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HYDROGEOCHEMICAL AND MICROBIAL CHARACTERISTICS OF ABAKALIKI SHALES, EBONYI STATE, NIGERIA

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Geochemical and microbial studies were carried out on surface and groundwater from the Abakaliki shales, Enugu, Nigeria. The study involved a total of twenty-five samples, which were analyzed to determine major ion concentrations and coliform status. Results of the analyses show that the pH of the waters range from 6.8 to 8.4 with most values clustering around 7.0 (neutral). Values of total dissolved solids concentration range from 827.8 to 1334 mg/l which suggest brackish water. High values of dissolved oxygen indicated strong oxidizing conditions in the regolith aquifer. The interpretation of ionic concentrations suggests that the chemistry of the ground water in the aquifer is established initially by the composition of ancient connate water trapped in the sediments. As the aquifer becomes increasingly recharged by rainwater there is a corresponding dilution plus the incipience of important reactions like natural softening and pyrite oxidation. The origin of the connate water is most probably marine. Microbial studies revealed that all the waters are heavily polluted with respect to coliform bacteria. The presence of specific pathogens like Salmonella spp, E. Coli and Pseudomonas spp in some of the samples suggest that the water supply of Abakaliki City should never be used without thorough treatment.

INTRODUCTION

The study area (Abakaliki) is defined by latitudes $6^{o}\,21'$ N and $6^{o}\,16'$N and longitudes $8^{o}\,10'$E and $8^{o}\,05'$E. It covers about 83 square kilometers and comprises Abakaliki capital city. The area is part of the Ebonyi River basin, which is a subset of the Cross-River Plains.

Abakaliki capital city lacks good aquifers because it is underlain by shales instead of aquiferous rocks like sands, sandstones or gravels. The shales provide quasi aquiferous conditions due to their highly weathered and jointed nature but the quantity of water provided is insufficient to meet the growing demands for potable water in the area. When Abakaliki city was elevated to the status of a state capital, the water demand rose sharply in such a way that every possible source of groundwater has to be considered as an option.

In view of the foregoing, it has become necessary to constantly evaluate both the quantity and quality of water available from the Abakaliki Shales. These shales belong to the Asu River Group and are known to generate conditions like high-run off because of their low permeability. The flat lying topography, high runoff and heavy tropical rains in the area have resulted to the existence of several surface water bodies like ponds and ephemeral streams. These ephemeral water bodies are not viable options for potable water availability because they often do not survive the long spells of the dry season and even in the rainy season periods; they harbor river blindness and guinea worm pathogens which make them unacceptable as water supply options. This is why it is so important to evaluate the quality of the water coming from the shales.

The focus of this paper therefore is to evaluate the geochemical and microbial content of the available waters from the fractured shale aquifers. This would help in designing proper water management models for the capital city.

GEOHYDROLOGIC SETTING

Marine sedimentation in the Abakaliki-Benue Trough area began in middle Albian times with the deposition of the Asu River Group. These groups of sediments consist largely of poorly bedded sandy shales, fine grained sandstones, limestone and sandy shales. Abakaliki Shales are the dominant shale rocks of the group but the formation (i.e. Abakaliki Shales) also have subordinate sandstones and sandy limestone lenses as shown in Figure 1.

The entire study area is underlain by the Abakaliki Shale formation. The shales are capped by laterites that have an average thickness of about 60 cm. There are local outcrops of sandstone lenses north of the town. The sandstones are fine grained, grayish to whitish in color with yellowish / dark brown iron stains and streaks of carbonaceous material. In a few outcrops, the sandstones are thickly bedded but others show evidence of lamination. Around the Water Works area, the sandstone outcrops show evidence of siliceous cementation instead of the calcareous cement found in all the other sandstone outcrops elsewhere. The average dips range from 64^{0} -70^{0} in the SE direction.

Good exposures of the Abakaliki Shales are found along the Ebonyi Rivers. Fresh surfaces are also exposed in a few hand-dug wells. Generally ,the shales are highly indurated particularly near the Juju Hill area where an intrusion occurred in Santonian times. The shales are dark grey to black in color and some outcrops show an evidence of fissility. Average dips of shales are in the range of 55^{0}- 57^{0} to the SE.

Two aquifer horizons were observed in the area. The upper 15-25 m of the Abakaliki Shales is

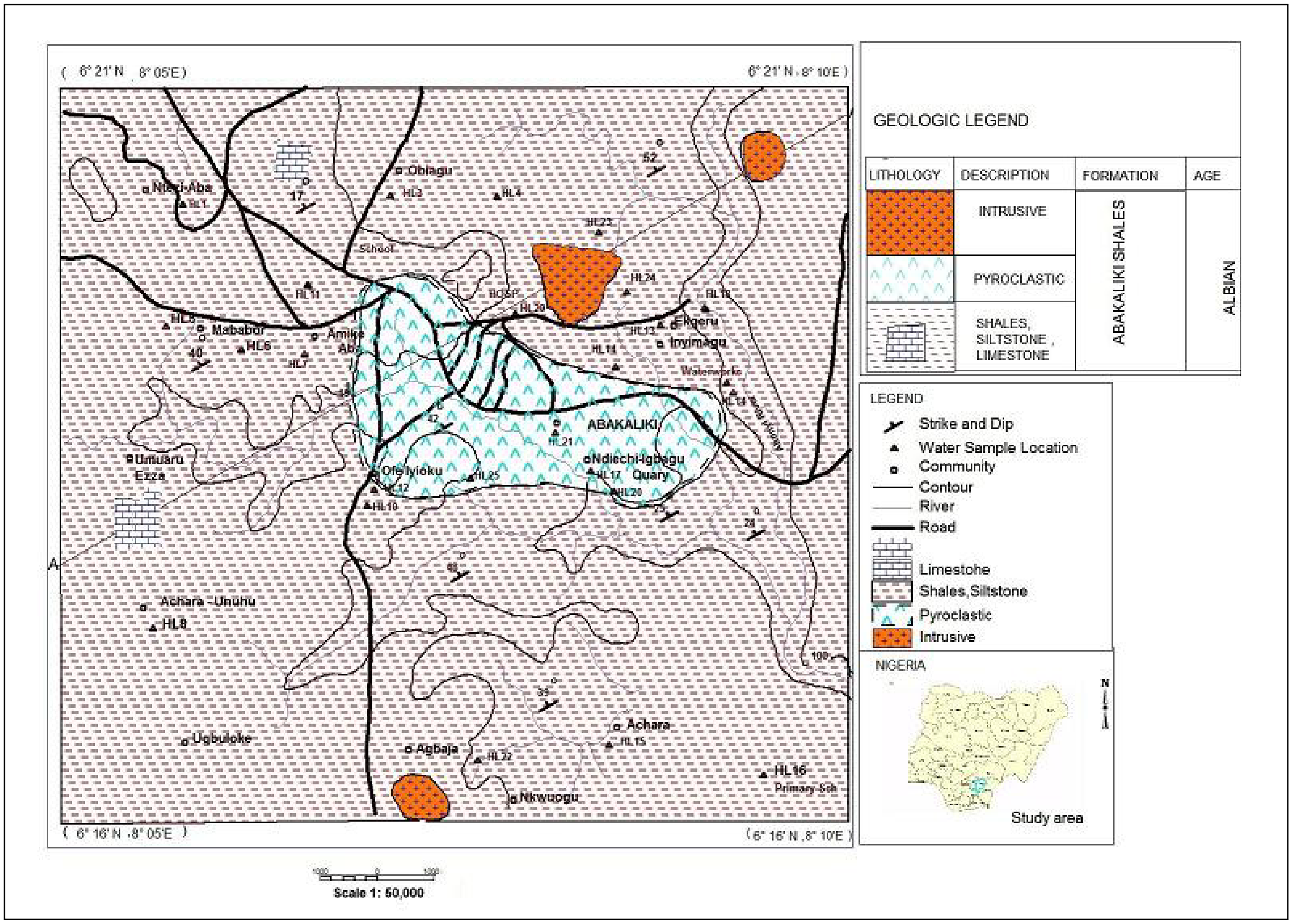

Figure 1. Geologic map of Abakaliki and environs.

highly fractured and weathered. It is considered to be a low yield unconfined, regolith aquifer while the deeper levels (i.e. > 25 m) are considered to be somewhat aquiferous because of deep level joints at depth. Agbo (1992) indicated that although depths to the fractured bedrock may average about 8.5 m, there are indications of deep fractures and joints of about 400 m.

It is not possible to determine the hydraulic properties of the unconfined regolith aquifer through conventional means like pumping test analyses or statistical methods but by the application of the equation below, it was possible to obtain an estimate of its hydraulic conductivity.

According to (Serafim, 1968), the equation is helpful in estimating the hydraulic conductivity values for flow through jointed and fractured rock mass (such as the jointed/fractured shale aquifer). It states that:

$$K = \frac{e^3 \gamma_w}{12\mu} \quad (1)$$

where

K = hydraulic conductivity in cm/s

γ_w = Measured opening (or gap) in a joint (cm)

e = distance of separation between two joints. (cm)

μ = viscosity of water. (ns/cm^2)

The evaluation of equation (1) for a system of joints in the Abakaliki Shale yielded the value of 6.06×10^{-3}cm/s. According to (Hamill and Bell 1986) this value of k indicates that the shales are moderately permeable. They found that the k value for fractured rock masses that have closely to moderately widely spaced discontinuities range from 10^{-5} to 10^{-2} cm/s. Hence this k value explains how an aquiclude like shale could be aquiferous.

METHODOLOGY

In addition to geological field work, the study also involved the field sampling of all natural waters contained in the unconfined, regolith shale aquifer. Samples were drawn from hand dug wells, shallow boreholes, ponds, stream and the Ebonyi River. Some parameters like pH, temperature and dissolved oxygen were tested for in the field while other major ions like Mg^{2+}; Ca^{2+}; Na^{+}; HCO_3^{-}; SO_4^{2-} and Cl^{-} were tested for in the laboratory using techniques by the American Water Works Association (AWWA 1970). This was followed by a detailed microbial analysis of the water samples using the methods described by Okafor (1985).

RESULTS AND DISCUSSION

A total of twenty five (25) water samples were collected from different parts of the study area. Figure 1 shows the sample locations on the geologic map. The samples were from hand-dug wells, ponds, shallow boreholes, ephemeral streams and the Ebonyi River.

The results are given in Table 1. The pH of all the water samples range from 6.8 to 8.4 with most values centering around the value of 7.0 (an indication that the waters are almost neutral to slightly alkaline). Temperature of the water samples taken in the field range from 19 ^{o}C to 24 ^{o}C while the values of total dissolved solids range from 827.8 mg/l to 1334.2 mg/l. The TDS values fall into the category expected for brackish water. In other words, the waters are dilute with respect to their composition. The TDS values are also suggestive of high values of electrical conductivity.

Values of dissolved oxygen in the waters are anomalously high which indicates high oxidizing conditions inside the shallow fractured shales aquifer.

The sodium (Na^{+}) ion is the principal cation in the area. Its concentration levels range from 68.7 mg/l (at the Quarry in HL 21) to 217 mg/l at Ntezi-Aba (hand-dug well). Its source in the aquifer may be from trapped sea water or connate water in the sediments. It is also possible that the sodium enrichment might arise from natural cation exchange reactions. In shales Na-montmorillonite clay will react with calcium and magnesium to release sodium into solution.

The concentration of the magnesium ion ranges from 20.3 (Achi stream) to 102 mg/l (at Ugbuloke hand dug well). In several water samples (eg. HL 2, 3, 4, 5, 7, 8, and 9), the Magnesium ion (mg^{2+}) exceeds Ca^{2+} in concentration. In such cases, the Mg^{2+}/Ca^{2+} ratio will be greater than unity which suggests a marine origin for the ion.

Ca^{2+} concentration ranges from 27.3 mg/l in the Hand dug well, (HL5) at Igbagu to 145.8 mg/l Hand dug well (HL 20) near limestone Quarry. The high value near the quarry may be due to dissolution of calcite from the nearby limestone rocks.

The sulphate (SO_4^{2-} ion) values range from 38.7 mg/l at the hand-dug well in Mgbabor to 121.2 mg/l near the Juju hill. Possible sources in the aquifer may be from gypsum, a possible constituent from the brine-rich waters of trapped seawater.

Table 1. Chemical characteristics of hand dug wells, ponds and streams in Abakaliki. (mg/l).

S/N	Location	Water Samples No	pH	Temp (^{0}C)	TDS	Dissolved oxygen (O_2)	Na^+	Mg^{2+}	Ca^{2+}	HCO_3^-	SO_4^{2-}	Cl^-	Fe (Total)	NO_3^-
1	Ntezi Abu	HL1	7.4	21	985.7	1072	217	36	42	20	80	70.4	0.3	1.2
2	Prison/ Hospital	HL2	7.1	20	911.5	996.4	204	54.3	37	25	88	265	BDL	0.2
3	Obiagu West	HL3	7.5	24	1102	600	147.2	70.1	32	24.3	90.4	287	3.20	2.4
4	Obiagu Central	HL4	7.4	20	1004.7	673.8	132.6	65	29.6	19.8	46.7	320	4.5	2.8
5	Igbagu	HL5	7.8	22	827.8	1102	125	32	27.3	40.2	62	110.7	BDL	BDL
6	Abakaliki (BH)	HL6	7.3	19	902.3	1048	142	27	52.4	17.5	57.3	63	0.7	0.3
7	Ebonyi River	HL7	7.3	20	1209	576.8	184.3	84	72.1	82	102	38.6	4.8	3.7
8	Ugbuloke	HL8	7.4	21	1001.2	1148.2	89	102	85	75	153	77	0.2	2.5
9	Mgbabor	HL9	6.9	22	877.6	1204.3	67.4	94	66.4	33.2	387	92.3	0.1	3.7
10	Ndiachi Igbagu	HL10	7.1	22	1324	753.4	120	25	57.2	16.4	104	98.4	7.3	4.3
11	Rice Farm Well	HL11	7.2	20	1159.8	709.8	135.3	32	60.8	33	107	84.7	6.9	5.7
12	Ofeiyi Oku	HL12	7.3	22	956.7	1126.4	102	41.2	90	36	120	52.6	0.4	BDL
13	Akaeru-lyimagu	HL13	6.9	22	904.8	1014.7	98.6	29	75	38	95.8	123	0.3	0.3
14	Waterworks Area	HL14	7.1	20	845.6	1247.6	1178	33	101.7	18.7	110	13.8	BDL	BDL
15	Achara near Govt. Admin Estate Pond	HL15	6.8	24	1227.4	803.4	202.4	45	48	22	119.6	96.2	7.9	2.7
16	School (primary) well	HL16	7.1	22	975.6	997.7	101.3	42	63	18.7	74.2	205	0.5	0.5
17	Pond near Quarry, Abakaliki	HL17	7.6	20	1198.7	923.4	75.2	22.7	85	44	39.6	306.4	0.8	3.4
18	Pond Near Quarry, Abakaliki	HL18	7.9	19	1334.2	720.3	83.7	31.4	69.3	82.6	43.2	250	3.75	5.8
19	Abia Stream (intermittent)	HL19	7.4	19	1206	850	94.2	32.2	38	25	50	210	3.6	4.6
20	Intermittent Stream Near Quarry, Abakaliki	HL20	7.1	22	1118.6	794	96.8	29.7	47.3	18.3	39.6	115.3	4.7	4.9
21	Limestone Quarry Abakaliki	HL21	8.4	20	1001	1008	68.7	21.8	145.8	100	58.4	70.2	BDL	BDL
22	Intermittent Stream Abia	HL22	7.0	22	997.8	1211.3	88.6	30	43.6	20.2	65.6	35.7	BDL	0.2
23	Near Juju Hill	HL23	7.4	24	1294	620	152.3	32.2	55.8	26.3	121.2	82	5.8	4.4
24	Achi-Stream	HL24	7.6	20	1206.4	680.4	104.8	20.3	67.2	30	86	94.2	5.2	3.9
25	Iyi-Okwu	HL25	7.7	20	1108.7	750.2	97.6	23.6	71.2	32.4	77.8	98.3	3.4	3.5

The bicarbonate (HCO_3) concentration is generally lower than the value for other anions in spite of the presence of calcareous cement in the sandstones and in the lenses of the shales. The range begins from as low as 16.4 mg/l (at the Ndiachi Igbagu hand–dug well) to as high as 100 mg/l at the limestone Quarry (HL 21). Primary sources here may be from atmospheric precipitation and organic matter in the shales. Higher concentration values would have occurred if the waters had been older or in prolonged contact with the carbonates in the area.

The chloride (Cl^{-1} ion) value ranges from 38.6 mg/l (at the Ebonyi River) to 306.4 mg/l in a pond near a Quarry site (HL 17). The chloride ion (Cl^{-}) ion is the principal anion in the area. The origin is also probably marine. Although the chloride ion concentration levels are higher than those of SO^{2-}, the sulphate ion is still significantly close to that of the chloride.

The ionic concentration in meq/l is provided in Table 2. The comparison of different chemical species ions in meq/L has been used to determine the possible origin or genesis of a water composition (Hounslow 1995). A study of the chloride and sodium concentration value show that in several samples (e.g. HL1; HL5; HL6; HL 7; HL8; HL10; HL11; HL12; HL14; HL15; HL22; HL23 and HL24), the value of Na^{+} exceeds that of Cl^{-} which indicates natural softening.

Again the comparison of the sulphate and calcium contents indicate that the sulphate (SO_4^{2-}) ion is generally greater than calcium (Ca^{2+}) in the waters. The inference is that the calcium has been removed or reduced from the waters most likely by natural softening or pyrite oxidation.

The implication of the foregoing is that the chemistry of the groundwater in the shallow, fractured regolith shale aquifer at Abakaliki is established initially by the composition of ancient connate water trapped in the sediments. As the aquifer increasingly is recharged by rainwater, there is a corresponding dilution plus the incipience of important reactions like natural softening and pyrite oxidation.

MICROBIAL STUDIES

The entire twenty-five water samples were also subjected to microbial studies in order to test for levels of fecal contamination and for the presence or absence of common pathogens in the shallow water bodies. Coliform count tests in Table 3 revealed that all sampled water from the area showed high degree of Coliform (i.e. more than 1 per 100 ml). This, according to (Freeze and Cherry 1979) is an indication that all the waters are highly polluted and should never be used without proper treatment.

In checking for pathogens, only *Salmonella Spp*; *E. Coli*; *Streptococcus Spp* and *Pseudomonas Spp* were considered. Samples from HL 4 and HL 17 indicated the presence of *Salmonella Spp* while the rest tested negative for the same pathogen. *E. Coli* usually is a strong indicator of faecal contamination. *E. Coli* is considered dangerous when it gets into the blood stream of humans. *Streptococci* contamination was also indicated for HL1, HL5, HL7, HL10, HL11, HL 142, HL 15, HL18, HL23, HL24 HL25 but tested negative for all other samples. The following samples HL4, HL6, HL9 HL10, HL12, HL13, HL15, HL19, HL 20, HL22, HL23 and HL25) tested positive for *Pseudomonas* contamination while others were free.

The general deduction from the microbial studies show that virtually all the sources of water in the Abakaliki capital city pose grave danger to human health if consumed without serious treatment.

CONCLUSION

Abakaliki groundwater belongs to the Na^{+}- Cl/SO_4^{2-} type with high T.D.S. The pH range is from slightly acidic to slightly alkaline (6.8-8.4). The geochemistry of the waters suggest a possible marine (ancient connate water) origin. Possible reactions / processes include natural softening

Table 2. Chemical characteristics of principal ions in the study area in milliequivalent per litre.

S/N	Location	Water sample	Na^+	Mg^{2+}	Ca^{2+}	HCo_3^-	SO_4^{2-}	Cl^-	Fe	NO_3^-
1	Ntezi Abu	HL1	1.085	0.18	0.21	0.1	0.4	0.352	0.001	0.006
2	Prison/Hospital	HL2	1.02	0.2715	0.185	0.25	0.44	1.325	BDL	0.001
3	Obiagu West	HL3	0.736	0.3505	0.16	0.121	0.452	1.435	0.016	0.012
4	Obiagu Central	HL4	0.663	0.325	0.148	0.099	0.233	1.6	0.022	0.014
5	Igbagu	HL5	0.625	0.16	0.1365	0.201	0.31	0.553	BDL	BDL
6	Abakaliki	HL6	0.71	0.135	0.262	0.087	0.286	0.315	0.003	0.0015
7	Ebonyi River	HL7	0.921	0.42	0.3605	0.41	0.51	0.193	0.024	0.0185
8	Ugbloke	HL8	0.445	0.51	0.425	0.375	0.265	0.385	0.001	0.0125
9	Mgbabor	HL9	0.337	0.47	0.332	0.166	0.193	0.461	0.0005	0.0135
10	Ndiachi Igbagu	HL10	0.6	0.125	0.2865	0.82	0.52	0.492	0.036	0.0125
11	Rice Farm Well	HL11	0.676	0.16	0.304	0.165	0.535	0.423	0.0345	0.0285
12	Ofeiyi Oku	HL12	0.51	0.206	0.45	0.18	0.6	0.263	0.002	BDL
13	Akaeru-lyimagu	HL13	0.493	0.145	0.375	0.19	0.479	0.615	0.0015	0.0015
14	Waterworks Area	HL14	0.589	0.165	0.5085	0.093	0.55	0.069	BDL	BDL
15	Achara near Govt. Admin	HL15	1.012	0.225	0.24	0.11	0.598	0.481	0.0395	0.0135
16	School (primary) well	HL16	0.506	0.21	0.315	0.935	0.371	1.025	0.0025	0.0025
17	Pond near Quarry, Abakaliki	HL17	0.376	0.1135	0.425	0.22	0.198	1.532	0.004	0.017
18	Pond Near Quarry, Abakaliki	HL18	0.418	0.157	0.3465	0.413	0.218	1.25	0.0187	0.029
19	Abia Stream (intermittent)	HL19	0.471	0.161	0.19	0.125	0.25	1.05	0.018	0.023
20	Intermittent Stream Near Quarry, Abakaliki	HL20	0.484	0.1485	0.2365	0.901	0.198	0.576	BDL	0.0245
21	Limestone Quarry Abakaliki	HL21	0.343	0.109	0.229	0.5	0.292	0.359	BDL	BDL
22	Intermittent Stream Abia	HL22	0.443	0.15	0.218	0.101	3.28	0.178	0.029	0.001
23	Near Juju Hill	HL23	0.761	0.161	0.279	0.131	0.606	0.41	0.026	0.022
24	Achi-Stream	HL24	0.524	0.1015	0.336	0.15	0.43	0.471	0.017	0.0195
25	Iyi-Okwu	HL25	0..48 8	0.118	0.356	0.162	0.389	0.491		0.0175

Legend: BDL= Below Detection Limit

(action exchange) and pyrite oxidation in the shales. The presence of pathogens like *Salmonella Spp* and *E. Coli* contamination of entire system makes the waters to be less potable as desired.

In any case, since the elevation of Abakaliki to the status of a capital city has seriously increased its demand for water, it would be wise to consider putting in place a program for recovering, purifying and using the available water from the unconfined, regolith aquifer in the state.

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Table 3. Coliform and pathogen of the waters in the study area.

S/N	Location	Water samples	Coliforms (MPN/100ml)	1 Samonella Spp	2 E. Coli	3 Streptococcus spp	Pseudomonas spp
1	Ntezi Abu	HL1	280	-	+	+	-
2	Prison/Hospital	HL2	< 4	-	+	-	-
3	Obiagu West	HL3	900	+	+	-	-
4	Obiagu Central	HL4	1600	+	+	-	+
5	Igbagu	HL5	17	-	+	+	-
6	Abakaliki	HL6	280	-	+	-	+
7	Ebonyi River	HL7	> 1600	-	+	+	+
8	Ugbloke	HL8	350	-	+	-	-
9	Mgbabor	HL9	350	-	+	-	+
10	Ndiachi Igbagu	HL10	900	-	+	+	+
11	Rice Farm Well	HL11	500	-	+	+	-
12	Ofeiyi Oku	HL12	220	-	+	-	+
13	Akaeru-lyimagu	HL13	240	-	+	-	+
14	Waterworks Area	HL14	<3	-	-	-	-
15	Achara near Govt. Admin	HL15	900	-	+	+	+
16	School (primary) well	HL16	350	-	+	+	-
17	Pond near Quarry, Abakaliki	HL17	1600	+	+	-	-
18	Pond Near Quarry, Abakaliki	HL18	1600	-	+	+	-
19	Abia Stream (intermittent)	HL19	900	-	+	-	+
20	Intermittent Stream Near Quarry, Abakaliki	HL20	500	-	+	-	+
21	Limestone Quarry Abakaliki	HL21	26	-	+	-	-
22	Intermittent Stream Abia	HL22	350	-	+	-	+
23	Near Juju Hill	HL23	900	-	+	+	+
24	Achi-Stream	HL24	900	+	+	+	-
25	Iyi-Okwu	HL25	1600	-	+	+	+

Legend: + = present
- = absent
MPN = most probable number

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