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GEOPHYSICAL SURVEY AND RADIOMETRIC ASSESSMENT OF AQUIFER STRATA AND VULNERABLE GROUNDWATER QUALITY OF UKWUANI COMMUNITIES IN DELTA STATE

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ABSTRACT

The study assessed the aquifer strata and groundwater quality of Obeti, Umuaja, and Ebedei communities of Ukwuani, Delta State, Nigeria using electrical resistivity technique and sodium iodide [Na(TI)] detector. The electrical resistivity technique revealed that lithology has five to six geoelectric strata, which ranged from topsoil to clay formations with thickness of 0.6 to 6.0 m sits and aquifer resistivity range of 182.1– 6032.0 Ωm with depth of 29–70 m. These ranges indicate significant changes in the aquifer level and sufficient reservoirs for groundwater. To assess the activity concentrations of ^{238}U, ^{232}Th and ^{40}K at the aquifer depth of 29–70 m groundwater, a total of fifteen groundwater samples were collect for analysis and the mean results are $9.00\pm1.24 Bql^{-1}$, $4.82\pm2.95 Bql^{-1}$ and $57.93\pm4.20 Bql^{-1}$ respectively. These results are all above world threshold limits. However, the computed mean radiological health risk values for radium equivalent (Raeq), representative index (Iy), external hazard index (Hin), internal hazard index (Hex), absorbed dose rate (D), annual effective dose equivalent (AEDE), outdoor and indoor, and excess lifetime cancer risk (ELCR) outdoor and indoor are $20.35\pm5.78\ Bql^{-1}$, $0.15 mSvy^{-1}$, $0.056 mSvy^{-1}$, $0.08 mSvy^{-1}$, $9.55 \mu Gyh^{-1}$, $11.71 mSvy^{-1}$, $46.84 mSvy^{-1}$and 0.04×10^{-3}, 0.16×10^{-3} and 0.20×10^{-3} for the addition of (ELCR) outdoor and indoor respectively. The computed mean radiological values are below world threshold limits. Hence, the studied communities' drinking groundwater is safe radiologically. It is advised that government, oil and gas operators and individuals should drill above 30 m depth for quality groundwater and should be treated before usage. These values will serve as baseline data.

Keywords: Aquifer; Ukwuani; Radiological; Groundwater; Electrical Resistivity; Health Risk

INTRODUCTION

Water in porous materials under the earth's surfaces are found in saturated zones with hydrostatic force equal and in most cases exceed air pressure. This water is simply referred to as groundwater. Because of the heavy tropical rainfall that falls on relatively permeable rock formations that store and exert enormous amounts of water, groundwater makes up a significant portion of the water in Nigeria (Egbai *et al.*, 2012). Great numbers of Nigeria population lacks permission to uncontaminated water supply sources (Okolie and Akpoyibo, 2012); hence, they depend on only hand-dug wells, rainwater, streams, and insufficient boreholes.

These heavy tropical rainfalls went through stages of soil profile in the process of seepage thereby interacting with the geological formations (the earth crust) before getting to the subsurface water aquifers. The geological formations contained naturally occurring radionuclides materials which may serve as radioactive pollutants to the groundwater through the process of radiation emission (Ilori *et al.,*2023; Agbalagba *et al.,* 2019; Taskin *et al.,* 2009; El-Bahi, 2004). Also, the released effluents waste from characterized hydrocarbon activity operator which may contain radionuclide when found in groundwater may be dangerous to man and the environment. To this end, it is important for groundwater within oil exploration and production area should be monitored properly for well-being of human and to protect the environmental. Similar done by researchers are (Atakpo and Ayolabi, 2009; Anomohanran, 2014; Ofomola *et al.,* 2017; Esi and Akpoyibo, 2023; Okolie and Akpoyibo, 2012; Anomohanran, 2015; Akpoyibo *et al.,* 2022; Anomohanran et al., 2023; Esi *et al.,* 2023) but no scientist report on the studied area. Therefore, the goal of the study is to map the optimal drilling boreholes areas and depth for good groundwater supplies in the studied communities and to ascertain radioactivity and the health risk or safety of the groundwater in the communities.

Geomorphology and geology of the study area

The Ukwuani Local Government areas of Delta State are home to the study areas, which include the Obeti, Umuaja, and Ebedei communities. They are located between 5.980 and 6.350 ^{0}E in longitude and 5.812 and 5.892 ^{0}N in latitude along the equator (Fig. 1). The research area is part of the Niger Delta, which is defined by the Sombrero plain's quaternary sands and flat, undulating longitudinal and transverse topography that slopes very little seaward (Atakpo and Ayolabi, 2009; Okolie and Akpoyibo, 2012). This region is without any outcrops and is located in the sedimentary basin. The area is dry during the dry season and inundated during the rainy season. There are some marshy places in the area. The region's vegetation isarepresentative of the belt of rainforests with exception along drainage streams.

Three major tertiary subsurface lithostratigraphic units make up the Niger Delta's geologic sequence, and these strata are covered in a variety of quaternary deposits (Anomohanran et al., 2023). The Akata formation, which forms the foundation of the unit, is primarily composed of marine shales with a small amount of sand beds. The thickness of the formation varies from roughly 550 metres to more than 6,000 meters. The formation has been linked to very few hydrocarbons. The overlaying paralic series, known as the Agbada formation, is made up of interbedded (stratified) sands and layered shale that vary in thickness from 300 metres to 4,500 metres, thinning both toward the sea and the Delta margin. The Benin formation is the highest unit. With shale intercalations, more than 90% of it is sandstone. It is gravely coarse-grains and fine locally, subangular to highly rounded, poorly sorted, and contains wood fragments and lignite streaks. The delta's center is where the unit is thickest (Atakpo and Ayolabi, 2009; Ofomola et al., 2017; Esi and Akpoyibo, 2023).

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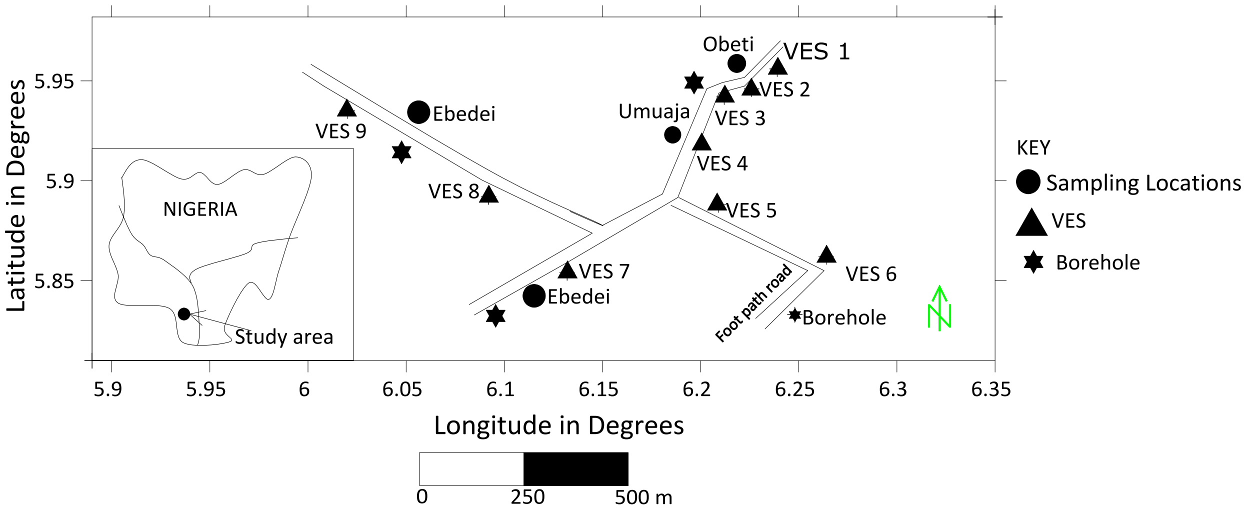
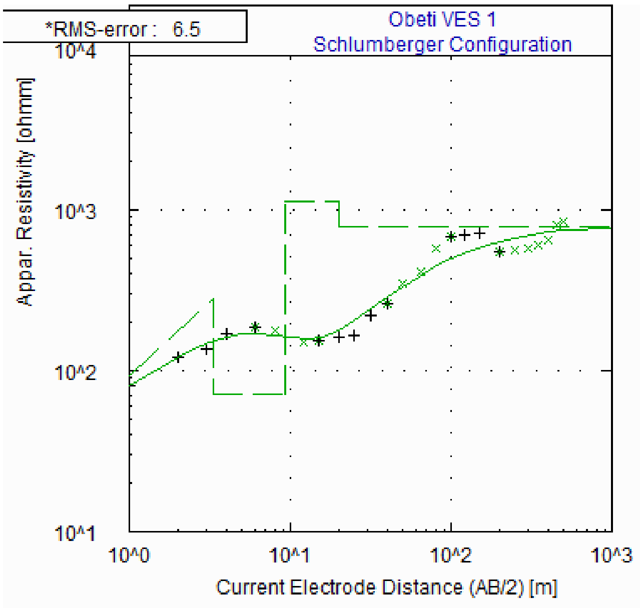


Fig. 1: Base map displaying the VES points

MATERIALS AND METHOD

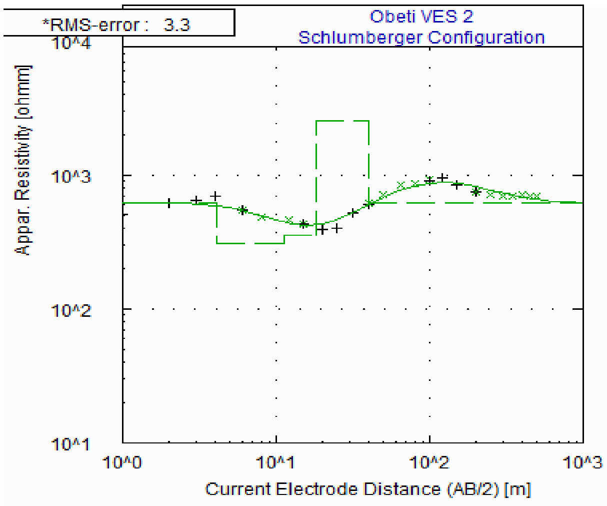
Utilizing the Abem SAS 4000 Terrameter and the setup Schlumberger array with a maximum (peak) current electrode spacing of 1000 m in Umuaja, Ebedei, and Obeti at various places, nine (9) VES (depth probing) were conducted. In the field procedure, two electrodes described as potential electrodes are buried in the ground and separated from one another, and electrodes pair referred to as current electrodes are positioned outside but parallel to the current electrodes. The voltage (potential difference) produced by the subsurface was measured and values recorded with the instrument (terrameter) and current was delivered through the current electrodes into the earth. As the potential was being monitored, the current electrode spacing was gradually raised. When it was noticed that the potential values acquired had grown feeble, the distance in between the collinearly potential electrodes increased. The potential difference against the current electrode separation graph was plotted using the apart current electrode and the measured (assigned) potential difference produced by the employed earth. The first-order geoelectric parameters (Table 2) were then obtained by curving and matching these plots and using the parameters thus obtained in the computer interpretation as inputted data using WinResist software, which is on basis of the work done by Vander Velpen (1988), Okolie and Akpoyibo (2012); Anomohanran et al. (2023). This iteration's result is the depth and actual resistivity of the several geo-electric layers that were encountered. VES curves are used to display the VES data from the engaged resistivity study, which is elucidated in Figs. 2–10.



No	Res	Thick	Depth
1	60.2	0.6	0.6
2	283.2	2.7	3.3
3	71.8	6.0	9.3
4	1130.7	10.6	19.8
5	780.8	-.-	-.-

* RMS on smoothed data

Fig. 2: Sounding curve image obtained from VES 1



No	Res	Thick	Depth
1	626.1	4.1	4.1
2	305.9	7.2	11.3
3	355.4	7.0	18.4
4	2533.9	21.6	40.0
5	615.4	-.-	-.-

* RMS on smoothed data

Fig. 3: Sounding curves image obtained from VES 2

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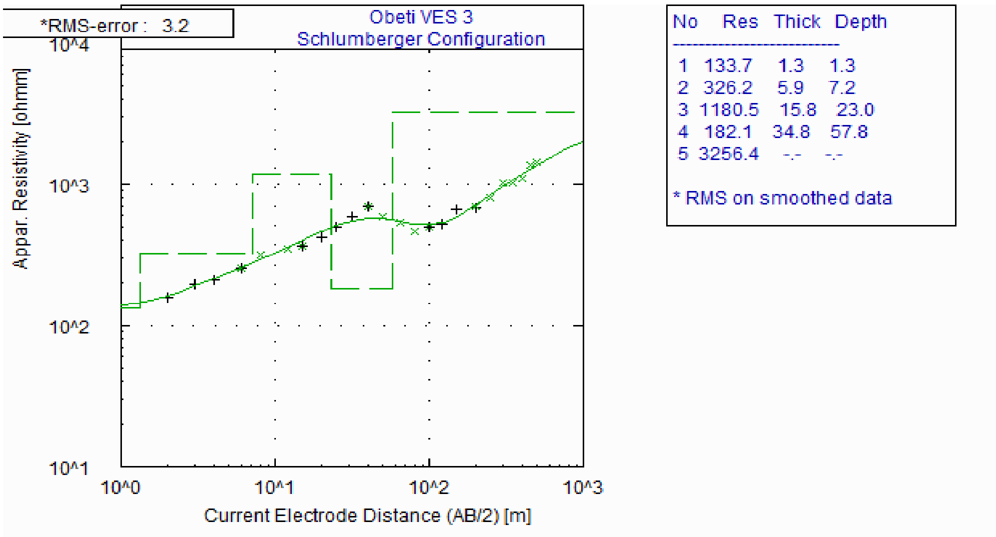

Fig. 4: Sounding curve image obtained from Obeti VES 3

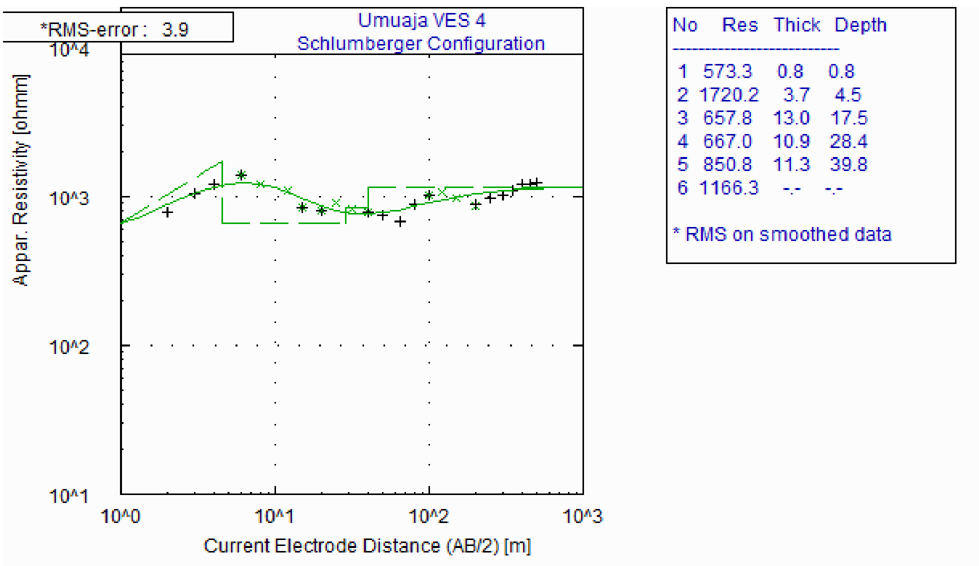

Fig. 5: Sounding curves image from Umuaja VES 4

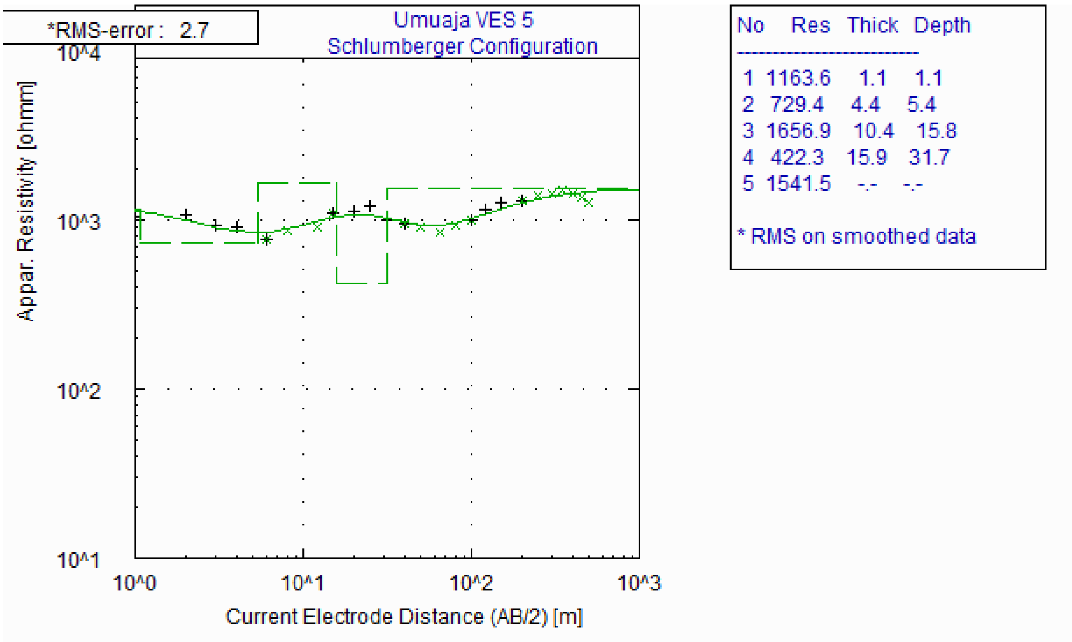

Fig. 6: Curves obtained from Umuaja VES 5

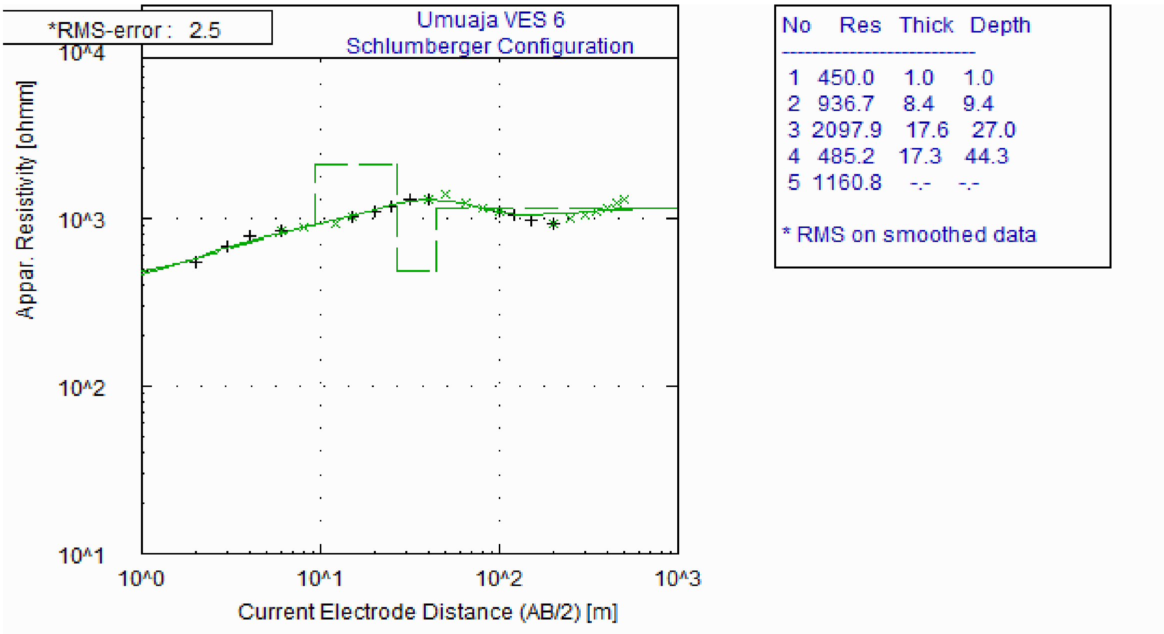

Fig. 7: Sounding curves acquired from Umuaja 6

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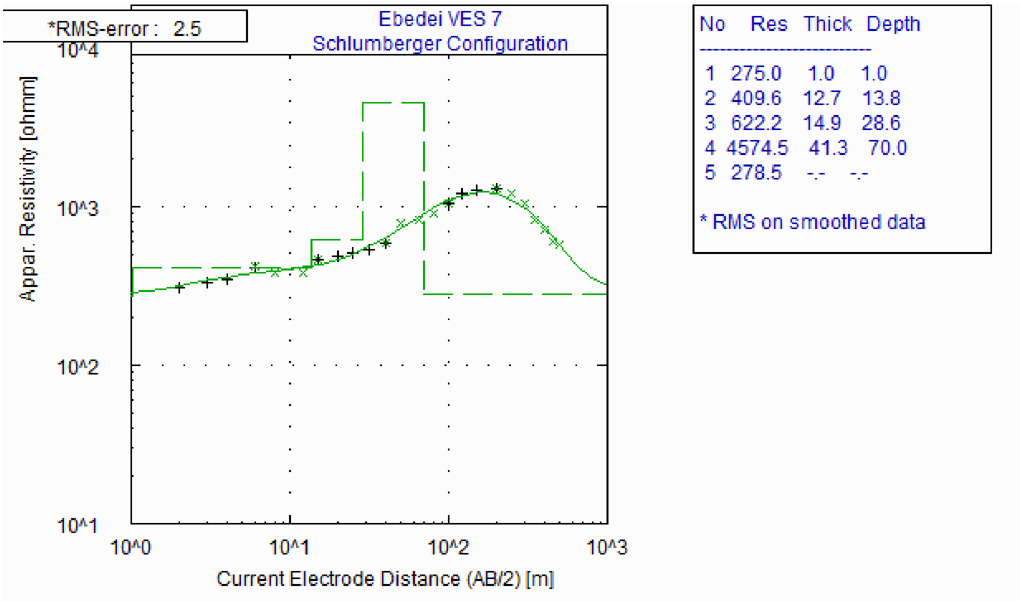

Fig. 8: Research sounding curves image taken along VES 7

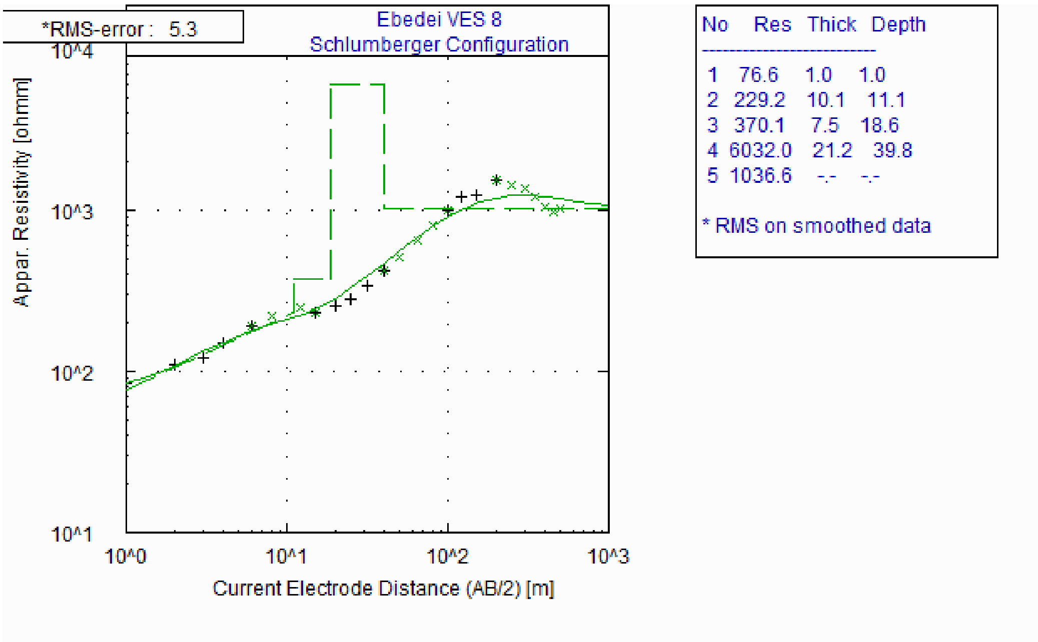

Fig. 9: Sounding curves image gotten Ebedei VES 8

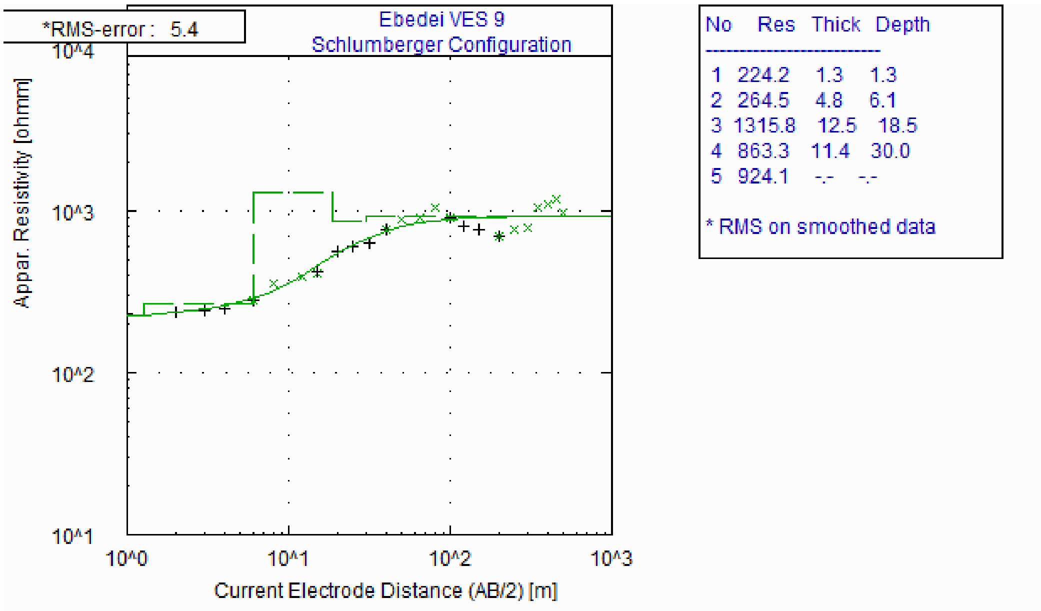

Fig. 10: Sounding curves procured image from VES 9

Sample collection, Preparation and Analysis for radioactivity

To ascertain the quality of water radiologically at aquifer depth of 29–70 m as reviewed by geophysical survey using vertical electrical soundings (depth probing), a total of fifteen water samples were collected for the drilled holes and prepared for radioactivity analysis following standard scientific methods (Oyebanjo and Magbagbeola, 2015; Tchokossa *et al.*, 2011; Aguko *et al.*, 2020; Ponaho and Issa, 2020). The Sodium iodide NaI (Tl) detector with lead thicken shielding 10 cm was used for the radioactivity analysis. The Multichannel Analyzer (MCA) detector was connected to ORTEC 456 amplifier and computer software GENIE 2000 which uses gamma-ray spectrum to detect radionuclides. The detector undergoesenergy calibration using standard point sources of ^{241}Am, ^{137}Cs, and ^{60}Co and efficiency calibration to ascertain the quality of radionuclideconcentration photopeak in SI unit Bq/l.The background spectra band was accumulated for 480m at 600 V to generate powerful peaks at gamma releasing energies of 1332.5kev for ^{40}K gamma energies peak; 834.8kev for ^{214}Bi gamma energies peak; 1274.5kev, 1173.2kev for ^{228}Ac to evaluate activity concentration of ^{40}K , ^{226}Ra and ^{232}Th, respectively using the equation:

- $$A = \frac{NPC}{Tff * I(CLT) * \in (DEP) * M} \quad \ldots\ldots\ldots\ldots \quad (1)$$

where NPC is the number of peak counts, I(CLT) is counting lifetime, ε(DEP) is detection energy performance and M is mass in kg.

Radiological Health Risks (RHR)

The RHR parameters were computed scientific standard Formulas as presented in Table 1. The computation is to ascertain and evaluate risk associated with potential radiation hazards in drinking water of the studied area. All the index parameters retained their scientific meaning. (UNSCEAR, 2000; Ohwoghere-Asuma *et al.*, 2021; Tchokosse *et al.*, 1999; Ohwoghere-Asuma and Esi, 2021; Agbalagba et al., 2012)

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Table 1: Formulas for computing radiological hazard risk of aquifer Drinking water

S/N	Hazard Index	Formulas
1	Radium Equivalent Index	$Ra_{eq}=G_{Ra}+1.43G_{Th}+0.077G_k$ (2)
2	Representation Level Index (I_{yr})	$I_{yr}=\frac{G_{Ra}}{150}+\frac{G_{Th}}{100}+\frac{G_k}{1500}$ (3)
3	External Hazard Index (HI_{ex})	$H_{ex}=\frac{G_{Ra}}{370}+\frac{G_{Th}}{259}+\frac{G_k}{4810}$ (4)
4	Internal Hazard Index (HI_{in})	$H_{in}=\frac{G_{Ra}}{185}+\frac{G_{Th}}{259}+\frac{G_k}{4810}$ (5)
5	Absorbed Does Rate (D)	$D=0.461G_{Ra}+0.623G_{Th}+0.04144G_k$ *(6)*
6	Annual Effective Dose Rate (Outdoor)	$AEDR\ (mSvyr^{-1}) = D(nGrh^{-1})\times 8760hryr^{-1}\times 0.7\times(10^3mSv/10^9)nGy\times 0.2$ *(7)*
7	Annual Effective Dose Rate (Indoor)	$AEDR\ (mSvyr^{-1}) = D(nGrh^{-1})\times 8760hryr^{-1}\times 0.7\times(10^3mSv/10^9)nGy\times 0.8$ *(8)*
8	Excess Lifetime cancer risk (ELCR)	$ELCR = AEDE \times LD \times RF$ *(9)*

RESULTS AND DISCUSSION

Discussion of Geoelectric Analysis

Interpretations of Vertical Electrical Soundings (VES) point to the presence of five to six layers in the Obeti, Umuaja, and Ebedei research areas shown in Table 2. Three soundings were conducted in each of the different communities, with AKH and AAK being the dominant curve types. The findings were used to design the geoelectric section (Figure 11) of the investigated locations and were correlated with extensive geological log data recorded from each borehole received from Obeti (VES 1-3), Umuaja (4-6), and Ebedei (VES 7-9). The initial layer of topsoil has a resistivity range of 60.2 to 1163.6 Ωm and a thickness ranging from 0.6 to 4.1 m and beneath the topsoil lie's a laterite grain sand formation with a resistivity range of between 283.2 and 1720.2 Ωm and a thickness varying from 2.7 to 12.7 m. The third stratum is made up of clay, fine, and medium sand and has a thickness ranging from 6.0 to 17.6 m to a depth of 28.6 m. It's iterated resistivity ranges from 71.8 to 2097.9 Ωm. Since this layer is an unconfined aquifer, it cannot always be relied upon to provide the local population with enough water, and the water in this layer will be highly susceptible to contamination by landfills and oil spills. The fourth subsurface layer is composed of medium and coarse sand and fine and smooth sand that ranges in thickness from 10.6 to 41.3 m and has a resistivity that varies from 182.1 to 6032.0 Ωm. Groundwater development is appropriate for this specified stratum. The fifth layer is made up of fine, medium, and coarse sand formations with resistivity ranging from 278.5 to 3256.4 Ωm and a thickness of 11.3 m for VES 4 at Umuaja and infinite thickness for other sounding points. The clay lithology that covers the fifth to sixth strata and aquifer of 29 to 70 meters in Obeti, Umuaja and Ebedei protects the water-supporting horizon. Thus, it is possible to use groundwater from the fifth-layer aquifer for industrial, agricultural, and residential purposes in the area. The findings of this investigation are consistent with those of Egbai et al. (2012) and Omosanya et al. (2021), who used VES to measure increased groundwater productivity yields in the studied areas.

Table 2: Lithology Depth interpretation and Classification of modeling parameters

VES	LAYERS	RESISTIVITY (Ωm)	THICKNESS (m)	DEPTH (m)	LITHOLOGY	CURVE TYPE	RMS % ERROR
	1	60.2	0.6	0.6	Topsoil		
	2	283.2	2.7	3.3	Laterite		
1	3	71.8	6.0	9.3	Clay	$P_1<P_2>P_3<P_4>P_5$	6.5
	4	1130.7	10.6	19.8	Coarse sand	KHK	
	5	780.8	---	---	Fine sand		
	1	626.1	4.1	4.1	Topsoil		
	2	305.9	7.2	11.3	Laterite		
2	3	355.4	7.0	18.4	Fine sand	$P_1>P_2<P_3<P_4>P_5$	3.3
	4	2533.9	21.6	40.0	Coarse sand	HQK	
	5	615.4	---	---	Medium sand		
	1	133.7	1.3	1.3	Topsoil		
	2	326.2	5.9	7.2	Laterite		
3	3	1180.5	15.8	23.0	Medium sand	$P_1<P_2<P_3>P_4<P_5$	3.2
	4	182.1	34.8	57.8	Smooth sand	AKH	
	5	3256.4	---	---	Coarse sand		
	1	573.3	0.8	0.8	Topsoil		
	2	1720.2	3.7	4.5	Laterite		
4	3	657.8	13.0	17.5	Fine sand	$P_1<P_2>P_3<P_4<P_5<P_6$	3.9
	4	667.0	10.9	28.4	Fine sand	KHAA	
	5	850.8	11.3	39.8	Medium sand		
	6	1166.3	---	---	Medium sand		
	1	1163.6	1.1	1.1	Topsoil		
	2	729.4	4.4	5.4	Laterite	$P_1>P_2<P_3>P_4<P_5$	
5	3	1656.9	10.4	15.8	Medium sand	HKH	2.7
	4	422.3	15.9	31.7	Fine sand		
	5	1541.5	---	---	Medium sand		
	1	450.0	1.0	1.0	Topsoil		
	2	936.7	8.4	9.4	Laterite	$P_1<P_2<P_3>P_4<P_5$	
6	3	2097.9	17.6	27.0	Medium sand	AKH	2.5
	4	485.2	17.3	44.3	Fine sand		
	5	1160.8	---	---	Medium sand		
	1	275.0	1.0	1.0	Topsoil		
	2	409.6	12.7	13.8	Laterite		
7	3	622.2	14.9	28.6	Fine sand	$P_1<P_2<P_3<P_4>P_5$	2.5
	4	4574.5	41.3	70.0	Coarse sand	AAK	
	5	278.5	---	---	Fine sand		
	1	76.6	1.0	1.0	Topsoil		
	2	229.2	10.1	11.1	Laterite		
8	3	370.1	7.5	18.6	Fine sand	$P_1<P_2<P_3<P_4>P_5$	5.3
	4	6032.0	21.2	39.8	Fine sand	AAK	
	5	1036.6	---	---	Medium sand		

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	1	224.2	1.3	1.3	Topsoil		
	2	264.5	4.8	6.1	Laterite		
9	3	1315.8	12.5	18.5	Medium sand	$P_1<P_2<P_3>P_4<P_5$	5.4
	4	863.3	11.4	30.0	Fine sand	AKH	
	5	924.1	---	---	Medium sand		

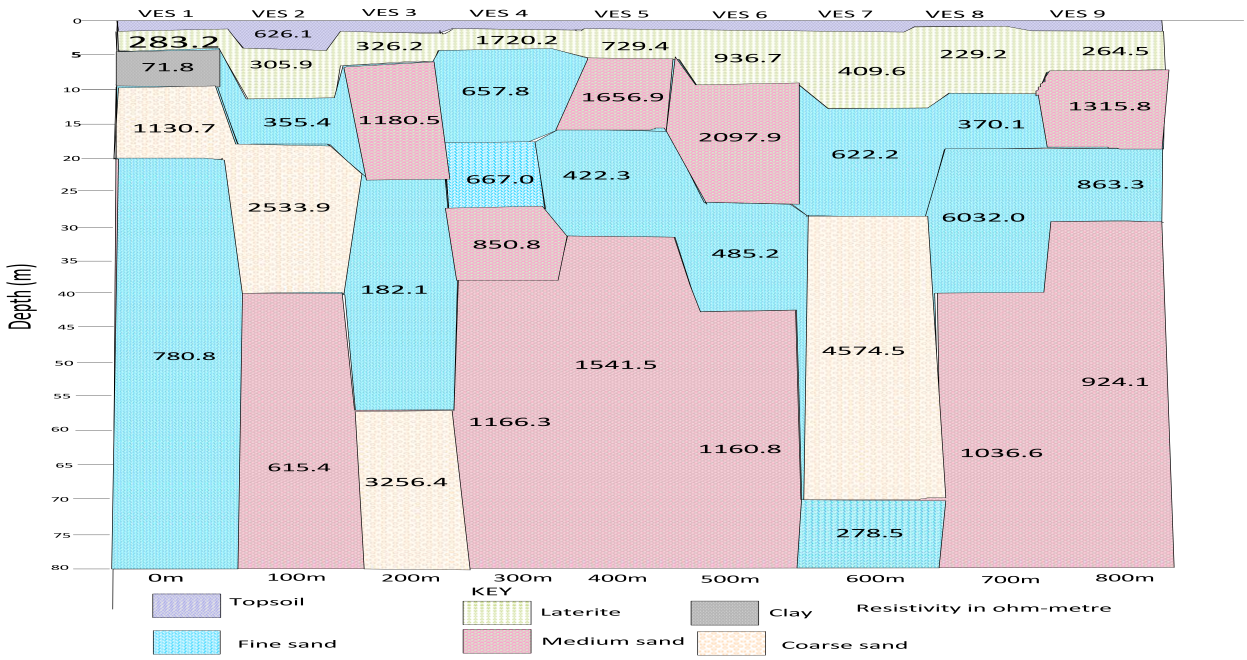

Fig. 11: Geoelectric sections of studied areas

Table 3: Mean activity concentration results of ^{238}U, ^{232}Th and ^{40}K in aquifer Drinking water

S/No	COMMUNITIES	ACTITIVY			
		^{238}U (Bq/l)	**^{232}Th (Bq/l)**	**^{40}K (Bq/l)**	**Raeq**
1	Obeti	8.54±2.56	5.24±4.33	73.12±3.08	21.66±8.99
2	Umuaja	13.14±0.85	6.15±3.15	48.32±7.34	25.66±5.93
3	Ebedei	5.31±0.31	3.06±1.36	52.35±2.19	13.72±2.43
Mean		9.00±1.24	4.82±2.95	57.93±4.20	20.35±5.78
Standard		1.0	0.1	10	370

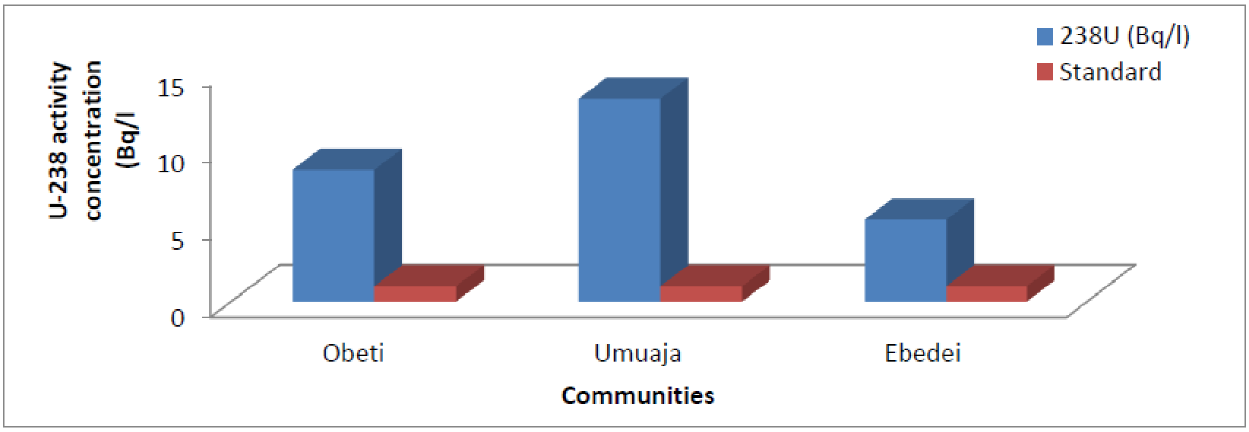

Fig. 12: Relationship of ^{238}U activity concentration of water and standard.

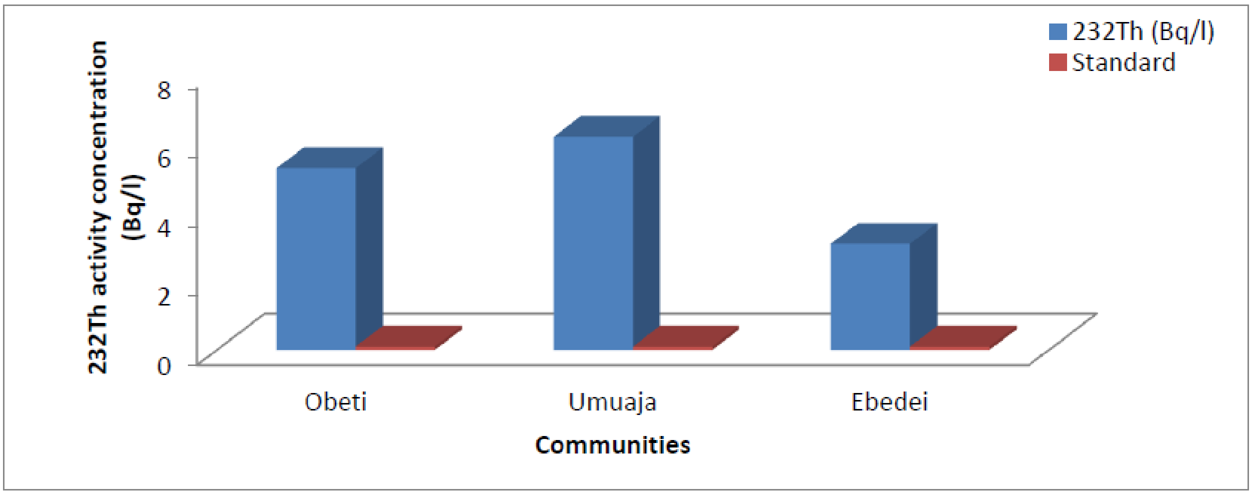

Fig. 13: Relationship of ^{232}Th activity concentration of water and standard.

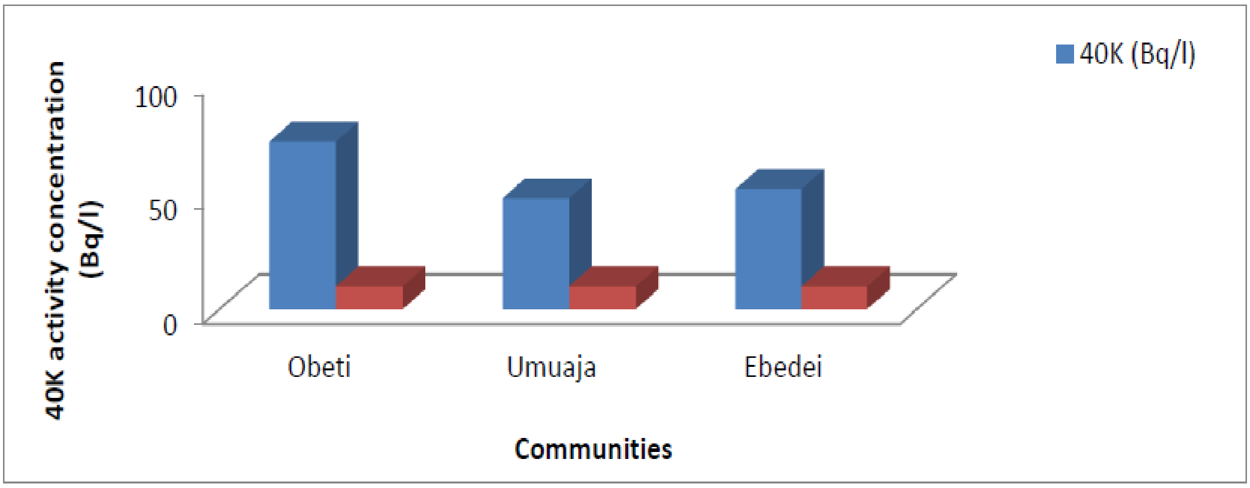

Fig. 14: Relationship of ^{40}K activity concentration of water and standard.

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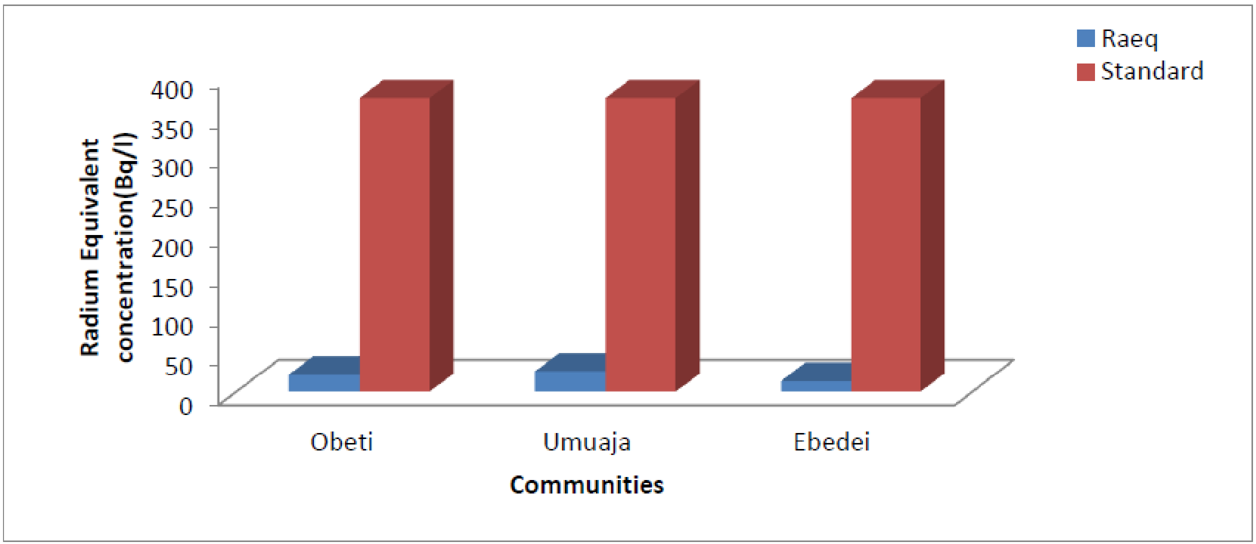

Fig. 15: Relationship of Radium Equivalent (Bq/l) activity concentration of water and standard.

Table 4: Computed Radiation Hazard Indices in Sediment sample.

S/N	Communities	Iyr	Hex	Hin	D	AEDE (Outdoor)	AEDE (Indoor)	ELCR×10^{-3} (Outdoor)	ELCR×10^{-3} (Indoor)	ELCR×10^{-3} (Outdoor+ Indoor)
1	Obeti	0.16	0.06	0.08	10.23	12.55	50.20	0.04	0.18	0.22
2	Umuaja	0.18	0.07	0.11	11.89	14.58	58.33	0.05	0.20	0.25
3	Ebedei	0.10	0.034	0.05	6.52	8.00	32.00	0.03	0.11	0.14
	Mean	0.15	0.056	0.08	9.55	11.71	46.84	0.04	0.16	0.20

Discussion of Radioactivity Analysis

The mean activity concentration results of ^{238}U, ^{232}Th and ^{40}K in aquifer depth of 29 -70 m grounwater are presented in Table 3. The activity concentration of ^{238}U ranged from 5.31±0.31Bql^{-1} at Ebedei community to 13.14±0.85Bql^{-1}Umuaja community with a mean value of 9.00±1.24Bql^{-1}. The activity concentration of ^{232}Th ranged from 3.06±1.36Bql^{-1} at Ebedei community to 6.15±3.15Bql^{-1}Umuaja community with a mean value of 4.82±2.95Bql^{-1}. While the activity concentration of ^{40}K ranged from 48.32±7.34Bql^{-1} at Umuaja community to 73.12±3.08Bql^{-1}Obeti community with a mean value of 57.93±4.20Bql^{-1}. All the mean activity concentration values for ^{238}U, ^{232}Th and ^{40}K in aquifer depth where water samples was collected exceeded world average value of 1.0 Bql^{-1}, 0.1 Bql^{-1} and 10 Bql^{-1} respectively (UNSCEAR 2000), with Figs. 12,13 and 14 showing the statistical pie chart of the communities. The obtained results were also compared with the other works published by scientists in similar environment (Awodugba and Tchokossa, 2008; Avwiri *et al.*, 2007; Agbalagba *et al.*,2012; Tchokossa *et al.*, 2011). The high activity concentration results of the aquifer groundwater with regard to depth of the soil profile may be accredited to the nature of the geological formation of the area and the anthropologic discharged waste by the oil and gas operators in the area. The obtained reaults were also compared with other scientific work in the Niger Delta and beyond (Efenji *et al.*, 2022; Alomari *et al.*, 2019; Altikulaç *et al.*, 2015; Tchokossa *et al.*, 2011). The computed radium equivalent

(Raeq) radiological risk values of the aquifergroundwater ranged from 13.72±2.43 Bql^{-1} to 25.66±5.93 Bql^{-1} with an mean value of 20.35±5.78 Bql^{-1}, which are less than the world permissible limit of 370 Bql^{-1} as shown in Fig. 12. The radioactivity index values of (Iyr), external hazard index and internal hazard index ranged from 0.10, 0.03 and 0.05 to 0.18, 0.07 and 0.11 $mSvy^{-1}$ with a mean values of 0.15, 0.06 and 0.08 $mSvy^{-1}$ respectively. These three mean radioactivity index values are all below word unity and other researcher works, which kept the grounwater radiologically insignificant (Ayodele *et al.,* 2020; Fasunwon *et al.,* 2010; Avwiri *et al.,* 2007). These shown that the groundwater will not cause respiratory and external diseases when put to use. The aquifer groundwater (D) values ranged from 6.52 to 11.89ηGyh^{-1} with a mean value of 9.55ηGyh^{-1}. The computed (AEDE) for outdoor and indoor, (ELCR) outdoor, indoor and addition of both are 11.71μSvy^{-1} and 46.84μSvy^{-1}, 0.04, 0.16 and 0.20 respectively were all lower world permissible limits. However, the overall measured radionuclides values and the computed health risk parameters obtained from the groundwater studied show that none of them can cause immediate radiological health challenge to those drinking the groundwater in the studied.

CONCLUSION

The investigation of aquifer strata and groundwater quality of Obeti, Umuaja, and Ebedei communities of Ukwuani, Delta State, Nigeria was done through depth probing (VES) of geophysical survey method and sodium iodide [Na(TI)] detector. The electrical resistivity technique revealed that lithology has five to six geoelectric strata with AKH, AAK, AKH, HKH, KHAA, HQH, and KHK type curves revealing both almost homogeneous and diverse terrain. The geophysical survey revealed that five to six geo-electric strata ranged from clay to coarse grain sand. The confined (best) aquifer zone is identified as the fourth formation, which has a depth range of 19.8 to 70.0 m, and any groundwater design project in the survey region should concentrate more on this domain. Also, to ascertain activity concentrations of ^{238}U, ^{232}Th and ^{40}K at the aquifer depth of 29–70 m groundwater, fifteen groundwater samples were analyzedand the mean results of 9.00±1.24Bql^{-1}, 4.82±2.95Bql^{-1} and 57.93±4.20Bql^{-1} were revealed respectively, which are above world threshold limits. However, the computed mean radiological health risk values for (Raeq), (Iy), (Hin), (Hex), (D), (AEDE), outdoor and indoor and (ELCR) outdoor and indoor are 20.35±5.78 Bql^{-1}, 0.15$mSvy^{-1}$, 0.056$mSvy^{-1}$, 0.08$mSvy^{-1}$, 9.55μGyh^{-1}, 11.71$mSvy^{-1}$, 46.84$mSvy^{-1}$and 0.04×10^{-3}, 0.16×10^{-3} and 0.20×10^{-3} for the addition of (ELCR) outdoor and indoor respectively. All the computed mean radiological values are below world threshold limits. Hence, the studied communities' drinking groundwater is safe radiologically from the drill depth of 30m and can be used for domestic, agricultural and industrial purposes. However, the groundwater should undergo same form of treatment before usage for industrial, agricultural and human consumption.

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