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Research Article

Estimation of Soil Porosity in Parts of Karnataka and Kerala by Gamma-Ray Attenuation Method

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ABSTRACT:
Background: Soil porosity (Φ) is a prime factor in environmental studies as pore spaces govern water and oxygen flow in the soil.
Purpose: Soil porosity has an impact on the durability and structural performance of cement pastes, mortars, and concretes by affecting the strength and mass transport processes. An exemplary determination of this is essential due to the inevitability of this physical property in numerous fields of natural science.
Methods: In this study gamma ray attenuation method was used for the examination.^{137}Cs was used for the mass attenuation process. The mass attenuation coefficient of dry samples was calculated from the transmission measurements.
Results: The porosity was obtained by using the values of mass attenuation, thickness of sample, soil particle density. Porosity for different thickness of the sample was calculated. The results of the five sample have variance which shows each sample was calculated. The results of the sample have its own characteristics.
Conclusions: Porosity values succors one in constructions and agriculture. The result obtained is found to be satisfactory.

KEYWORDS: Soil porosity, Gamma-ray attenuation, Mass attenuation, Linear attenuation

1. Introduction

The voids in the soil is designated as porosity and the structure of the soil is related to a building [1]. Soil structure is a key parameter and highly significant property that impacts the cultivation and crop production process as it is responsible for the amount of water that can be held by soil, depth up to which the roots can grow and movement of air and water through soil [2]. Soil porosity is inevitable for many reasons and its role in every aspect. A primary reason being soil pores contain the ground water many of us drink, another key aspect of soil porosity is the oxygen found within these pore spaces and all plants need oxygen for respiration, so a well-aerated soil is necessary for growing crops. Therefore, soil texture can alter porosity and disrupting these pores would affect the yield of crop. Soil compaction can occur due to various methods such as tillage, chisel plough, etc. which leads to loss of soil pores.The predominant morphological effects of soil compaction results in stunted growth, leaf discoloration, reduced plant height, and shallow root systems, along with reduced nutrient uptake, reduced leaf gas exchange, carbon assimilation and lower Photosynthetic translocation [3]. Soil structure is akin to the building, skeleton structure of the soil maintains the size, stability, and continuity of pores within and between. Soil deteriorates when it loses its pores and continuity within the soil profile and the atmosphere. The value of soil porosity generally varies from 0.3 to $0.6 gm/cm^3$. Porosity is conceptually divided into two components, called textural and structural porosity. Textural porosity, the pores and their size distribution concern the particle size distribution. The structural porosity, a dynamic subsistence, and a few exogenous that affect structural porosity include climate, cropping systems, and other bio-tic factors. The concept of soil structure was primarily used in a subjective way and evaluating it was an arduous task. Within soil science region, Gamma-Ray Attenuation Method (GAM) has been broadly utilized for the assurance of the soil bulk thickness (ρ_s) and soil water content (θ). Apart from these few other soil properties can be assessed by utilizing this method. GAM permits measurement of the porosity at a scale of millimeter and even smaller without compromising the sample's physical integrity. Its non-destructive properties allow for repeated measurements of soil properties at the same location at different times.Typically, making it GAM's most salient preferences over other conventional strategies.

Scattering and transmission are typically the two techniques used to assess soil properties by GAM. The radioactive source used in the transmission method is introduced into the soil profile prior to measurements in field studies. In the traditional method, soil porosity, Φ is determined from the particle and bulk density relationship. Rather than this one, there are other specific methods which are formed of nuclear techniques, Gamma-Ray Attenuation (GRA) or Computed Technique (CT). Wherein, both these methods are based on the interaction of radiation with matter.Gamma-ray transmission technology enables the assessment of a number of characteristics, including density, the spatial and temporal profiles of moisture and porosity in amorphous materials, and the location of the sample's pores. In developed soils, bulk thickness, dampness substance, porosity, and field capacity are crucial rural parameters. Exact estimation of these parameters is fundamental for choosing appropriate crops each soil and way better administration of water system. In addition to this, porosity of the soil directly affects the construction. The porosity of the soil can affect its strength in supporting a foundation or its reduced bearing capacity. After a foundation is laid and a building is constructed, very porous soil may settle, leading to structural failure. However, non-porous soil materials like clay or silt prevent water is absorbed and held, reducing the material's composite strength. The porosity of the soil is the first thing an engineer looks at while designing dams, reservoir, bridges, buildings, and other high loaded structures. Consequences that arise from seepage barriers cracking include: (1) reduction of the effective hydraulic conductivity of the barrier; (2) potential for the internal erosion of the seepage barrier; and (3) potential for soil erosion through the barrier [4]. High porosity and permeability mean higher hydraulic conductivity.

The gamma-ray attenuation method (GAM) is a non-destructive method that permits quick measurements of different physical properties. This technique has been widely used in other fields such as medicine, engineering, nuclear sciences, agriculture, geology, etc. In the field of soil science GAM plays a major role, it is widely employed for the estimation of soil bulk density and soil water content (θ). GAM is applied in both laboratory and field studies and its non-destructive characteristics allow repeated measurements of soil properties in the same position at different times [5]. This is one of the major advantages of GAM over other traditional methods. And along with that another interesting advantage of this method is the possibility of a non-destructive evaluation of soil physical properties at fixed positions. GAM permits measurements in the same sample several times due to its non-destructive nature but also allows measurements in several positions of a small sample to identify changes each soil and way better administration of water system in the soil structure [5]. Reginato and van Bavel (1964) employed an uncollimated beam to measure θ over a path length of about 30 cm. GAM allowed them to obtain measurements with a resolution of the order of 1 cm. The authors pointed out that the greatest advantages of the method were accuracy, resolution, and absence of time lag and site disturbance [5].The soil characteristics (porosity) of five different samples were studied in the northern and southern region of Kerala State and Karnataka State, India. The study region is spread over $4486.24 km^2$ and is a part of the Western Ghats. These regions have different terrains and the soil type have extreme differences when we compare them. Some have Black soil on other hand some are Red loamy soil and Laterite soil. Some samples which are near by to forest and some are near industrial areas have great difference in their porosity because of soil compaction, because sample near industrial area undergoes soil compaction most times [6, 7]. In total this region consists of different soil types and these samples are in different soil terrains.

2. Method & Materials

2.1. Soil Samples

Soil samples with different consistency were scrutinized. The samples were collected from various parts belonging to South Karnataka and North Kerala. The soil sample was taken 5 inches below the ground level. Roughly 900 to 1000 gm of soil was collected from five different locations. The sample consisted of black and laterite soil and was collected from different terrain. Care was taken such that the sampling location was 15 kilometers away from each other (for D, B, and E). Samples A and C have been collected from 1.5 kilometers away from each other. To evaluate the μ, samples were filtered by handpicking method to remove roots, leaves, etc. The filtered samples were dried in an oven at 104 ^0C for 43 hours.

2.2. Soil Particle Density and Bulk Density Measurement

To determine the porosity, soil particle density, and bulk density, two methods were employed: bulk density and particle density. Bulk density is defined as the mass of many particles of a material divided by the total volume they occupy, which includes particle volume,

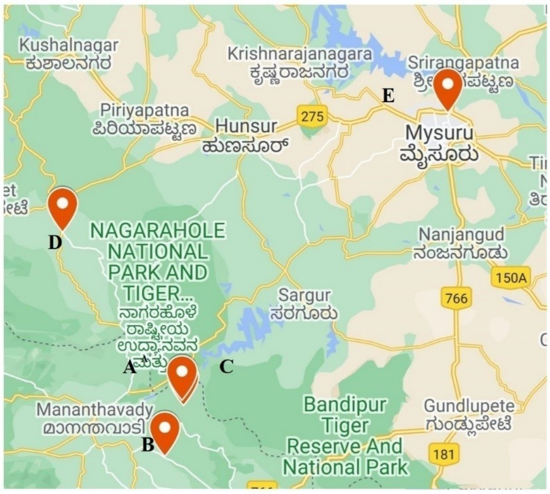

Figure 1: Location of the soil samples.

inter-particle pore volume, and internal pore volume. On the other hand, particle density is defined as the mass per unit volume of sediment solids. To determine the porosity, soil particle density and bulk density are required. To determine the two entities two methods are opted for, bulk density and particle density. Bulk density is defined as the mass of many particles of a material divided by the total volume they occupy. Total volume includes particle volume inter-particle pore volume, and internal pore volume.Whereas particle density is defined as the mass per unit volume of sediment solids. Take the required amount of sample in a container and calculate its mass and volume to obtain the soil bulk density [8]. The below equation is used to compute the soil bulk density.

$$\rho_p = \frac{Mass}{Volume} \qquad (1)$$

One needs to perform a rigorous method to glean the value of soil particle density. To obtain the soil particle density we need to subtract the volume occupied by the void in the sample. To do that we take a quantified amount of soil sample in a container and make sure the sample is uniform in the container. Next, we add water to the sample in such a way that the water doesn't float above the sample and make sure the sample is uniformly wet. Estimate the weight of the soil sample before and after adding water to the sample. The water will fill the voids in the sample and we subtract the volume of water added from the volume of the sample we have taken. The density of the water is a proven commodity. By rearranging the equation, we can calculate the density of the particle with its mass and volume values.

$$\rho_s = \frac{\text{Mass of soil particle}}{\text{Volume of soil particle}} \quad (2)$$

where,

Volume of soil particle

$$= \text{Volume of sample} - \text{Volume of water} \quad (3)$$

2.3. Mass Attenuation Measurement

A radioactive source of ^{137}Cs (11.1 GBq) was used in this study. We have used a 7.62 × 7.62 cm NaI(Tl)(2” ×2” well type) SD152W scintillation detector with GR611M (Modular) coupled to a photo-multiplier tube. Circular Lead collimator adjusted between source and detector to produce a narrow beam. A glass beaker of 100 ml is filled with soil for μ measurements [9]. The γ-ray equipment was arranged vertically. The background count for the scintillator was determined for 600s without the ^{137}Cs source. The radioactive source and detector were placed 18 cm apart, and the beaker was placed between them. The beaker was placed close to the head and the collimator so that the maximum amount of beam could pass through the sample uniformly. The room temperature was 27±1 ^0C. The counting time chosen in μ measurements was 600s for ^{137}Cs, and two trials were taken for all six different thicknesses varying in 0.5cm. We calculate the linear attenuation coefficient (K) first then divide the linear attenuation coefficient with the bulk density of the respective sample [10].

2.4. Porosity Measurement

The total porosity obtained by γ-ray attenuation approach was based on the equation (4):

$$\Phi_2 = 1 - \frac{1}{x\mu_s\rho_p} ln\frac{I_0}{I_{ds}} \quad (4)$$

Where, I_{ds} represents the beam intensity after having passed through the dry soil. In the experimental procedures by the nuclear method, the intensities of the mono-energetic photons were measured along the

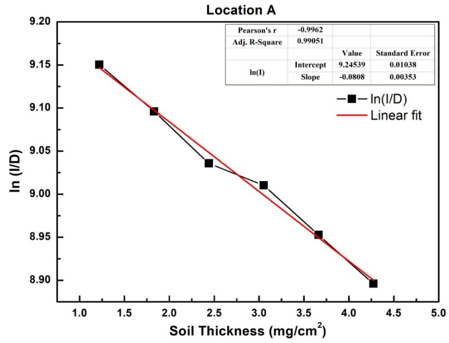

Figure 2: Linear Attenuation Coefficient of Sample A

center of the beaker filled with soil. The thickness (x) of the samples in the way of the beam varies in each trial. The beaker was placed close to the source so that the maximum amount of beam could go through the soil uniformly throughout the sample, as previously mentioned. The counting time chosen in Φ measurements was 300s for the Cesium, and the monitored background radiation was 685 cps [11, 12]. To estimate the error in the measured soil porosity value the following equations (5-9) were used. Statistically rigorous ways are there to determine the uncertainty. First, we do the measurement of the quantity X, some number of (statistically independent) times N. We can call these measurements $x_1, x_2, \ldots, x_N$.Then, we obtain the average of the results, $\bar{x}$ and to find the uncertainty of the average we use equation (5).

$$\sigma_{\bar{x}} = \frac{\sqrt{(x_1 - \bar{x})^2 + (x_2 - \bar{x})^2 + - - - + (x_N - \bar{x})^2}}{N(N-1)} \quad (5)$$

Where,

$$\bar{x} = \frac{x_1 + x_2 + \ldots + x_N}{N} \quad (6)$$

Here we use the quadrature method to determine the error in the final result. Quadrature is used when the errors are random and independent not systemic, it gives us the most probable error.In simple combinations of data with random errors, three rules can summarize the correct procedure. Those three are rules of multiplication and division, addition and subtraction and raising to power which are referred from Guide to Uncertainty Propagation and Error Analysis by Stony Brook University Introductory Physics Lab [13]. Following equations helps to deduce the error as per the mentioned rules.

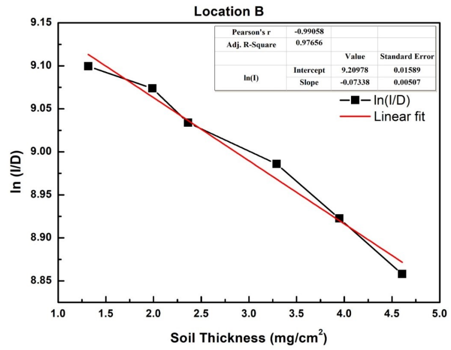

Figure 3: Linear Attenuation Coefficient of Sample B

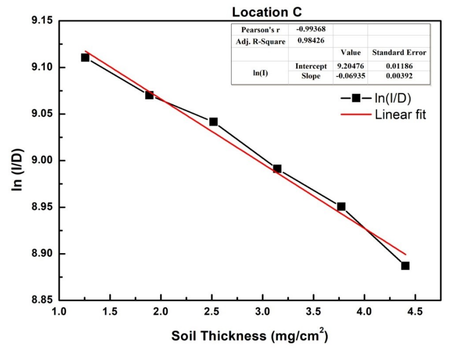

Figure 4: Linear Attenuation Coefficient of Sample C

$$\frac{\Delta z}{z} = \sqrt{(\frac{\Delta x}{x})^2 + (\frac{\Delta y}{y})^2} \quad (7)$$

$$\Delta z = \sqrt{\Delta x^2 + \Delta y^2} \quad (8)$$

$$\frac{\Delta z}{z} = \frac{n\Delta x}{x} \quad (9)$$

When you add or subtract two quantities with error, you add the relative errors in quadrature to get the relative error of the product or quotient.

Scintillation detectors have few shortcomings since all machines cannot be 100 efficient. These detector assemblies offer excellent stability, superior performance, and resolution in the range of 8.0 to 9.5 for ^{137}Cs.

3. Results and Discussion

Soil bulk density (ρ_s) and soil particle density (ρ_p) for the samples collected were determined and are shown in table 1. The linear attenuation coefficient explains how much the radiant flux from behind is diminished when it travels through a certain substance. The linear attenuation coefficients for the five samples are shown in the graphs.

When comparing the linear attenuation coefficients of these five graphs, there are more than minor differences. Samples E and C had the lowest linear attenuation coefficients out of these five samples. The samples with the highest linear attenuation coefficients are Samples A and D.

The linear attenuation coefficients' growth and decrease indicate how transparent and opaque a material is. The graph and table illustrate how the five samples' various linear attenuation coefficients differ from one another. It displays the quantity of Gamma radiation

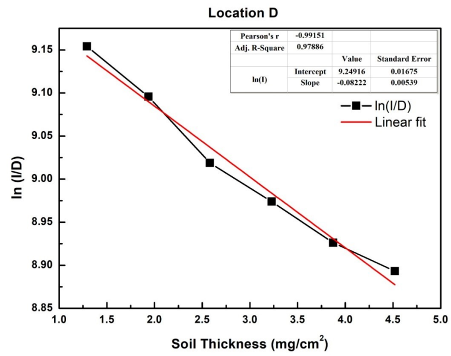

Figure 5: Linear Attenuation Coefficient of Sample D

that has passed through each sample. Through this, it is possible to estimate the samples' porosity and the quantity of radiation that has gone through them.

4. Conclusion

In this work, the gamma-ray attenuation technique was used to estimate soil porosity. Along with this nuclear method, soil porosity in the traditional way is also calculated. Among the five samples, Sample A has a high porosity value of 0.504, and Sample E has a low porosity value of 0.295; it is observed that

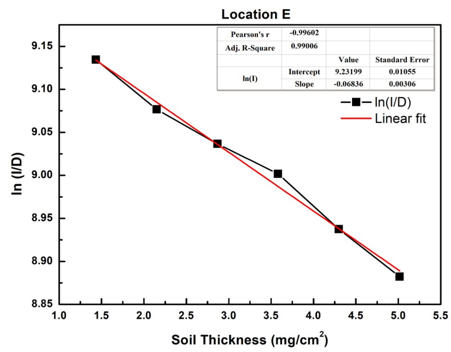

Figure 6: Linear Attenuation Coefficient of Sample E

Table 1: The calculated value of porosity from nuclear method, mass attenuation coefficient, linear attenuation coefficient and particle density and bulk density.

Sample	Particle density ρ_s (mg/cm^3)	Bulk density ρ_p (mg/cm^3)	Linear Attenuation Coefficient, K (cm^{-1})	Mass Attenuation Coefficient μ_s (cm^2/g)	Porosity from Nuclear method
A	1.221	2.421	0.081	0.0661	0.504±0.061
B	1.316	2.297	0.074	0.056	0.413±0.059
C	1.258	2.171	0.069	0.551	0.432±0.059
D	1.291	2.325	0.082	0.064	0.423±0.058
E	1.433	2.037	0.068	0.048	0.295±0.052
Min	1.221	2.037	0.068	0.047	0.295
Max	1.433	2.421	0.082	0.551	0.504
Average	1.303	2.250	0.074	0.156	0.4134
Std. Dev.	0.080	0.148	0.006	0.220	0.075

ability of soil to store more water is proportional to the porosity of the soil. Since soil A has a high porosity value, it has the ability to keep underground water. Whereas in the case of sample E with a low porosity value, the underground water-storing power is less in comparison with sample A. Samples A, B and C are black soil. Still, three samples are from three different areas, sample B is close to the forest, and sample C is close to a paddy field (clay-type soil). Among these, sample C has less porosity than the other two samples. Sample D is laterite soil with a porosity value of 0.423. The quantity of radiation that passes through the soil sample is shown by the linear attenuation coefficient. The sample can be described as being relatively opaque if the linear attenuation is higher, and as transparent if the linear attenuation is lower. The linear attenuation value demonstrates the soil samples' porosity and aids in calculating porosity. Of the five samples we have, sample D has the highest linear attenuation coefficient, while sample E has the lowest. The porosity of the soil sample directly affects the ability of the soil to withhold water.

Hence vegetation in different soil terrains have notable variations in their roots and stems. Just like in the case of plants soil porosity plays a vital role in constructions, porosity in the soil can affect its strength for supporting a foundation or reduced bearing capacity. On comparing the observed value soil porosity values with the standard values, it can be seen that the samples belong to silty clay or sandy clay. On further studying the composition of these samples, they can be classified as silty/clay or inorganic silty/clay. The probable error of each sample is calculated using quadrature method.

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Authorship contribution

Abin and Akshaya contributed towards systematic analysis of the samples and obtaining results. All authors contributed to the preparation of manuscript. Namitha mentored the work.

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Conflict of Interest

Authors declare there is no conflict of interest. The manuscript's contents have been reviewed and approved by each co-author, and there are no competing financial interests to disclose.

Declaration

The result reported here is the obtained ethically, reporting of those involved in this article.

Similarity Index

I hereby confirm that there is no similarity index in abstract and conclusion while overall is less than 10% where individual source is less than is 2% or less than it.

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