IOSR Journal Of Applied Physics (IOSR-JAP)
e-ISSN: 2278-4861.Volume 13, Issue 4 Ser. I (Jul. – Aug. 2021), PP 39-43
www.Iosrjournals.Org

Application of Variations of Photon Attenuation Coefficients of Different Textural Classes of Southwest Nigerian Soils for Radiation Shielding

[1]Fajemiroye, J.A, [2*]Adejumo, O.O, [1] Ademi, A.G and [1] Tanpioruobari, J.R
[1] *Department of Physics, The Polytechnic, Ibadan, Nigeria.*
[2] *Department of Physics and Solar Energy, Bowen University, Iwo, Nigeria*

Abstract
In this work, the variations of photon attenuation coefficients at varying photon energies by different naturally occurring soil textures to ascertain their suitability for radiation shielding purposes were investigated. The photon attenuation coefficient of different textural classes of soils is of extreme importance in shedding light on the properties of soils in many applications. Eight (8) different soil textural classes' samples from four (4) different locations in Ibadan, southwest Nigeria were collected and prepared for atomic absorption spectroscopic, AAS elemental analysis. Using a Buck scientific 210 VGB Atomic Absorption Spectrophotometer located at the SMO laboratory in Ibadan, Nigeria in the flame configuration mode, this analysis reveals the presence of 12 elements (Na, Mg, Al, Si, K, Ca, Pb, Mn, Cu, Zn, and Fe) in varying concentrations. The fractional values of these elemental concentrations were inserted into the XCOM web-based software to generate the photon attenuation coefficients at different photon energies by each soil textural class, and the result presented in Table 3 of this work. This result suggests that sandy loam acts as a better radiation shield than other soil textures at lower photon energies. At intermediate photon energies, sand and loamy sand should act as good radiation shields, while sand, loamy sand, and clay appear to attenuate more at high photon energies and may, therefore, be used as a depository of spent radiation sources at high gamma photon energies.
Keywords: *Photon attenuation coefficient, Radiation shielding, Soil textural class, Atomic absorption spectrometry, Elemental concentration.*

Date of Submission: 14-07-2021 Date of Acceptance: 30-07-2021

I. Introduction

Soil, the weathered top layer of the earth's crust which forms the platform on which all structures stand is a natural and complex mixture of solid, liquid and air, resulting from the interaction of weathering and biological activity on the parent material or underlying hard rock (Smyth and Montgomery, 1962). Soil texture shows the relative content of different sized particles in the soil, indicating the percentage of various sizes of particles like sand, silt, and clay present in the soil. Quantitatively, soil texture can be defined as the relative proportion of sand, silt, and clay content on a weight basis, while the overall textural designation of soil as determined from the relative proportion of its sand, silt and clay contents is called the textural class. According to the United States Department of Agriculture, USDA Soil Taxonomy, twelve soil textural classes are classified as sand, loamy sand, sandy loam, loam, silt loam, silt, sandy clay loam, clay loam, silty clay loam, sandy clay, silty clay, and clay (Soil Science Division Staff, 2017). The attenuation coefficient is a basic quantity which describes the extent to which each of the interaction processes of a photon passing through an absorber removes photon from the beam (reduction of the intensity of the beam) as it passes through a material medium such as a soil sample (Knoll, 2000). The study of different types of soils, seeking the determination of their mass attenuation coefficient, for example, is of extreme importance in shedding light on the properties of soils in agricultural and other applications (Adejumo *et. al.*, 2015). Singh and Mudahar, in 1992 opined that the photon attenuation coefficient is an important parameter characterizing the penetration and diffusion of X- and Gamma-rays in complex media (Singh and Mudahar, 1992). The possible implication of the variations of soil textural class attenuation of photons on radiation shielding and its consequent use as a depository of spent radionuclide is no doubt a matter of great interest. Adejumo in 2009, opined that the variation of soil attenuation coefficient with soil depth indicates decreasing gamma-ray penetrability down the soil profile (Adejumo, 2009). Therefore, the ability of different naturally occurring soil textures to attenuate photon intensity at varying photon energies should serve as a useful tool to ascertain their suitability or otherwise for radiation shielding purposes. Soils have a chemical composition and the determination of the elemental composition of soils of different textural classes, and insertion of these values in a computer software database called XCOM gives the photon mass attenuation coefficients of different soil textural classes at different gamma-ray energy values. Different techniques are used in the determination of the elemental composition of soils, and in this work, the Atomic Absorption Spectrometric, AAS technique was employed. The photon attenuation coefficient of each soil textural class at different gamma-ray energies for eight soil textural classes at Ibadan, southwest Nigeria were determined by imputing the soil textural class elemental fractional composition in the computer software, XCOM database. The total attenuation coefficient is the sum of the individual process's attenuation coefficient, and in this work, the online version of XCOM was used (Berger *et. al.*, 2010).

II. Literature Review

Previous workers on the measurement of the mass attenuation coefficients of soil include Al-Masri et. al., 2013, and in their work, titled "Mass attenuation coefficients of soil and sediment samples using gamma energies from 46.5 to 1332 keV ", the authors' used gamma-ray spectrometry and gamma-ray energies of 46.5, 59.5, 88, 122, 165, 392, 661, 1173, and 1332 keV and the XCOM software to determine the average mass attenuation coefficients for 60 Syrian soil samples. The results gave values of 0.513, 0.316, 0.195, 0.155, 0.134, 0.096, 0.077, 0.058, and 0.055 cm^2/g at the respective gamma energies (Al-Masri *et. al.*, 2013). Costa et. al., in 2014, in the work, titled "Soil mass attenuation coefficient: Analysis and evaluation", opined that the mass attenuation coefficient μ is an important parameter to characterize the penetration and interaction of gamma-rays in the soil. In that study, theoretical values of μ were calculated using the program XCOM, and experimental results were compared with theoretical ones showing a good correlation between the methods (Costa *et. al.*, 2014). Nasehi and Ismail in 2019, in the work, titled "Evaluation of X and Gamma-rays Attenuation Parameters for Polyacrylamide and ZnO Composites as Light Shielding Materials Using MCNP and X-COM Simulation" used the general-purpose Monte Carlo N-Particle code, MCNP-X version 2.4.0T as a tool to determine the mass attenuation coefficient and the half-value layer of the shielding samples. In their work, the authors simulated a new form of shielding material by MCNP code and evaluated its correctness by comparing it with the X-COM program (Nasehi and Ismail, 2019).

III. Materials And Method

Location of Soil Sample Collection Sites

Eight different soil textural classes' samples were collected from four different locations; three, at sites within the University of Ibadan, UI, central southwest Nigeria (7.4443^{0}N, 3.8995^{0}E), and one, at Akingbile (7.5127^{0}N, 3.9126^{0}E), near Moniya in Ibadan, central southwest Nigeria. Using a hand trowel, soil samples in their different textural classes were collected and prepared for AAS analysis. Sandy Clay Loam soil was collected from a test pit behind the screen house of the UI department of agronomy. Sandy Clay soil was collected from an empty test pit at the Parry road cassava plot of the UI agronomy farm. Loamy Sand soil was collected from an empty test pit at the Parry road agronomy farm of UI. Silt soil was collected from UI's Awba dam and Silty Loam was collected at the Oil Palm Valley road of UI. Sandy Loam, Clay, and Sand soils´ were collected at Akingbile, near Moniya in Ibadan, Nigeria. The collected samples were labelled Samples 1 through 8, respectively.

Digestion Process

5g each of the soil samples was measured using an analytical weighing balance. 10ml of aqua regia (a combination of two acidic reagents HNO_3 and HCl) was added to each of the beakers containing the eight soil samples and the solution was heated for 1hour. The digested samples cooled to room temperature and were filtered. The filtrate (in each case) was then transferred into a 100 ml flask and made up to mark with distilled water. Two other replicate samples were prepared to achieve triplicate measurements in each case.

Theory and Instrumentation

The Atomic Absorption Spectroscopy technique determines the concentrations of chemical elements present in a sample by measuring the absorbed radiation of the chemical element of interest when reading the spectra produced when the sample is excited. The five essential components of an atomic absorption spectrophotometer, namely, the light source, the burner assembly, optics, detector, and signal processing are designed such that each component produces minimum disruption to the overall system and many design features are installed to keep the signal-to-noise ratio as low as possible. In this work, the Buck scientific 210 VGB Atomic Absorption Spectrophotometer located at SMO Laboratory Services, Ring Road Ibadan, Nigeria was used in the flame configuration mode for the elemental analysis.

Fig. 1: Atomic Absorption Spectrophotometer Set-Up

The elements suspected to be present in each soil sample were set at specific wavelengths, the analyses commenced, and the concentrations of each element present in the soil sample in parts-per-million, ppm was obtained. The mean value in each case was presented as the result in table 1. The percentage concentration value of each of the element was calculated using

$$\%\ \text{Conc. value} = \frac{\text{Conc. of each element}}{\text{Total Conc.}} \times 100$$

And the results are presented in Table 2.

NIST XCOM Program

XCOM software, a web program generated by the United States of America, USA based National Institute of Standards and Technology, NIST calculates the photon cross sections for scattering, photoelectric absorption, and pair production, generating the total photon attenuation coefficients by any element, compound or mixture at various photon energies. The percentage concentration values of each element present in each textural class were inserted into the XCOM software to generate the mass attenuation coefficients for each soil textural class and the result presented in Table 3.

IV. Result

Table 1: Elemental concentrations in ppm

Soil Textural Class	Elements											
	Na	Mg	Al	Si	K	Ca	Cr	Pb	Mn	Cu	Zn	Fe
	Concentration (ppm)											
Sandy clay loam	2.053	1.046	0.461	11.970	155.000	22.470	0.336	0.025	0.645	0.004	0.009	5.466
Sandy clay	2.076	1.084	0.473	12.150	178.000	22.680	0.369	0.051	0.681	0.014	0.050	3.488
Loamy sand	2.039	1.036	0.446	11.730	137.000	22.360	0.325	0.175	0.682	0.006	0.004	0.457
Silt	2.049	1.042	0.456	11.920	151.000	22.420	0.343	0.059	1.323	0.003	0.003	5.642
Silty loam	2.072	1.068	0.471	12.110	173.000	22.650	0.366	0.047	1.373	0.002	0.023	3.986
Sandy loam	2.069	1.073	0.465	12.060	167.000	22.560	0.347	0.440	0.019	0.011	0.077	6.705
Clay	2.044	1.039	0.453	11.890	148.000	22.380	0.328	0.152	0.048	0.005	0.008	0.892
Sand	2.041	1.032	0.437	11.690	139.000	22.330	0.334	0.261	0.006	0.028	0.181	0.034

Table 2: Percentage concentration of elements present in each soil sample

Soil Textural Class	Elements											
	Na	Mg	Al	Si	K	Ca	Cr	Pb	Mn	Cu	Zn	Fe
	% Concentration											
Sandy clay loam	1.029	0.524	0.231	6.001	77.700	11.264	0.168	0.013	0.323	0.002	0.005	2.740
Sandy clay	0.939	0.490	0.214	5.495	80.501	10.257	0.167	0.023	0.308	0.006	0.023	1.577
Loamy sand	1.157	0.588	0.253	6.655	77.726	12.686	0.184	0.099	0.387	0.003	0.002	0.259
Silt	1.044	0.531	0.232	6.073	76.929	11.422	0.175	0.030	0.674	0.002	0.015	2.874
Silty loam	0.954	0.492	0.217	5.576	79.662	10.430	0.169	0.022	0.632	0.001	0.011	1.835
Sandy loam	0.972	0.504	0.219	5.667	78.468	10.600	0.163	0.207	0.009	0.005	0.036	3.151
Clay	1.092	0.555	0.242	6.350	79.043	11.953	0.175	0.081	0.026	0.003	0.004	0.476
Sand	1.157	0.582	0.246	6.591	78.366	12.589	0.188	0.147	0.003	0.016	0.102	0.019

Table 3: Values of Mass Attenuation Coefficient Generated by XCOM Software Program

Soil Textural Class	Energies (keV)					
	60	344	511	661	1173	1393
	Soil Attenuation Coefficient (cm^2/g)					
Sandy clay loam	0.5175	0.1054	0.0852	0.0787	0.0556	0.0507
Sandy clay	0.5118	0.1054	0.0852	0.0787	0.0556	0.0507
Loamy sand	0.5054	0.1057	0.0854	0.0789	0.0556	0.0508
Silt	0.5207	0.1055	0.0936	0.0787	0.0556	0.0507
Silty loam	0.5145	0.1054	0.0852	0.0787	0.0556	0.0507
Sandy loam	0.5272	0.1060	0.0853	0.0788	0.0556	0.0507
Clay	0.5047	0.1057	0.0853	0.0788	0.0556	0.0508
Sand	0.5054	0.1059	0.0854	0.0789	0.0557	0.0508

V. Discussion

The results displayed in table 3 show the variations of the attenuation of gamma photons at various energies. Soils of different textural classes display varying attenuating abilities for gamma rays. From the results obtained, generally, the attenuation of the gamma-ray varies from high values to low values with increasing photon energies. Sandy loam showed the highest attenuation coefficient of 0.5272 cm^2/g for photon energy 60keV, while Clay showed the least attenuation coefficient of 0.5047 cm^2/g at this energy. As photon energy increases to about 344keV, sandy loam still displays the highest attenuation coefficient value of 0.1060cm^2/g while sandy clay loam, sandy clay, and silty loam exhibit the least attenuation coefficient value of 0.1054cm^2/g. With increasing photon energy at 511keV, silt displays the highest attenuation coefficient value of 0.0936cm^2/g, closely followed by sand and loamy sand, clay, and sandy loam, while sandy clay and sandy clay loam exhibit the least attenuation coefficient value at that energy. At intermediate photon energy of 661keV, sand and loamy sand showed the highest mass attenuation coefficient value of 0.0789 cm^2/g, followed by sandy loam and clay (0.0788cm^2/g each), while sandy clay loam, sandy clay, silt, and silty loam all followed closely with mass attenuation coefficient value of 0.0787cm^2/g. As the photon energy rises to 1173keV, sand displays the highest attenuation coefficient value of 0.0557cm^2/g, and the others closely follow with a value of 0.0556cm^2/g. At high photon energy of 1393 keV, sand, loamy sand and clay showed the highest mass attenuation coefficient value of 0.0508 cm^2/g, while the others followed closely with a value of 0.0507cm^2/g. This result suggests that sandy loam acts as a better radiation shield than other soil textures at lower photon energies. At intermediate photon energies, sand and loamy sand should act as good radiation shields, while sand, loamy sand, and clay appear to attenuate more at high photon energies. Soil textures such as sand, loamy sand, and clay may be used as a depository of spent radiation sources at high photon energies since they can attenuate the effect of radiation at high gamma photon energies. In a related work by Medhat *et. al.*, in 2014, to calculate the mass attenuation coefficients of Egyptian soil samples by XCOM using gamma-ray spectrometry system to determine the elemental composition of the soil samples and gamma-ray photon energies 59.5, 81.0, 356.5, 661.6, 1173.2, and 1332.5 keV emitted by ^{241}Am (2.78 GBq), ^{133}Ba (2.92 GBq), ^{137}Cs (3.14 GBq), and ^{60}Co (3.7 GBq) radioactive point sources, the results obtained for the Egyptian soils show that Sandy soils have low photon attenuation parameters than other ones at 59.5 keV. At intermediate photon energies, sandy soils exhibit slightly higher photon attenuation parameters than clayey soils. At high photon energies, sandy clay loam soils present the highest value of mass attenuation than clayey soils (Medhat *et. al.*, 2014). Comparing our results with the one obtained for Egyptian soils, we notice a somewhat close pattern of variation of the mass attenuation coefficient of the gamma-ray photon from high values to low values with increasing photon energies, however, the Nigerian soils display slightly higher photon attenuation parameters than the Egyptian soils. Attribution of this variation of photon attenuation values to soil classification should be a subject of further study. The central southwest Nigerian soils are classified (following the United States Soil Classification System) in the great group of "Ultustalfs" belonging to the suborder of "Ustalfs" in the order of "Alfisols"; others in which the degree of segregation of free iron oxides is sufficient to constitute an "oxic" horizon, would be placed in the order of "Oxisols" and possibly in the sub-order of "Idox" and the great group of "Haplidox". This central southwest Nigeria area was mapped as having a complex of Ferrisols and Ferrallitic soils (Adejumo and Balogun, 2012).

VI. Conclusion

This study had succeeded in demonstrating the usefulness of the variability of photon attenuation coefficient at varying photon energies by different naturally occurring soil textures to ascertain their suitability or otherwise for radiation shielding purposes. Deposition of spent radiation sources on land can pose radiation hazard and to avoid the effects of these spent radiation sources, this study, therefore, recommends that appropriate soil textures should be used as a depository of spent radiation sources for appropriate photon energies as outlined in the section on discussion above.

Acknowledgments

The authors would like to express their sincere thanks to the authorities of SMO Laboratory Services, Ring Road Ibadan, Nigeria, for providing the instrumentation facility to carry out the research work.

Disclosure Statement

No potential conflict of interest was reported by the authors.

ORCID

Adejumo, O.O http://orcid.org/0000-0003-0147-5756

References

[1]. Adejumo, O.O (2009). Soil Bulk Density and Water Content Measurements of Southwestern Nigerian Soils by Dual Energy Gamma-Ray Transmission Method. Ph.D. Engineering Physics Thesis, Obafemi Awolowo University, Ile-Ife, Nigeria.

[2]. Adejumo, O.O & Balogun, F.A (2012). Using the Dual Energy Gamma-Ray Transmission Technique to Measure Soil Bulk Density and Water Content of Central Southwestern Nigerian Soils. Journal of Environmental Protection, **3,** 1409-1427.

[3]. Adejumo, O.O, Balogun, F.A & Ogundare, F.O (2015). The Variations of Gamma-Ray Attenuation Coefficients with Depth for Southwestern Nigerian Soil Types. Journal of Earth Sciences and Geotechnical Engineering, **5(4),** 45 – 56.

[4]. Al-Masri, M.S, Hasan, M, Al-Hamwi, A, Amin, Y & Doubal, A.W (2013). Mass attenuation coefficients of soil and sediment samples using gamma energies from 46.5 to 1332 keV. Journal of Environmental Radioactivity **116,** 28 - 33.

[5]. Berger, M.J., Hubbell, J.H., Seltzer, S.M., Chang, J., Coursey, J.S., Sukumar, R., Zucker, D.S., & Olsen, K. (2010), XCOM: Photon Cross Section Database (version 1.5). [Online] Available: http://physics.nist.gov/xcom [18 June 2020]. National Institute of Standards and Technology, Gaithersburg, MD.

[6]. Costa, J.C, Borges, J.A.R, Pires, L.F, Arthur, R.C.J & Bacchi, O.O.S (2014). Soil mass attenuation coefficient: Analysis and evaluation. Annals of Nuclear Energy **64,** 206 – 211.

[7]. Knoll GF (2000). Radiation Detection and Measurement, Third Edition. John Wiley & Sons.

[8]. Medhat, M.E, Demir, Nilgun, Tarim, Urkiye Akar & Gurler, Orhan (2014). Calculation of Gamma-Ray Mass Attenuation Coefficients of Some Egyptian Soil Samples using Monte Carlo Methods. Radiation Effects and Defects in Solids: Incorporating Plasma Science and Plasma Technology, DOI: 10.1080/10420150.2014.918129. **169**(8), 706 - 714.

[9]. Nasehi F & Ismail M (2019). Evaluation of X and Gamma-rays Attenuation Parameters for Polyacrylamide and ZnO Composites as Light Shielding Materials Using MCNP and X-COM Simulation. Journal of Nuclear Medicine & Radiation Therapy **10** (2).

[10]. Singh, Makhan and Mudahar, Gurmel (1992). Energy Dependence of Total Photon Attenuation Coefficients of Composite Materials. International Journal of Radiation Applications and Instrumentation Part A Applied Radiation and Isotopes **43**(7), 907-911.

[11]. Smyth, A.J and Montgomery, R.F (1962). Soils and Land Use in Central Western Nigeria. Government Printer Ibadan, Western Nigeria.

[12]. Soil Science Division Staff (2017). Soil survey manual. Ditzler, C, Scheffe, K & Monger, H.C. (eds.). USDA Handbook 18. Government Printing Office, Washington, D.C.

Fajemiroye, J.A, et. al. "Application of Variations of Photon Attenuation Coefficients of Different Textural Classes of Southwest Nigerian Soils for Radiation Shielding." *IOSR Journal of Applied Physics (IOSR-JAP)*, 13(4), 2021, pp. 39-43.