Journal of Earth Sciences and Geotechnical Engineering, vol. 5, no.4, 2015, 45-56
ISSN: 1792-9040 (print), 1792-9660 (online)
Scienpress Ltd, 2015

The Variations of Gamma-Ray Attenuation Coefficients with Depth for Southwestern Nigerian Soil Types

O.O Adejumo[1], F.A Balogun[2] and F.O Ogundare[3]

Abstract

The Gamma-Ray transmission method was used in this work to experimentally determine the attenuation coefficients of soil layers collected at eight locations in Southwestern Nigeria at depths of 0-15, 15-30, 30-50, 50-70, 70-90, and 90-120cm into the soil profile. Undisturbed samples from Iwo, Ondo, Egbeda, Itagunmodi, Okemessi, Mamu, Origo and Jago soil series of Southwestern Nigeria were collected in June 2006 and using gamma-ray energy pairs of 122 and 1112 keV and 344 and 1408 keV obtained from europium-152 (^{152}Eu) radionuclide, the mass attenuation coefficients for soil, μ_s, at varying soil depths of these series were calculated. The measured attenuation coefficients are observed to vary exponentially with photon energy for all the soil series studied in this work. The variation of μ_s with soil depth show that in all the series, the top soil (0-15cm depths) is least attenuating with gamma ray penetrability decreasing down the profile. The variations of μ_s for the individual soil series are graphically displayed in this work. Regular monitoring and documentation of μ_s over a long period of time can be used to develop (mathematical) models for the variation of this important soil physical property in this part of the world.

Keywords: Gamma-Ray, Attenuation coefficient, Soil types, Variations, Elemental concentrations

1 Introduction

The study of different types of soils, seeking the determination of its mass attenuation coefficient, for example, is of extreme importance in shedding light on the properties of soils in agricultural and other applications. In principle, any of the three major photon interaction modes could be employed in a non-destructive examination of soil. However,

[1]Department of Physics and Solar Energy, Bowen University, Iwo, Nigeria.
[2]Centre for Energy Research and Development, Obafemi Awolowo University,Ile-Ife,Nigeria
[3]Department of Physics, University of Ibadan, Nigeria.

because of its good photon efficiency, the transmission mode has been widely used. [1]. In this work, the Dual Energy Gamma-Ray Transmission Technique was employed to determine the mass attenuation coefficient values for the eight (8) soil series of Southwestern Nigeria at depths of 0-15, 15-30, 30-50, 50-70, 70-90, and 90-120cm into the soil profile in June 2006. From transmission measurements, the photon attenuation coefficients for soil, μ_s, at the varying soil depths of these series were determined. Generally, the measured soil attenuation coefficients μ_s were observed to decrease exponentially with increasing photon energy for all the soil series studied in this work. For the individual soil series, the variations in μ_s values did not follow a definite pattern which may be a consequence of variations in the elemental compositions of the differing soil series at varying depths. The central southwestern Nigeria, an area classified by Vine, [2] as having moderately to strongly leached soils of low to medium humus content, weakly acidic to neutral surface layers and moderately to strongly acidic sub-soils, occurring in hot lowlands has a mean annual rainfall of about 1527mm and mean monthly air temperature approximately 31^0C. Furthermore, this area lays within a single geographical unit, described by Vine as an area with friable porous sands to sandy clays, commonly reddish in colour. Following the United States Soil Classification System, many of the soils in this area would be placed in the Great group of 'Ultustalfs' belonging to the sub-order 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'. In the approximation of the soils map of Africa [3], this area was mapped as having a complex of Ferrisols and Ferrallitic soils. Geologically, the entire area described as central southwestern Nigeria overlies metamorphic rocks of the Basement complex, the great majority of which are very ancient being of Pre-Cambrian age. These rocks show great variation in grain size and in mineral composition, ranging from very coarse-grained pegmatite to fine-grained schist and from acid quartzite to basic rocks consisting largely of amphibole [4]. From the foregoing, the observed variations in μ_s values may be due to these variations in the differing soil series.

2 Preliminary Notes

For dual-energy gamma sources, each with different mass absorption coefficients, incident on an absorber like soil, that is composed of solid, water and gas phase, a modified form of Lambert-Beer's equation can be applied to each source, after which two simultaneous attenuation equations result, which can be solved to yield estimates of the mass attenuation coefficients for water, μ_w and soil, μ_s at the different gamma-ray energies. As earlier reported by Adejumo [5], the Lambert-Beer's equation was rewritten as

$$I_\lambda = I_0 \exp\left(-\mu_s \rho_s x - \mu_w \rho_w x \theta_v\right) \qquad (1)$$

the modification of equation 1 and subsequent analysis yielded the following relations for the mass attenuation coefficients for soil and water as

$$\mu_s = -\frac{1}{\rho_s x} \ln \frac{N}{N_0} - \mu_w w \quad (2)$$

and

$$\mu_w = -\frac{1}{\rho_w x} \ln \frac{N}{N_0} \quad (3)$$

Using these equations above, the mass attenuation coefficients for soil (at the different depths into the soil profile) and water were computed at the different gamma-ray energies.

2.1 Sample Collection and Attenuation Coefficient Measurement Experiment

Within the teaching and research farm of Obafemi Awolowo University, OAU, Ile-Ife, around latitude 7^0 28´N and longitude 4^0 33´E the following soil types were identified; Iwo, Ondo, Egbeda and Jago. In the area around the OAU incinerator, at Asunle area, near Abagboro village the Ondo soil type was located. Around the production plot of the OAU teaching and research farm, the Iwo type was identified and located. Also within this teaching and research farm, at Kajola village the Egbeda type was located. The Jago type was located also around this Kajola village. The Itagunmodi type was located at Mokuro village, latitude 7^0 30´N and longitude 4^0 35´E, near Nigerian Television Authority, NTA, Ile-Ife. At a location around Gareji-Olode, around latitude 7^0 32´N and longitude 4^0 36´E, off the Ife-Ondo highway, the Okemessi soil type was located. Near the Cocoa Research Institute of Nigeria, CRIN, south of Ibadan, latitude 7^0 14´N and longitude 3^0 52´E, the Mamu soil type was located. Off the new Iwo-Awo highway at Ojisun village (about five kilometres from Awo), around latitude 7^0 41´N and longitude 4^0 14´E the Origo type was located. At each of these eight (8) locations, undisturbed soil samples were taken at depths of interest (as earlier indicated in section 1 (Introduction) of this work) into the soil profile using a core sampler driven in one continuous motion into the soil profile. The soil samples were collected into similar cylindrical plastic containers, each of diameter 5.68cm and height 7.47cm. Soil samples were collected for June 2006. The contribution of gamma-ray attenuation by the plastic sample container which could lead to errors in the attenuation coefficients determined was taken care of by accounting for the attenuation of the gamma-ray by the material of the sample container.

The experimental set-up consists of a gamma-ray spectrometer arrangement having the sample container placed over collimated lead shields which enclosed a NaI(Tl) scintillator detector. A cylindrical shaped BICRON corporation manufactured detector, model 3M3/3 and serial number FF-669 was used, a photomultiplier, model number PA-14 and serial number AG-472 was used. From the photomultiplier end of the detector, connections were made to a high voltage power supply, HVPS unit; model 3106D and a spectroscopic amplifier, both CANBERRA manufactured. Connections from the detector were made separately to the preamplifier and amplifier on opposite ends of the unit making a total of three pin connection from the detector to the HVPS, preamplifier and amplifier. From the Unipolar option pin of the output stage of this amplifier unit, connection was made to the analogue-to-digital converter, ADC unit, which is also CANBERRA manufactured. All of these units are arranged and controlled on the frame of the multichannel analyser, MCA. From the ADC, connection was made via a multipin plug to the computer with the software CANBERRA S100 interfacing to provide the spectrum display on the computer screen. The source was placed over a collimated lead shield which was in turn placed over the soil sample container. The HVPS unit was set at 0.75 kV. On the amplifier unit, the coarse gain was set at 10, the fine gain at 4.7 and the shaping time at $2\mu s$. For the data acquisition setup, the full memory was set at 4K and the livetime was preset at 10,800 seconds (3 hours). The spectrum display was observed on an IBM computer in the Gamma Spectrometry laboratory at CERD, OAU, Ile-Ife. From the acquired spectra, the number of gamma-ray photons, N was determined. The height of the cylindrical soil sample container was used as the parameter x of equations 2 and 3. Using Gamma-ray energy pairs of 122 and 1112 keV; and 344 and 1408 keV obtained from europium-152 (^{152}Eu) radionuclide, the mass attenuation coefficient values for the eight (8) soil series at the depths of interest for June 2006 was also computed from raw data obtained following a pattern earlier reported by Adejumo and Balogun [6].

3 Main Results

The soil mass attenuation coefficients, μ_s at the different gamma ray energies and at the varying depths into the soil profile for June 2006 for all the eight soil series are shown in table 1 and displayed graphically in figures 1.1 to 1.8 and figures 2.1 to 2.8 to show variations of soil attenuation coefficients with gamma-ray energies and depths into the soil profile respectively.

4 Labels of Figures and Tables

Table 1: Soil Mass Attenuation Coefficient μ_s for all the eight soil series

Ondo Soil Series						
Energy(keV)	0-15cm	15-30cm	30-50cm	50-70cm	70-90cm	90-120cm
122	0.1728	0.1826	0.1866	0.1929	0.1707	0.178
344	0.1281	0.1338	0.1373	0.1436	0.1243	0.1294
779	0.1035	0.1115	0.1182	0.1209	0.0992	0.1003
964	0.0893	0.0947	0.1032	0.1172	0.0855	0.0864
1112	0.0665	0.0839	0.0892	0.0935	0.0634	0.065
1408	0.0585	0.0683	0.0743	0.0803	0.0564	0.0578
	Iwo Soil Series					
122	0.1667	0.1731	0.1771	0.1817	0.1724	0.1736
344	0.1208	0.1263	0.1307	0.1364	0.1211	0.1229
779	0.0976	0.1012	0.1078	0.1133	0.0919	0.0942
964	0.0841	0.0889	0.0933	0.1018	0.0811	0.0826
1112	0.0621	0.0794	0.0832	0.0901	0.0615	0.0629
1408	0.0522	0.0586	0.0677	0.0745	0.0511	0.0517
	Egbeda Soil Series					
122	0.1734	0.1873	0.1891	0.1912	0.1941	0.1886
344	0.1417	0.1456	0.1491	0.1532	0.1568	0.1472
779	0.1123	0.1158	0.1188	0.1233	0.1291	0.1169

964	0.1008	0.1046	0.1091	0.1138	0.1176	0.1062
1112	0.0822	0.0857	0.0893	0.0931	0.0985	0.0879
1408	0.0632	0.0685	0.0732	0.0794	0.0821	0.0697
	Itagunmodi Soil Series					
122	0.1706	0.1741	0.1839	0.1871	0.1881	0.1902
344	0.1374	0.1395	0.1421	0.1453	0.1488	0.1524
779	0.1087	0.1113	0.1158	0.1189	0.1213	0.1262
964	0.0983	0.1024	0.1072	0.1103	0.1147	0.1188
1112	0.0852	0.0894	0.0939	0.1012	0.1059	0.1097
1408	0.0671	0.0689	0.0713	0.0742	0.0773	0.0724
	Okemessi Soil Series					
122	0.1521	0.1552	0.1617	0.1687	0.1726	0.1736
344	0.1253	0.1282	0.1312	0.1355	0.1389	0.1411
779	0.0945	0.0983	0.1015	0.1087	0.1113	0.1132
964	0.0813	0.0842	0.0884	0.0921	0.0972	0.1008
1112	0.0685	0.0715	0.0756	0.0791	0.0835	0.0857
1408	0.0537	0.0568	0.0603	0.0634	0.0687	0.0704
	Mamu Soil Series					
122	0.1504	0.1532	0.1603	0.1632	0.1527	0.1553
344	0.1211	0.1268	0.1309	0.1325	0.1259	0.1281
779	0.0907	0.0958	0.0991	0.1036	0.0947	0.0972
964	0.0798	0.0821	0.0866	0.0902	0.0812	0.0844
1112	0.0652	0.0689	0.0745	0.0772	0.0681	0.0708
1408	0.0511	0.0552	0.0593	0.0618	0.0545	0.0572
Jago Soil Series						
122	0.1736	0.1883	0.1905	0.1949	Nd	Nd
344	0.1523	0.1562	0.1598	0.1641	Nd	Nd
779	0.1307	0.1332	0.1371	0.1396	Nd	Nd
964	0.1198	0.1231	0.1285	0.1318	Nd	Nd
1112	0.1073	0.1094	0.1126	0.1177	Nd	Nd
1408	0.0828	0.0852	0.0897	0.0916	Nd	Nd
	Origo Soil Series					
122	0.1735	0.1887	0.1919	0.1971	0.1988	Nd
344	0.1509	0.1545	0.1581	0.1632	0.1648	Nd
779	0.1292	0.1324	0.1353	0.1386	0.1392	Nd
964	0.1191	0.1223	0.1281	0.1309	0.1332	Nd
1112	0.1069	0.1086	0.1112	0.1165	0.1187	Nd
1408	0.0811	0.0838	0.0874	0.0902	0.0934	Nd

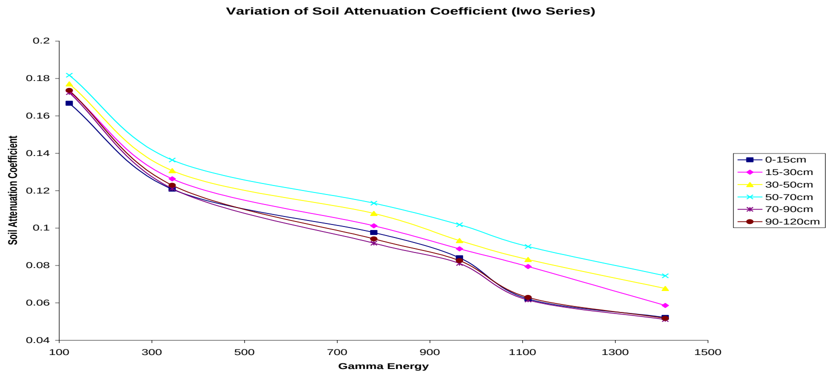

Figure 1.1: Variation of Soil Attenuation Coefficient with Gamma-Ray Energy for Iwo Soil Series

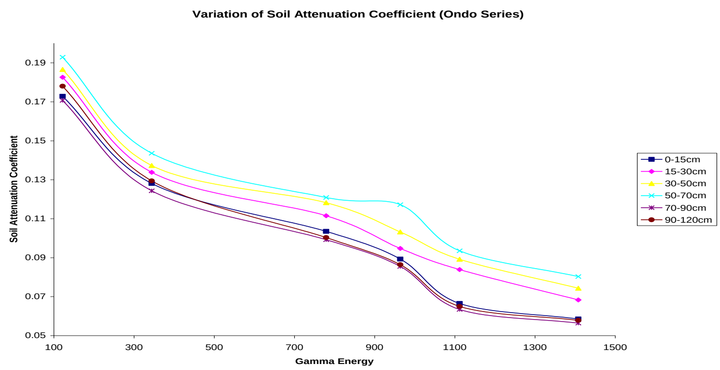

Figure 1.2: Variation of Soil Attenuation Coefficient with Gamma-Ray Energy for OndoSoil Series

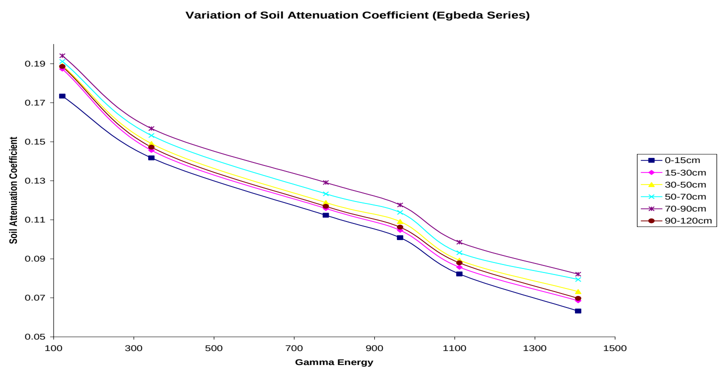

Figure 1.3: Variation of Soil Attenuation Coefficient with Gamma-Ray Energy for Egbeda Soil Series

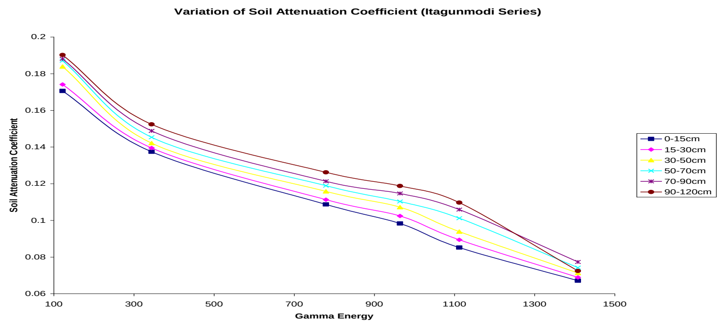

Figure 1.4: Variation of Soil Attenuation Coefficient with Gamma-Ray Energy for Itagunmodi Soil Series

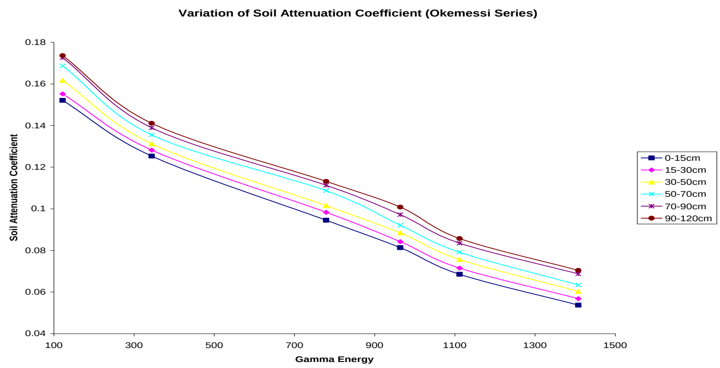

Figure 1.5: Variation of Soil Attenuation Coefficient with Gamma-Ray Energy for Okemessi Soil Series

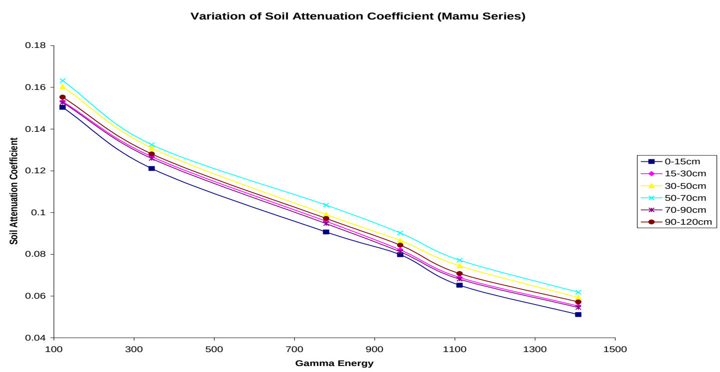

Figure 1.6: Variation of Soil Attenuation Coefficient with Gamma-Ray Energy for Mamu Soil Series

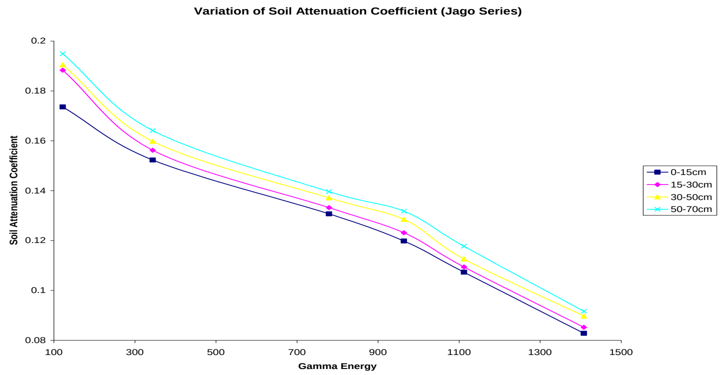

Figure 1.7: Variation of Soil Attenuation Coefficient with Gamma-Ray Energy for Jago Soil Series

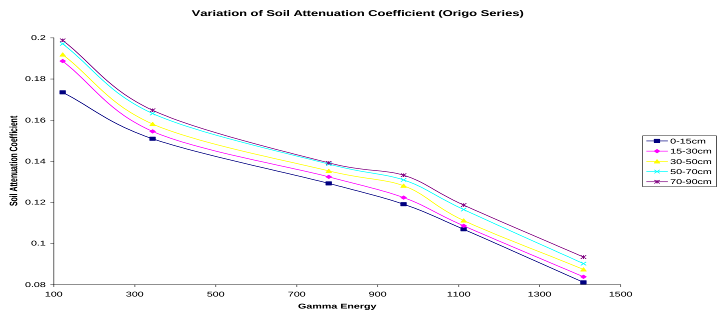

Figure 1.8: Variation of Soil Attenuation Coefficient with Gamma-Ray Energy for Origo Soil Series

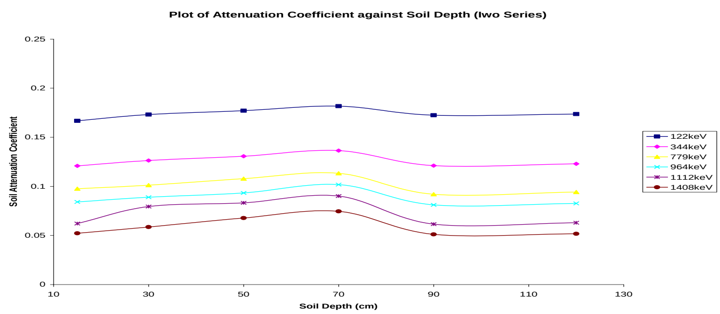

Figure 2.1: Variation of Soil Attenuation Coefficient with Soil depth for Iwo Soil Series

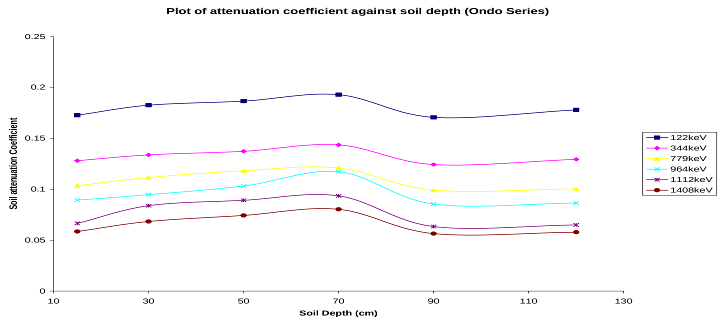

Figure 2.2: Variation of Soil Attenuation Coefficient with Soil depth for Ondo Soil Series

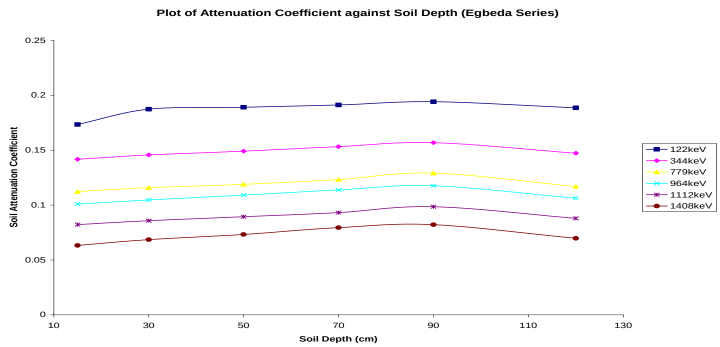

Figure 2.3: Variation of Soil Attenuation Coefficient with Soil depth for Egbeda Soil Series

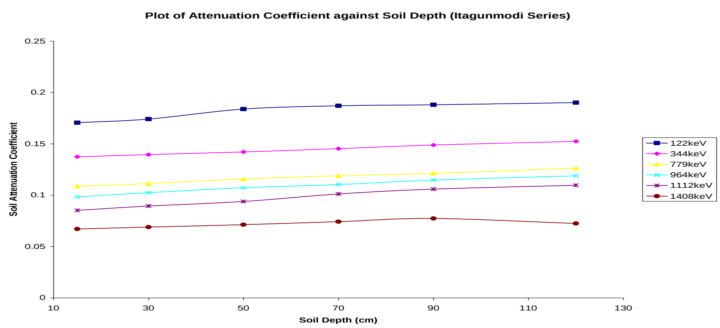

Figure 2.4: Variation of Soil Attenuation Coefficient with Soil depth for Itagunmodi Soil Series

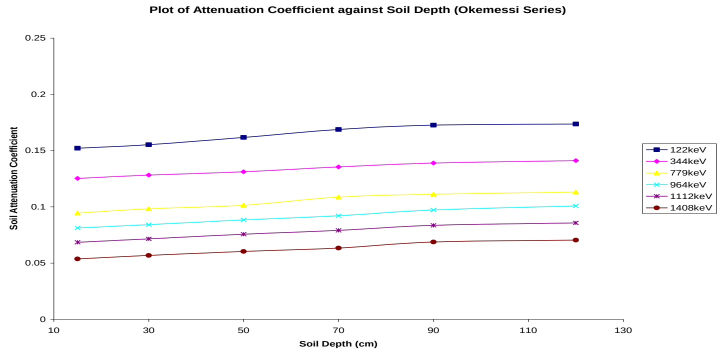

Figure 2.5: Variation of Soil Attenuation Coefficient with Soil depth for Okemessi Soil Series

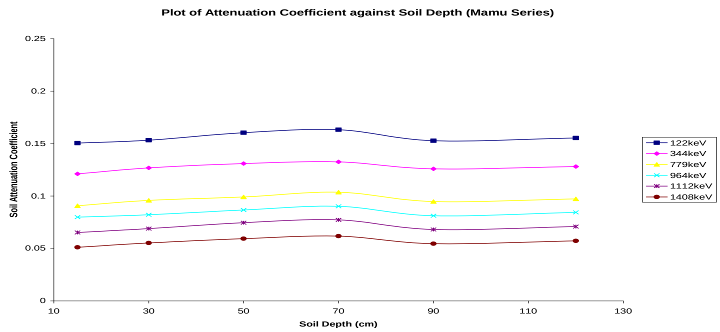

Figure 2.6 Variation of Soil Attenuation Coefficient with Soil depth for Mamu Soil Series

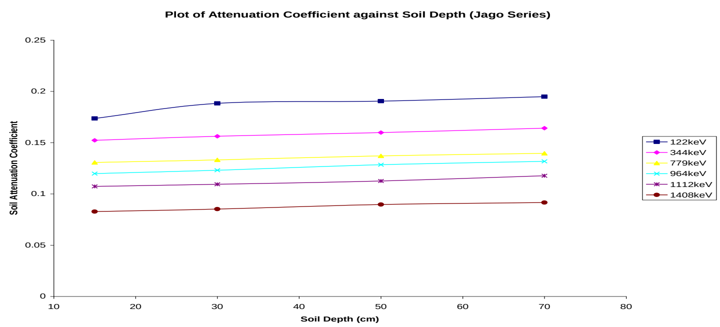

Figure 2.7 Variation of Soil Attenuation Coefficient with Soil depth for Jago Soil Series

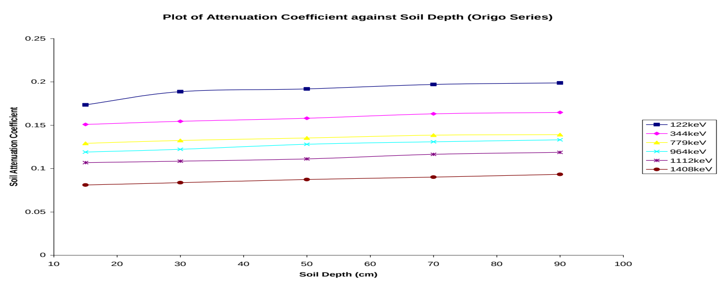

Figure 2.8 Variation of Soil Attenuation Coefficient with Soil depth for Origo Soil Series

5 Conclusion

The variation of μ_s with soil depth show that in all the series, the top soil (0-15cm depths) is least attenuating with gamma ray penetrability decreasing down the profile. However, for the individual soil series, (i) the Iwo soil series show low μ_s values at 0-15 cm depth, increasing down the profile and reaching a maximum at 50-70 cm depth, then it falls at 70-90 cm and slightly rises at 90-120 cm. This observation correlates very well with the elemental concentrations measured using the EDXRF technique [7]. The fact that the elemental concentrations at the 0-15 cm are fairly low and increasing down the soil profile may partly account for the pattern of variation observed for μ_s in this soil series. At the 50-70 cm depth, relatively high concentration values for Fe and K were reported by Adejumo et. al., in 2014 and the high μ_s value obtained at this depth may be due to this. (ii) the Ondo soil series also show a similar pattern to the Iwo series. The highest Fe concentration for this soil series was obtained at the 50-70 cm and at the 90-120 cm depth, very high Fe concentration value was reported. (iii) the Egbeda series also show low μ_s values at 0-15 cm depths, increasing down the profile and reaching a maximum at 70-90 cm depth, and then drops at 90-120 cm. This soil series has high Fe and K concentrations at the 70-90 cm and 90-120 cm depths. (iv) the Itagunmodi series show a different pattern from the foregoing in that its μ_s increased from values at 0-15 cm depths, down the profile and reaching a maximum at the 90-120 cm depth. In this soil series, fairly high elemental concentrations of Fe, K, Ti and Ca were reported all through the soil depths. (v) the Okemessi series is similar to Itagunmodi in pattern. Fairly high elemental concentrations for Ca, Fe, K and Ti down the soil depths were also reported for this soil series. (vi) the Mamu series show a pattern similar to the Iwo and Ondo series with μ_s values low at 0-15 cm depths, increasing down the profile and reaching a maximum at 50-70 cm depth, thereafter falling at 70-90 cm and rising at 90-120 cm. At the 50-70 cm depth, the highest K and Fe concentrations were reported, followed by the 90-120 cm depth. (vii) the Jago series show a pattern different from the foregoing with low μ_s values at 0-15cm depths, increasing down the profile and reaching a maximum at 50-70 cm depth, beyond this no reasonable data was obtainable. The Fe elemental concentration for this soil series peaked at the 50-70 cm depth. (viii) the Origo soil series is similar to the Jago series in pattern except that the maximum μ_s value was attained at the 70-90 cm depth. The Fe elemental concentration for this soil series peaked at the 70-90 cm depth. Regular monitoring and documentation of this soil physical parameter over a long period of time can be used to develop (mathematical) models for the variation of this important soil physical property in this part of the world.

Further work can be carried out to determine soil water potential, and in conjuction with measurements of soil water content, advance computer prediction programs may be developed for the hydrological movement of soil water. Further work can also be carried out using the principles of tomography which makes use of reconstruction algorithms to resolve the internal distribution of phase content or density (three dimensional) of the soil sample in the determination of volumetric soil water content. This tomographic image techniques can be used to determine the volume of available water in suspected ‘temporary water reservoirs’ in the Jago and Origo soil types. Exploiting ground water from these reservoirs for irrigation purposes will go a long way in conserving the surface freshwater resource of this region.

ACKNOWLEDGEMENTS: The authors acknowledge the kind gesture of the authorities of the Centre for Energy Research and Development, Obafemi Awolowo University, Ile-Ife, Nigeria, for the use of its Gamma Spectrometry Laboratory in this work.

References

[1] Demir, D, Un, A, Ozgul, M, Sahin, Y. Determination of photon attenuation coefficient, porosity and field capacity of soil by gamma-ray transmission for 60, 356 and 662 keV gamma-rays, *Applied Radiation and Isotopes*, **66,** (2008), 1834 – 1837.

[2] Vine, H, Latosols of Nigeria. *Proc. Second Inter-African Soils Conference, Leopoldville, Congo*, (1954).

[3] D' Hoore, J, Third Draft S.P.I Soils Map of Africa. *Presented at Seventh International Congress of Soil Science. Madison, U.S.A.*, (1960).

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

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

[6] Adejumo, O.O and F.A Balogun, 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**(11), (2012), 1409-1427.

[7] Adejumo, O.O, Balogun, F.A, Jegede, O.O and Akinloye, M.K, Elemental Compositions at various depths into the soil profile for Central Southwestern Nigerian Soil Associations. *Nigerian Journal of Physics*, **25**(1), (2014), 1-12.