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Aspects of Geophysical Exploration for Groundwater Using Vertical Electrical Sounding (VES) in Parts of University of Benin, Benin City, Edo State

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KEYWORDS: Vertical Electrical Sounding (VES), Hydrogeological Parameters, Aquifer

ABSTRACT.: A geophysical survey using vertical electrical sounding (VES) was undertaken within the University of Benin (Ugbowo Campus) in an attempt to ascertain aspects of the hydrogeological parameters for groundwater exploitation. Six (6) vertical electrical soundings with electrode spacing of 215m AB/2 were occupied along the traverse, with the aid of ABEM SAS 1000 Terrameter set. The data were interpreted using the IXID and 3-D field-map computer softwares. The subsurface stratigraphy is as follows; (262.43-784.7Ωm); topsoil, (205.65-3666.4Ωm); wet laterite, (44.017-2201Ωm); anomalous soil, (601.03-1450Ωm); clayed/silty sand, (2712.38-11741Ωm); dry sand, and (2909.7-12423Ωm); as aquifer. The results reveal depth to water table ranges of 31.2-65.5m. The range of values of minimum thickness of the aquifer across the VES is from 45-63m. VES 3 is the shallowest and may be the cheapest to drill and install a borehole. VES 6 with a inferred depth of 63-65.5m, will probably be the best area to site a borehole in spite of the expected cost imperatives. The area shows slight spatial variations and plausibly attests to natural inhomogeneity, anthropogenic interplay in the course of the development of the area via construction, and very marginal susceptibility to contamination from the health centre and hostels within the study area. Furthermore, the results conformed to those of previous writers who described the aquifer as sandy and highly prolific. © JASEM

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Introduction:
Earth masses have electrical properties. The electrical resistivity of different geological materials is a function of a number of factors, which include variations in water contents, dissolved ions in water and material make-up. Resistivity investigations can thus be used to identify zones with different electrical properties. The Schlumberger resistivity method has over the years proved useful in delineation of groundwater and aquifer characteristics due to its better depth interpretation. Previous investigators such as Van Overmeeren, (1989), McNeil, (1990), and Atakpo and Akpoborie, (2008), have buttressed this. However, it is possible for different rock types to have the same range of resistivity (Ezomo, and Akujieze, 2010), this usually make electrical resistivity data ambiguous to interpret. The operational efficiency of six points per decade in subsurface geophysical study in groundwater exploration has been documented arising from theoretical approach to electrical resistivity (Ezomo, 2010). Electrical resistivity methods involve the measurement of the apparent resistivity. Given expansion and population growth in the university, there is the need to proactively map outs areas of optimal groundwater supply for exploitation. This forms the main thrust of this investigation, which attempts to delineate the appropriate aquifer area with a view to producing a blueprint to siting high yield boreholes in the area in view of its concomitant benefits.

Description of the Study Area: The area of investigation lies within longitude 5.62^{0}E and latitude 6.4^{0}N approximately 350km SW of Abuja. University of Benin has a human population of over 40,000. The Ugbowo Campus in Benin City of Edo State lies within the tropical rain forest and has two distinct seasons (wet; April to October, and dry; November to March). The study area lies within the Benin Formation (Fig 1-3) which extends from the west across the whole of the Niger Delta area and southward beyond the present coastline. It consists of over 90% sandstone with shale intercalations. It is coarse grained, gravelly, locally fine grained, poorly sorted, sub-angular to well- rounded and bears lignite streaks and wood fragment. It is a continental deposit of probably upper deltaic depositional environment. Various structural units (point bars, channels fills, natural levees, back swamp deposit, ox-bow fills) are identifiable within the formation, indicating a

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variability of the shallow water depositional medium. In the subsurface, it is of Oligocene age in the north and becoming progressively younger southward. In general, it ranges from Miocene to Recent. The thickness is variable but generally exceeds 2Km. In terms of hydrogeological potentials; Offodile, (2002) described the Benin Formation as the most aquiferous formation in Southern Nigeria. It has transmissivity of 880-30,000M^2/day 1.53-3.16×10^{-3}-storage coefficient average porosity is 30%. Akujieze, (2004) investigated the Benin Formation and reported unconfined to semi confined aquifers in certain places. Etu-Efeotor, and Akpokodje, (1990), identified three major aquifers therein.

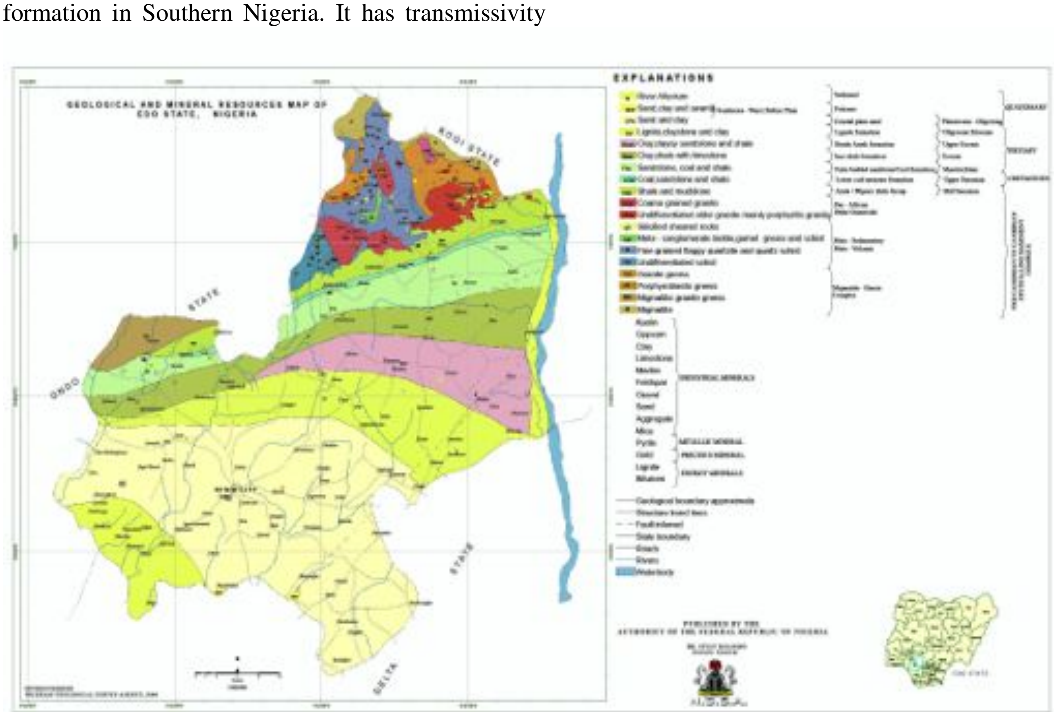

Fig.1: Geological Map of Edo State Showing Benin City and other Locations (Nigerian Geological Survey Agency, 2006)

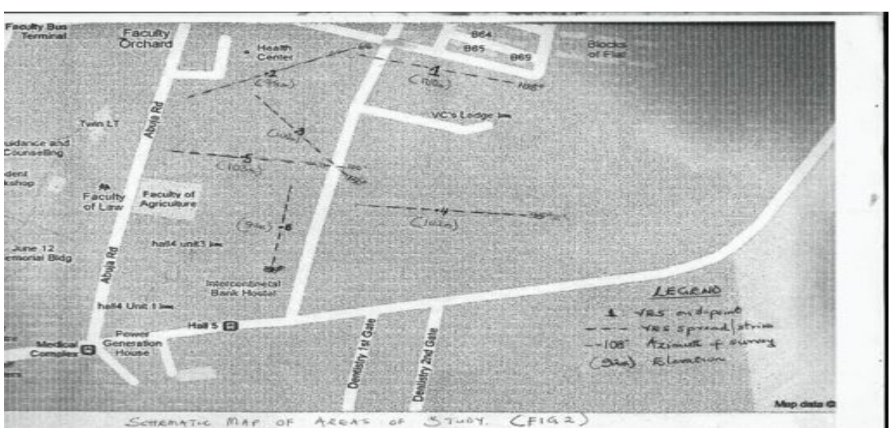

Fig 2; Schematic Map of the Study Area.

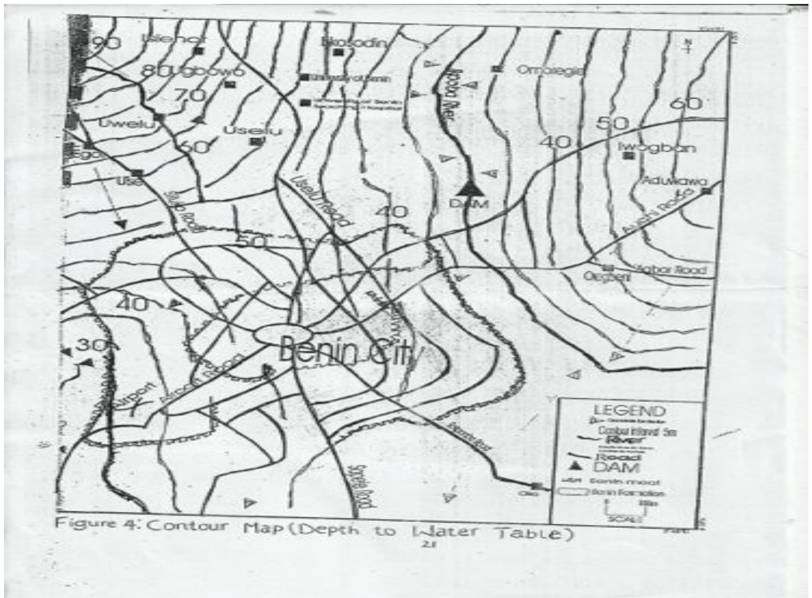

Fig 3; Groundwater Depth to Water Table Map of Benin City (From Edo State Water Board)

Methodology: Six (6) VES points were acquired. Data were generated at six points per decades which covered 215 meters of AB/2 and 430 metres of AB. The Schlumberger array method was employed in the study. The potential electrodes remained fixed at a point while the current electrodes were expanded symmetrically about the centre of the spread. The potential electrodes were also increased when the current electrode were too far apart (in other to maintain a measurable potential). The inner potential electrodes were maintained to have spacing, which is small compared to that of the outer current electrodes (AB/2).

Measurement were made by introducing an artificially generated electric current into the ground through two electrodes (AB) and the resulting voltage differences (potential drop) across the other two potential electrodes (MN) were taken.

The ABEM SAS1000 Terrameter) was used for electrical measurements. It is designed so that the ratio of the potential drop to the measured current is read directly as resistivity in ohms (Ω) or milli ohms (MΩ) after a minimum average of two cycles or maximum average of four cycles. The values obtained are the resistivity of all earth materials to the depth that is proportional to the electrode spacing. Apparent resistivity is defined as the resistivity of an electrically homogeneous and isotropic half-space that would yield the measured relationship between the applied current and the potential difference for a particular arrangement and spacing of electrodes.

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RESULTS AND DISCUSSION

Table 1: VES 1 results and interpretation.

Apparent Resistivity	Thickness	Depth	Elevation	Inferred lithology	Curve Type
262.43	0.57741	0.57741	99.423	top soil	QHAQ
205.65	2.7185	3.2959	96.704	wet laterite	
44.017	3.3174	6.6133	93.387	anomalous soil	
601.03	2.8527	9.466	90.534	clayey soil	
3061.4	4.4239	13.89	86.11	silty sand	
29238	31.322	45.211	54.789		
				dry sand	
2909.7	47.193	92.405	7.5952	aquifer	
393.24					

Table 2: VES 2 results and interpretation

Apparent Resistivity	Thickness	Depth	Elevation	Inferred lithology	Curve Type
400.78	0.35401	0.35401	77.646	top soil	AQHAK
1134.8	0.93292	1.2869	76.713	wet laterite	
425.81	1.1152	2.4021	75.598	clayey soil	
759.82	3.3851	5.7872	72.213	laterite	
3994.6	10.756	16.543	61.457	silty sand	
12985	17.854	34.397	43.603	dry sand	
1410.8	45.712	80.108	-2.1082	aquifer	
737.35					

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Table 3: VES 3 results and interpretation

Apparent Resistivity	Thickness	Depth	Elevation	Inferred lithology	Curve Type
635.6	0.29159	0.29159	99.708	top soil	AKQHAK
4757.3	0.64201	0.93359	99.066	soaked soil	
968.98	2.05	2.9836	97.016	clayey soil	
1220.1	4.5422	7.5258	92.474	laterite	
1172.3	6.9165	14.442	85.558	silty sand	
24893	16.716	31.158	68.842	dry sand	
12423	28.616	59.774	40.226	aquifer	

Table 4: VES 4 results and interpretation

Apparent Resistivity	Thickness	Depth	Elevation	Inferred lithology	Curve Type
784.79	0.43396	0.43396	101.57	moist top soil	AKQHAKQ
3666.4	1.0394	1.4733	100.53	saturated sub soil	
2201	2.3191	3.7924	98.208	laterite	
1450	5.0052	8.7976	93.202	clayey soil	
1965.5	7.6536	16.451	85.549	silty sand	
11741	31.709	48.16	53.84	dry sand	
3436.4	25.985	74.145	27.855	aquifer	
1298.3	98.361	172.51	-70.507	silty sand	
1602.2					

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Table 5: VES 5 results and interpretation

Apparent Resistivity	Thickness	Depth	Elevation	Inferred lithology	Curve Type
750.92	0.60056	0.6006	102.4	saturated sub soil	QHAKQHAKQ
332.69	0.95453	1.5551	101.44	laterite	
2798.4	2.1375	3.6926	99.307	clayey soil	
470.57	4.5254	8.218	94.782	silty sand	
990.04	6.418	14.636	88.364	dry sand	
3665.3	32.979	47.615	55.385	aquifer	
647.43	71.863	119.48	-16.477	silty sand	
949.6					

Table 6: VES 6 results and interpretation

Apparent Resistivity	Thickness	Depth	Elevation	Inferred lithology	Curve Type
805.32	0.7756	0.7756	91.224	saturated sub soil	AKQHAK
1453.4	1.29	2.0656	89.934	laterite	
578.3	2.1761	4.2417	87.758	clayey soil	
1211.8	3.6069	7.8486	84.151	silty sand	
1744.7	15.323	23.171	68.829	dry sand	
9349	42.312	65.483	26.517	aquifer	
2268.1	62.721	128.2	-36.204	silty sand	

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The interpretation of the sounding curves is based on the assumption that the subsurface consists of a sequence of distinct layers of finite thickness. Each layer is assumed horizontal and electrically homogeneous and isotropic. However, in actuality, this is not always so. Unknown in the field, VES1 breached some precautionary measures. This section seems to have buried pipelines (reflected by changes in flow paths due to the high conductivity of metals), plausible topographical variations- from construction/ trenching (distort potential field), and possession of anisotropic material (a joint set in bedrock filled with water can cause electrical current to have a preferred path).

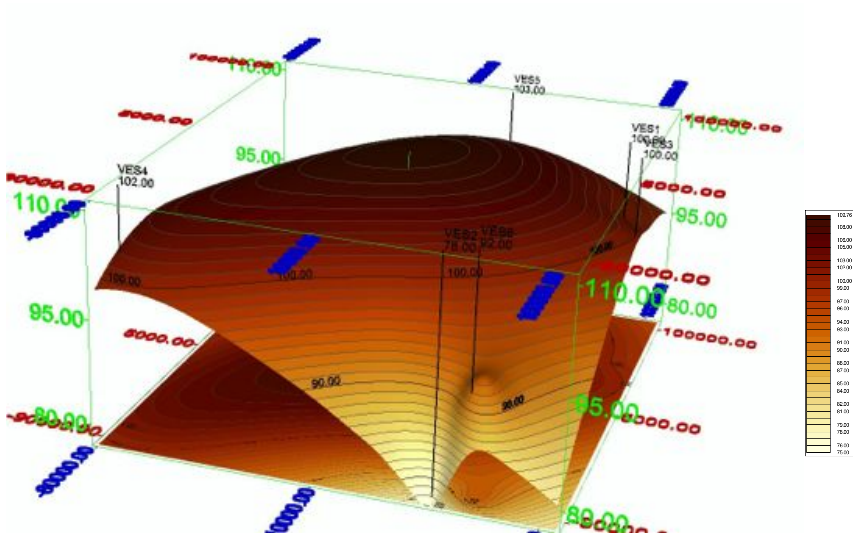

Fig 4: Schematic 3-D representation of the topography of the study area. (A comparison with the 3-D view of the saturated water level (fig 5) reveals striking similarities and seems to suggest that the groundwater flow is structural controlled in the study area).

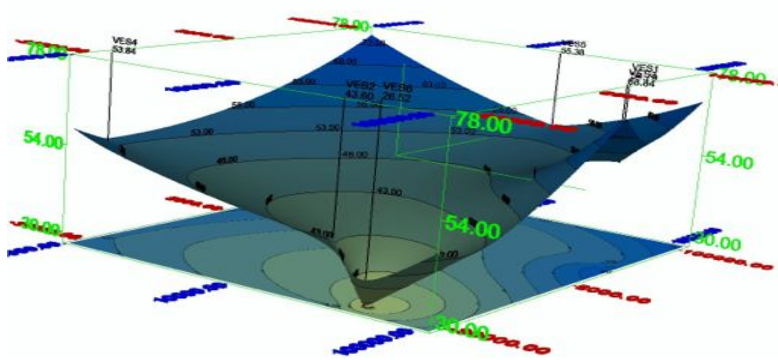

Fig. 5: 3-D view of the saturated water level of the study area showing VES points

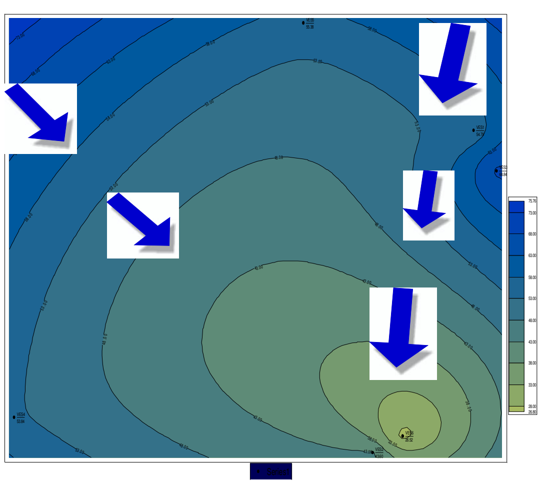

Fig.6: Apparent flow direction of groundwater

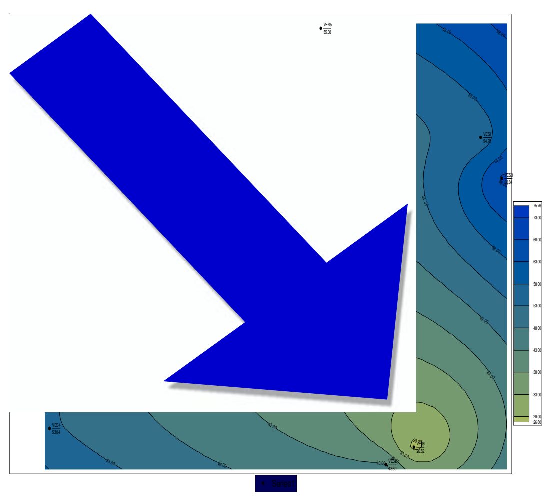

Fig . 7: True flow direction of groundwater flow. (estimated using the 3-D software and a 3-point solution)

Despite the series of adjustment and computation iteration, it became obvious that the resistance of an additional point had to be included for the entire survey to be sufficiently meaningful. Albeit, combining a mix of physics and geomathematics this was achieved. Thus: The ratios of the adjacent resistance at the potential spacing of 10m were evaluated. (ie, 1.03/0.84 =1.2261, 0.84/0.58 =1.448, 0.58/0.27 =2.1481 ,) Using extended equivalence, it was found by approximation to be 0.1. Thus: If 1.2261 =100%, then 1.448 =118%, 2.1481=175. Hence the difference in per cent: 118-100 =18, 175-118 =57. The difference (57-18)% =39%. This is equivalent percent for the next point. That is, 175+39 =214. Therefore, 0.27/*=214. Hence, * =0.1 Ω. This is the resistance sought. The Geometric factor (GF) can be calculated using: GF={[(AB/2)2 –(MN/2)2] /(MN/2)} π /2.(Where the designations take their regular meanings). Substituting, GF=14,123.29. The apparent resistivity is given by the product of the GF and the resistance to be 1,412.32 Ωm.

Computer iteration techniques were employed by using IXID and 3-D field map software to exhibit models of the lithologies. Resistivity of soils and rocks is also a function of depth or position. Typically, resistivity of geologic material and of near surface material is heavily affected by groundwater which is a low resistivity material. In general, finer grained sediments have low resistivity, and bedrock has high resistivity (table 1-6). Resistivity is reduced by: increasing porosity, increasing ion content of groundwater, increasing content of clay, decreasing grain size, etc. Apparent resistivity was from about 400 Ωm to about 24,000 Ωm. The anomalous values obtained in VES 1 are considered to be resultant from interference. Seemingly, against the norm, which stipulate that soundings be taken across suspected underground cables to attenuate its effects, this particular VES was inadvertently applied parallel to the interfering medium. It however produced very interesting outcomes that may be the subject of future research work. For instance, it also revealed that metal/ cables were buried up to a depth of about 3.3m in a lateritic horizon below the surface. Again, it is highly plausible that certain other metals were buried at a depth of 6.61m near the Vice- Chancellor's lodge. The effect of tunnelling also seems contributory to this anomaly.

The saturated water level (SWL) values hover from 26.3-68.8m with a mean of approximately 50.5m. The depth to the aquifer is between 31.2-65.5m. The lower limit of 65.5m correlates more with the established depth for this area of the Benin Formation (Fig. 2).The inferred lithologies are laterites, clay, silty sand, dry sand. The aquifer inundates the sandy formation. These were deduced from the sounding curves and profiling. The observed sounding curves for the six locations show that of H – type (Table 1-6) ($\rho_1 > \rho_2 < \rho_3$), KA – type ($\rho_1 < \rho_2 > \rho_3 < \rho_4$), HQ – type ($\rho_1 > \rho_2 < \rho_3 > \rho_4$), HA – type ($\rho_1 > \rho_2 < \rho_3 < \rho_4$) and A – type ($\rho_1 < \rho_2 < \rho_3$), etc.

The entire area is suitable for borehole siting for water abstraction. Nonetheless, it may add value to double-check geophysical results here with well-logging analysis of actual boreholes. Depth to water table ranges from 31.2 – 65.5m. These depth values are expected to be higher in the dry seasons and in periods of significant abstraction. VES 3 area is the shallowest and may be the cheapest to drill and install a borehole. However, for the purposes of long-term and large-scale abstraction, and assuming this borehole is to be operated simultaneously with other boreholes, the best area to site a borehole will be the VES 6 area. But, it is the deepest at 65.5m -with attendant cost imperatives. The average minimum thicknesses of the aquifer are from 45-63m. The thickness at VES 6 is about 63m.

To optimise the use of the entire aquifer, it is good practice to drill just below the aquifer. While the entire aquifer area is screened, the limiting area just below the aquifer is not screened but should be used for reinforcement of the borehole casing structure. The impermeable area below the aquifer is often made of clay/ shale. Screening this area will clog the borehole at worst or introduce colloidal materials to the borehole at the least. A comparison with the 3-D view of the saturated water level (fig 4&5) reveals striking similarities and seems to suggest that the groundwater flow is structurally controlled in the study area). Corollary, from the preponderance of deductions from the data acquired and processed, it was possible to estimate the true direction of groundwater flow (Fig. 6 & 7) and this reinforces the veracity of the claim of the use of VES 6 as the best borehole siting area in this study. Overall, the results did not reflect significant concerns for groundwater contamination.

Conclusion: The aquifer in the study area seems prolific. All VES areas are suitable for drilling, nonetheless; VES 6 area holds the best hydrogeological parameters for water borehole siting and should be the least susceptible to the impact of groundwater variations in terms of abstraction and recharge. The true groundwater flow direction takes a clue from topography, depth and thicknesses of the inferred clayey lithology. The resistivity values combined with reconnaissance survey seems to suggest the negligible role of contaminants in the environment. However, to ascertain the authenticity of this inference, further work will be required.

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