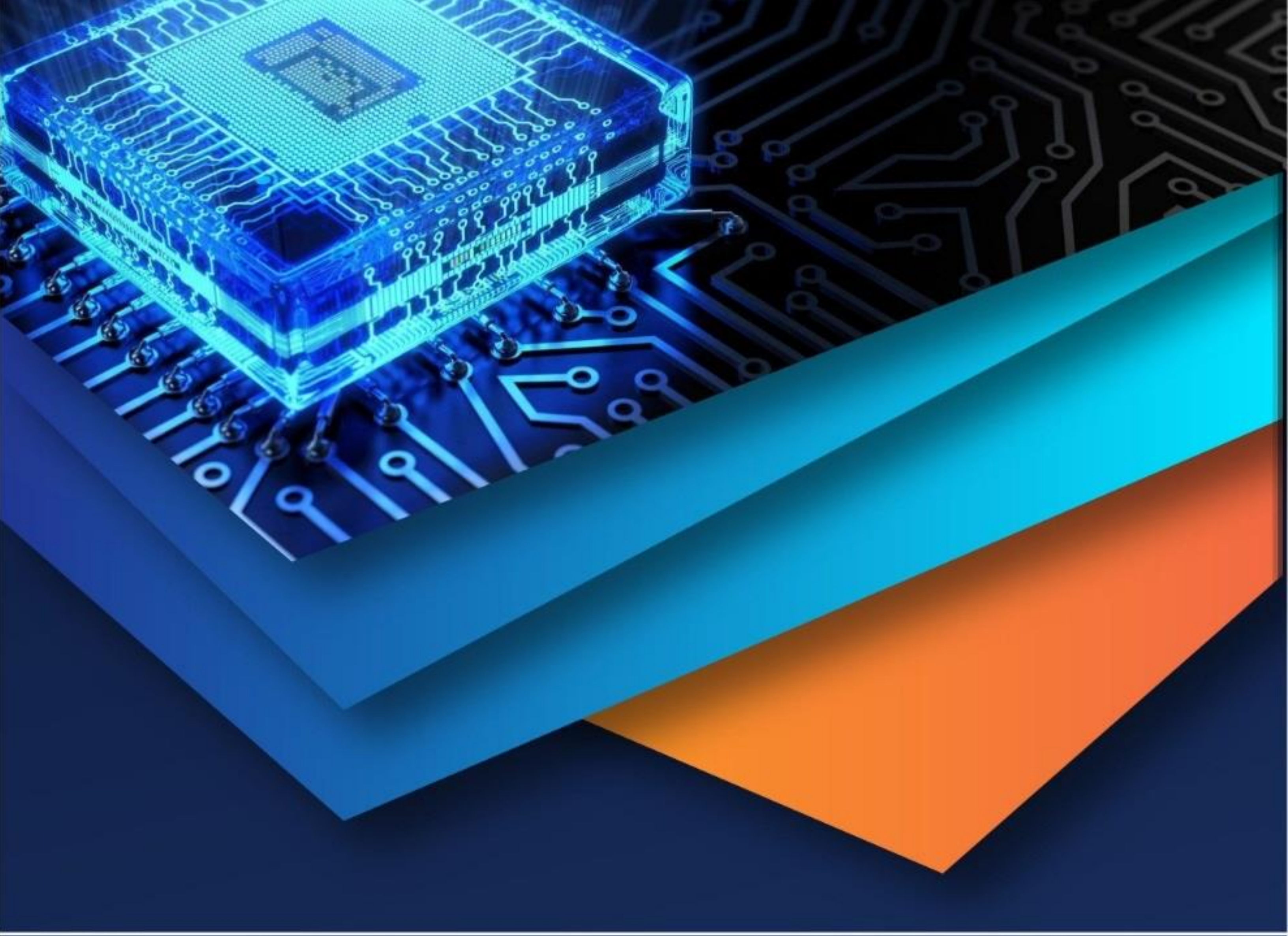
Overall, the results demonstrate that gamma-ray attenuation measurements can effectively be used for simultaneous estimation of bulk density, porosity, and attenuation properties of soils. The gamma-ray techniques can be efficiently employed for soil characterization, offering valuable applications in environmental monitoring, agriculture, and nuclear data studies.

V. ACKNOWLEDGMENT

The author [V. D. Bharud] are thankful to Vice-Chancellor Research Motivation Scheme (VCRMS) sanction number: KBCNMU/11A/VCRMS/2023-24/304/2023 for the financial support. Authors are grateful to Prof. Dr. J.V. Sali from Department of Physics, KBCNMU Jalgaon.

REFERENCES

[1] D. A. Rose, "Lal, R. & Shukla, M.K. Principles of Soil Physics. Marcel Dekker, New York, 2004. x + 716 pp. US$95, hardback. ISBN 0-8247-5324-0.," Eur. J. Soil Sci., vol. 56, no. 5, pp. 683–684, Oct. 2005, doi: https://doi.org/10.1111/j.1365-2389.2005.0756c.x.
[2] "Soil_Physics".
[3] D. Hillel, Introduction to environmental soil physics. Elsevier, 2003.
[4] J. Borges, L. Pires, and P. Belmont, "Computed Tomography to Estimate the Representative Elementary Area for Soil Porosity Measurements," ScientificWorldJournal., vol. 2012, p. 526380, May 2012, doi: 10.1100/2012/526380.
[5] W. E. Pöttker and C. R. Appoloni, "Measurement of amorphous materials porosity by gamma-ray transmission methodology," Radiation Physics and Chemistry, vol. 61, no. 3, pp. 535–536, 2001, doi: https://doi.org/10.1016/S0969-806X(01)00324-3.
[6] N. Dhingra, "Gamma-Ray Spectrometry for the Measurement of Mass Attenuation Coefficient and Bulk Density of Soil: A Review," Commun. Soil Sci. Plant Anal., vol. 54, pp. 1–7, Jun. 2023, doi: 10.1080/00103624.2023.2223650.
[7] D. F. Swinehart, "The Beer-Lambert Law," J. Chem. Educ., vol. 39, no. 7, p. 333, Jul. 1962, doi: 10.1021/ed039p333.
[8] J. H. Hubbell, "Photon mass attenuation and energy-absorption coefficients from 1 keV to 20 MeV," Int. J. Appl. Radiat. Isot., vol. 33, no. 11, Jan. 2025.
[9] L. Pires and A. Pereira, "Gamma-Ray Attenuation to Evaluate Soil Porosity: An Analysis of Methods," ScientificWorldJournal., vol. 2014, p. 723041, Jan. 2014, doi: 10.1155/2014/723041.
[10] L. F. Pires, "Soil analysis using nuclear techniques: A literature review of the gamma ray attenuation method," Soil Tillage Res., vol. 184, pp. 216–234, 2018, doi: https://doi.org/10.1016/j.still.2018.07.015.
[11] CNSPEC, Software for nuclear data acquisition and analysis



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