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Determination Of Poisson's Ratio Of Surface Soils And Shallow Sediments Of Uyo And Environ From Seismic Compressional And Shear Wave Velocities

Ubong E. Essien[1], Akaninyene O. Akankpo[2], Nyakno J. George[3] and Emmanuel B. Umoren[2]
[1]*(Department of Science Technology, AkwaIbom State Polytechnic, IkotOsurua, Nigeria)*
[2]*(Department of Physics, University of Uyo, Uyo, Nigeria)*
[3]*(Department of Physics, AkwaIbom State, University, IkotAkpaden, Nigeria)*
Email: akaninyeneakankpo@uniuyo.edu.ng

Abstract
Poisson's ratio σ has been effectively used in engineering, groundwater and hydrocarbon investigation.This research was conducted to determine the Poisson's ratio of topsoil using seismic refraction method in Uyo and environ, Southern Nigeria as an aid in determining the degree of stability of engineering foundation. The study area lies between latitudes $4^0 45'$ and $5^0 15'$ N and between longitudes $7^o 45'$ and $8^o 30'$ E in the Niger Delta region of southern Nigeria. The area is located in the Tertiary to Quaternary Coastal Plain Sands (CPS) and Alluvium environments of the Niger Delta region of southern Nigeria. A 24 - channel signal enhancement seismograph, geophones, sledge hammer and a metal plate (source) for generating seismic wave were used. Poisson's ratio (σ) values were calculated for different locations using the V_p/V_s ratios usually viewed as lithology discriminator. Poisson's ratio values ranged from 0.3708 – 0.3725 for layer 1 with an average of 0.3714. The second layer ranged from 0.3697 and 0.3706 with an average of 0.3701. All the locations under study had Poisson's ratios greater than 0.3, which falls within Poisson's ratio of sand (of 0.20 - 0.45).The closeness of the Poisson's ratios for the two layers shows consistency and near homogeneity in the arrangement of grain sizes of the unconsolidated sands.

Key Words: *lithology, soil, Vp, Vs, seismic refraction, Uyo.*

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I. INTRODUCTION

The elastic properties of soils (shear modulus, Young's modulus, or Poisson's ratio) measured at low strain are useful for the characterization of soils in terms of geotechnical and mechanical properties (Karray et al., 2008). These parameters are essential for dynamic response analysis and soil-structure interaction problems and can play an important role in the study of liquefaction potential under seismic loading.Poison's ratio is for specific direction, the ratio of lateral contraction to the longitudinal extension during the stretching of a material in the direction of the stretching force.Poison's ratio is positive for tensile deformation and negative for compressive deformation. Although a negative Poison's ratio is not forbidden by thermodynamics, this property is generally believed to be rare in crystalline solids (Baughman et al., 1998). For most materials, the value of Poisson's ratio lies in the range, 0 to 0.5.Poisson's ratio σ has been effectively used in engineering, groundwater and hydrocarbon investigation. Poisson's ratio or compressional wave velocity are good indicators of the depth of saturation in deposits.

According to Milton and Cherkaev (1995) and Greaves et al. (2011), in nature, most conventional isotropic materials have a positive Poisson's ratio of nearly 0.5. Rigid metals and polymers as a rule have a Poisson's ratio ranging between 0.2 and 0.45. By contrast, only a few natural materials such as bone have negative Poisson's ratio (Wojciechowski, et al., 2015). David et al (2019) explored the ranges of anisotropy of Young's modulus (E), Poisson's ratio (ν), shear modulus (G) and linear compressibility (β) in 86 rock-forming minerals, using previously published data, and showed that the range is much wider than commonly assumed.

Gercek (2007) provided a useful review of Poisson's ratio for rocks and included some data for specific minerals. Workers in the fields of chemistry, physics and engineering have published methods and tools for visualising the elastic anisotropy of various groups of solid elements and compounds and these predominantly focus on Poisson's ratio (Karki&Chennamsetty, 2004; Lethbridge et al., 2010; Marmier et al., 2010; Gaillac et al., 2016).Poisson's ratios are critical in interpreting seismic data of lithospheric plates and subduction zones in terms of petrology and tectonic processes (Kern et al., 2002).This research was conducted to determine the Poisson's ratio of topsoil using seismic refraction method in Uyo and environ, Southern Nigeria, which will aid in the determination of the degree of stability of engineering foundation.

II. Location and Geology of the Study Area

The study area shown in Figure 1lies between latitudes $4^0$45' and $5^0$15' N and between longitudes 7^o45' and 8^o30' E in the Niger Delta region of southern Nigeria. The study was designed to cover IbionoIbom, Itu, Uyo, Uruan, IbesikpoAsutan, Etinan, NsitUbiom, NsitIbom and NsitAtai Local Government Areas. The study area is located in an equatorial climatic region that is characterised by two major seasons: the rainy season (March – October) and dry season (November – February) (Evans *et al*., 2010; George *et al*., 2010 a, b). Geologically, the study area is located in the Tertiary to Quaternary Coastal Plain Sands (CPS) (otherwise called the Benin Formation) and Alluvium environments of the Niger Delta region of southern Nigeria as shown in Fig. 1. The Benin Formation which is underlain by the parallicAgbada Formation covers over 80% of the study area. The sediments of the Benin Formation consist of interfringing units of lacustrine and fluvial loose sands, pebbles, clays and lignite streaks of varying thicknesses while the alluvial units comprise tidal and lagoonal sediments, beach sands and soils are mostly found in the southern parts and along the river banks(Emujakporue, &Ekine, 2009; Reijers*et al*., 1997; Nganje*et al*., 2007).

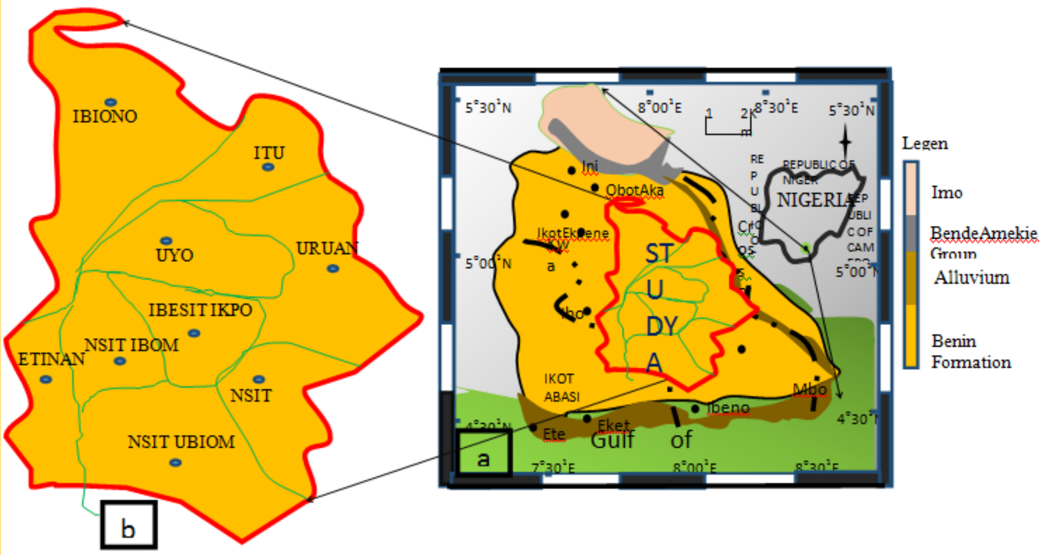

Figure 1: Map showing (a) the study area location and general geology of AkwaIbom State of Nigeria (b) Map showing the nine (9) central Local Government Areas in Uyo Senatorial district that the study area situates.

III. Materials and Methods

A 24 - channel signal enhancement seismograph, geophones, sledge hammer and a metal plate (source) for generating seismic wave were used.The electromagnetic geophone which were in direct contact with the earth, transformed the seismic energy generated by the source to electrical voltage which is a function of velocity. The mechanically generated seismic disturbances sensed by the geophones were received and recorded by a seismograph cascaded with the geophones (Reynolds, 1997). The double seismic source, in which one of them was for shear wave source and the other, compressional wave source, has two set of geophones for the S-wave and P-wave respectively (Kesavula, 1993).The generated energy penetrated into the subsurface and refracted off at various interfaces corresponding to the geological boundaries and consequently returned to the surface at later time to be picked up by the geophone (Kearey, & Brooks, 1991). The seismic wave received by the geophone was converted into electrical pulse and was amplified by the preamplifier.

This plot was printed out from the seismograph from which arrival times were obtained. The refraction time-distance measurement at the surface of the ground led to the determination of V_p/V_s ratio and other principal properties of the near surface rocks. P-wave and S-wave velocities were obtained from seismic refraction survey covering a spread line of 50 m, with 2 m geophones spacing in the foundation layer of Uyo and its environs,AkwaIbom State, Southern Nigeria. The arrival times of recorded signal (seismogram) were picked and plotted against the offset distance using IX Refrax and Pickwin software programmes.The velocity variations obtained gave the geological implications of the geomaterials. The V_p/V_s ratios usually viewed as lithology discriminator were determined for each location. Poisson's ratios (σ) were calculated for different locations using this expression (Essien et al., 2014).

$$\sigma = \frac{\left[\left(\frac{V_p}{V_s}\right)^2 - 2\right]}{\left[2\left(\frac{V_p}{V_s}\right)^2 - 2\right]} \quad \ldots\ldots \quad \ldots\ldots \quad \ldots.. \quad \ldots.. \quad \ldots.. \quad \ldots. \quad \ldots.. \quad \ldots.. \qquad (1)$$

Table 1: Summary of layer parameters obtained in the study area

Location Name		**Lat°**	**Long°**	**Elevation (m)**	**Layer**	**Vp (m/s)**	**Vs (m/s)**	**Vp/Vs**	**σ**
	1	5.9833	7.8500	67.00	L1	285.0	128.8	2.2120	0.3716
					L2	556.9	252.9	2.2019	0.3701
Etinan	2	4.9500	7.8333	61.00	L1	327.5	148.2	2.2093	0.3712
					L2	503.4	228.5	2.2030	0.3702
	3	4.8333	7.8510	31.00	L1	317.0	143.4	2.2099	0.3713
					L2	495.1	224.7	2.2032	0.3703
	1	4.8166	7.8330	36.00	L1	350.0	158.5	2.2081	0.3710
					L2	656.3	298.3	2.2004	0.3698
NsitIbom	2	4.8667	7.9167	46.00	L1	350.0	158.5	2.2081	0.3710
					L2	603.7	274.3	2.2011	0.3700
	3	4.8510	7.9000	43.00	L1	291.0	131.6	2.2115	0.3715
					L2	745.3	338.9	2.1993	0.3697
	1	4.7833	7.9000	34.00	L1	285.5	129.1	2.2119	0.3716
					L2	429.2	194.7	2.2051	0.3705
NsitUbiom	2	4.7833	7.9166	49.00	L1	326.0	147.6	2.2094	0.3712
					L2	519.9	236.0	2.2027	0.3702
	3	4.8167	7.9667	37.00	L1	269.0	121.5	2.2132	0.3717
					L2	483.5	219.4	2.2035	0.3703
Ibesikpo	1	4.8500	7.9667	49.00	L1	350.5	158.7	2.2081	0.3710
					L2	621.0	282.1	2.2009	0.3699
	2	4.9000	7.9833	133.00	L1	218.0	98.3	2.2183	0.3725
					L2	518.9	235.6	2.2027	0.3702
	3	4.9500	7.9667	72.00	L1	325.0	147.1	2.2094	0.3712
					L2	507.5	230.4	2.2030	0.3702
Uruan	1	4.9167	8.0167	52.00	L1	295.0	133.4	2.2113	0.3715
					L2	653.1	296.8	2.2004	0.3699
	2	4.9167	8.0333	52.00	L1	334.5	151.4	2.2089	0.3711
					L2	749.3	340.7	2.1993	0.3697
	3	4.9500	8.0000	57.00	L1	306.5	138.7	2.2105	0.3713
					L2	509.4	231.2	2.2029	0.3702
NsitAtai	1	4.8667	8.0500	45.00	L1	313.0	141.6	2.2101	0.3713
					L2	558.4	253.6	2.2019	0.3701
	2	4.8000	8.0667	37.00	L1	302.5	136.8	2.2108	0.3714
					L2	501.3	227.5	2.2031	0.3703

	3	4..8333	8.0333	31.00	L1	303.0	137.1	2.2107	0.3714
					L2	464.7	210.9	2.2040	0.3704
Uyo	1	4.9833	8.0000	50.00	L1	372.5	168.8	2.2071	0.3708
					L2	558.3	253.6	2.2019	0.3701
	2	5.0000	7.9500	82.00	L1	341.0	154.4	2.2086	0.3711
					L2	533.8	242.4	2.2024	0.3701
	3	5.0333	7.9167	67.00	L1	319.5	144.6	2.2097	0.3712
					L2	560.8	254.7	2.2019	0.3701
Itu	1	5.0500	7.9167	65.00	L1	272.5	123.1	2.2129	0.3717
					L2	569.9	258.9	2.2017	0.3700
	2	5.0667	7.9167	68.00	L1	301.0	136.1	2.2109	0.3714
					L2	538.4	244.5	2.2023	0.3701
	3	5.1000	7.9500	57.00	L1	268.5	121.3	2.2132	0.3717
					L2	614.7	279.3	2.2010	0.3699
Ibiono	1	5.1833	7.9000	66.00	L1	237.5	107.2	2.2161	0.3722
					L2	416.5	188.9	2.2055	0.3706
	2	5.1832	7.8667	63.00	L1	278.5	125.9	2.2124	0.3716
					L2	485.2	220.2	2.2035	0.3703
	3	5.2000	7.8500	72.00	L1	331.0	149.8	2.2091	0.3711
					L2	492.2	223.4	2.2033	0.3703

Table 2. Summary of Poisson's ratio σ values obtained in the area

Layers		σ	
	Minimum	Maximum	Mean
L_1	0.3708	0.3725	0.3714
L_2	0.3697	0.3706	0.3701

Table 3:Poisson's ratioσ values for different materials (after Sas, *et al*., 2013)

Material	**Poisson's ratio**
Rubber	≈ 0.50
Gold	0.42
Saturated clay	0.40 – 0.50
Magnesium	0.35
Titanium	0.34
copper	0.33
Aluminum alloy	0.33
Clay	0.30 – 0.45
Stainless steel	0.30 – 0.31
Steel	0.27 – 0.30
Cast iron	0.21 – 0.26
Sand (unconsolidated)	0.20 -0.45
Concrete	0.2
Glass	0.18 – 0.30
foam	0.10- 0.40
cork	≈ 0.00

IV. Results and Discussion

Table 1 presents the location names andgeoelastic parameters such as Poisson's ratios(σ), shear modulus(μ), Young modulus$(E)$and Bulk modulus(K). Table 2 presentsthe summary of Poisson's ratio σ values obtained in the area. Poisson ratio is an essential parameter in assessing the elastic properties of topsoil.

The Poisson's ratio of a stable, isotropic, linear elastic material will be greater than −1.0 or less than 0.5 because of the requirement for Young's modulus, the shear modulus and bulk modulus to have positive values. However, Poisson's ratio in rock/soil is governed by the following aspects of the microstructure: the presence of rotational degrees of freedom, non-affine deformation kinematics, or anisotropic structure. The formation under examination seems to be consistent judging from the values of the Poisson's ratio. In layers 1 and 2, the Poisson's ratios range from 0.3708 - 0.3725 and 0.3697 - 0.3706 respectively while the average Poisson's ratios are 0.3714 and 0.3701 respectively. The closeness of the Poisson's ratios for the two layers shows consistency and near homogeneity in the arrangement of grain sizes of the unconsolidated sands. However, the minor variation in the Poisson's ratios can be attributed to saturation effect and availability of intercalation of fine and medium grains within the formation at some points. The distribution of the Poisson's ratios given in table 1 as well as in the 2D and 3D contour maps of Figures 3 and 4 are symptomatic of the fact that the mapped area is made up of unconsolidated sands of various grains sizes. The figures show that all the locations under study have Poisson's ratios greater than 0.3, which according to Sas*et al.* (2013) falls within Poisson's ratio of sand (with Poisson's ratio range of 0.20 - 0.45) (table 3). With these attributes, the topsoil may not easily creep vertically or horizontally because of the uniformity of the microstructure of the formation.Wang et al. (2001) and Bhagat et al. (1992) worked on the Poisson's ratios of garnet and omphacite and obtained the results as 0.265– 0.275 and 0.248 respectively.

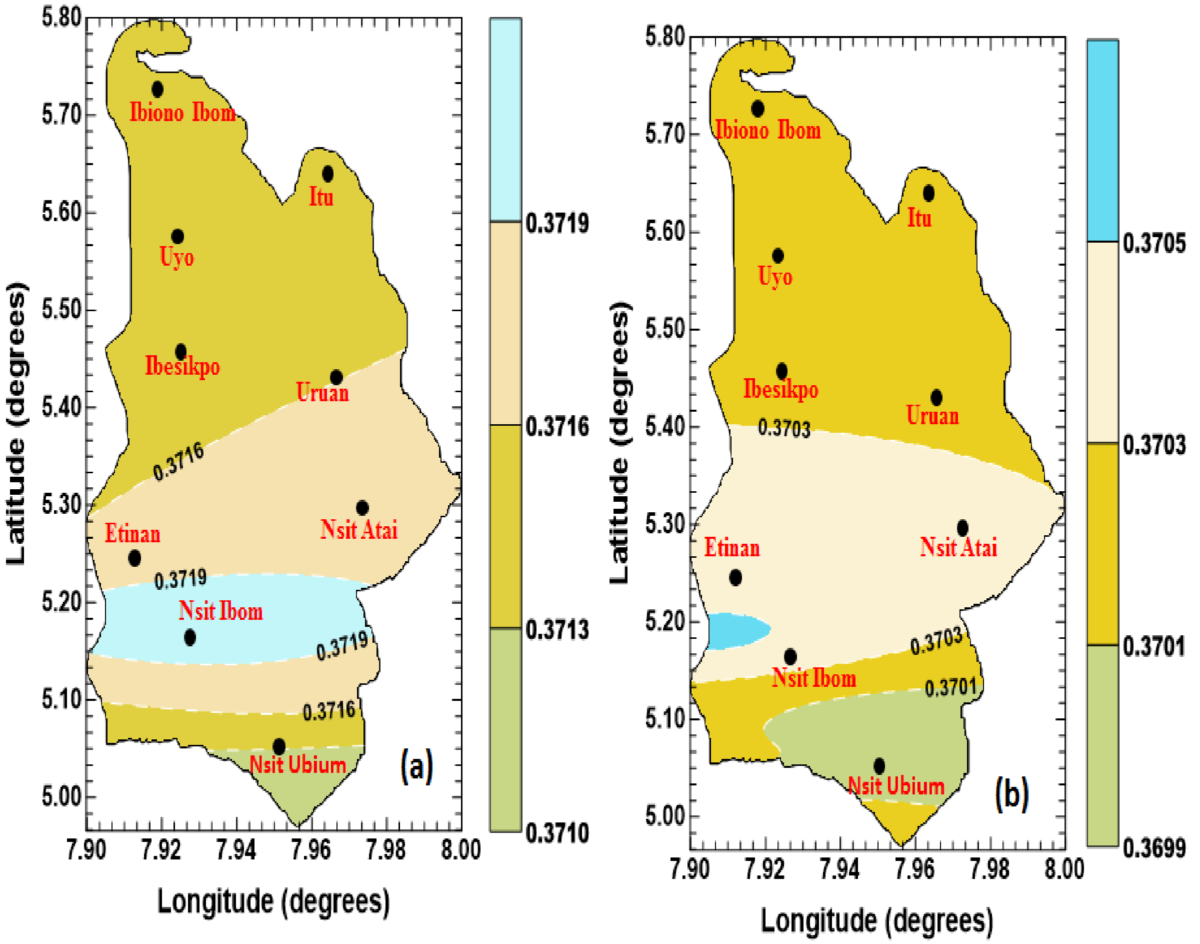

Figure 2: Blanked 2D contour map of layer 1 Poisson's ratio (a) and layer 2 Poisson's ratios (b) showing their distributions in the study area

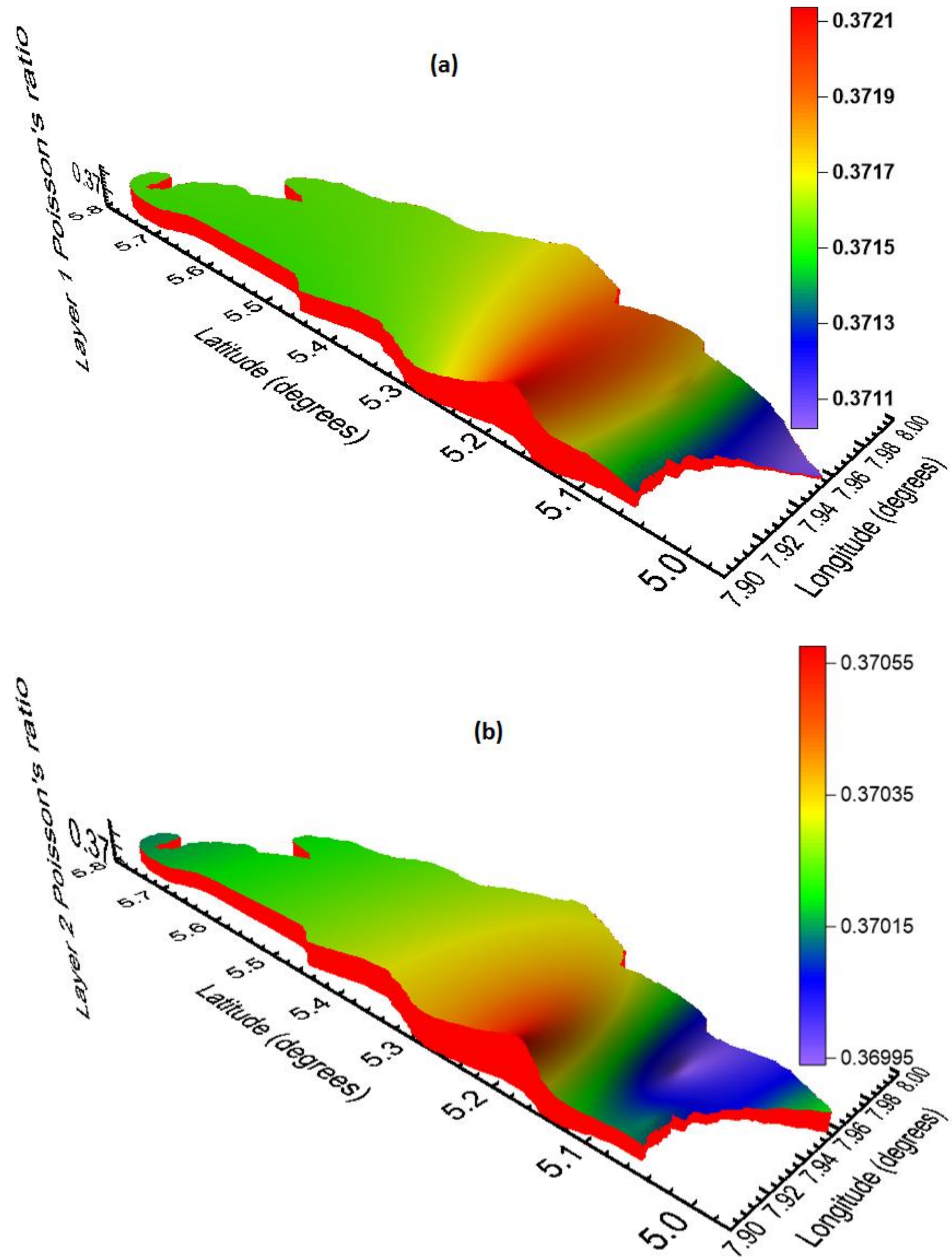

Figure 3: Blanked 3D contour map of layer 1 Poisson's ratio (a) and layer 2 Poisson's ratios (b) showing their distributions in the study area

V. Conclusion

The results of refraction technique was used to characterise thesurface soils and shallow sediments of Uyo and environs. Based on the results and interpretations of refraction data, extensive and collated information of topsoil in the study area, the Poison's ratio for the area was estimated. The Poisson ratio (σ)values were all positive at all the locations, which corresponded to Sas et al. (2013) Poisson values for different materials. An average Poison's ratio value of 0.3714 was obtained for layer 1, while layer 2 had an average value of 0.3701. The closeness of the Poisson's ratios for the two layers shows consistency and near homogeneity in the arrangement of grain sizes of the unconsolidated sands.

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