

The Geology of Perched Aquifers and Hydrochemistry of Springs in Nsukka Area, South-Eastern Nigeria

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Abstract
The lithology of perched aquifers in Nsukka consists of laterites, red sands and gravels. The aquifers yield small but significant volumes of water to various hand-dug wells and springs in the area. It was found that they also contribute significantly to the iron enrichment in the spring waters. The spring waters and hand-dug waters are basically acidic. The Eh range is from 109mv to 389mv. The principal ions are Mg^{2+} and HCO_3^- thus yielding a Mg^{2+}-HCO_3 type. While Mg^{2+}/Ca^{2+} ratios indicate that cation exchange reactions help in defining the cation chemistry. The Na^+/Cl^- ratios shows that the aquifers are well flushed.
Keywords: Perched aquifers; springs; iron; ratios; hand-dug wells.

A. INTRODUCTION

Water is essential to all life forms on earth and also for the sustenance of urban centers and cities. The area of study (Nsukka) is a growing urban center that is surrounded by many thickly populated rural communities. Ozoko (1988) and Ezeigbo and Ozoko (1989) delineated two important aquifer systems in the area. These are the shallow, perched aquifer systems within the Nsukka Formation and the deep, unconfined and semi-confined aquifer system within Ajali Formation. This work aims at investigating the geology of perched aquifers in detail with emphasis on the hydrochemistry of springs.

According to Fetter (2001), perched aquifers have been known since the development of hydro geology as a science but they have not been studied in detail. Hamill and Bell (1986) prefer to use the term perched groundwater or perched water table to explain the phenomenon.

A perched aquifer is actually a phenomenon that occurs in the vadose or unsaturated zone. It is a situation where the movement of percolating groundwater is trapped by a lens of less- porous/permeable rock leading to the accumulation of water in the area immediately above the lens or to the horizontal flow of the trapped water towards the edge of the lens. If the edge of the less-permeable lens cuts the ground surface, a spring might issue. Sometimes the accumulated water might be tapped by a shallow well. It is pertinent to point out that all these conditions usually occur well above the main or original water table.

There is a rising interest in understanding the hydrogeology of perched aquifers. Bagtzouglou et al (2000) examined perched aquifers with respect to the recharge dynamics of arid environments. Rains et al (2005) discussed the role of perched aquifers in the recharge and biogeochemistry of vernal pools in California.

Since perched aquifers occur in the unsaturated zone, it is clear that they will impact on the movement of nutrients in the soil zone and on the movement of recharge water down to the water table

B. GEOLOGY AND HYDROGEOLOGIC SETTING

The area of study is situated between latitudes $6^0\,45^I$ and $7^0\,00^0$ N and longitudes $7^0\,15^I$ to $7^0\,30^I$ E. The areas is underlain by three geologic formations which are mainly (from the oldest to the youngest), Mamu Formation, Ajali Formation and Nsukka Formation but the formation of interest here is the Nsukka Formation. Figure 1 shows the geologic map of Nsukka and environs. Mamu Formation consists of mudstones, sandy shales and sandstones with occasional coal seams while Ajali Formation consists of medium to coarse grained, poorly consolidated and cross-bedded Sandstones with subordinate shales and clays. All the perched aquifers are found within the Nsukka Formation which consists of an alternating succession of sandstones, dark shales and sandy shales. All three formations regionally dip 2^0 –5^0 to the NW direction.

An interesting geomorphic characteristic of the study area is that the Nsukka Formation occurs mainly as outliers on the Ajali Sandstone. These outliers of Nsukka form hills while the valleys are underlain by Ajali Formation. Ofomata (1978a) described the shapes of these outliers. These shapes might have an effect on the shapes of the perched water tables. (see Figure 2).

Figure 3 shows the relationship between the perched aquifers and the springs in the study area. Here, the percolating groundwater moves horizontally towards the edge of the lens to issue as a spring. The two types of springs in the area are contact springs and valley springs. Some of the springs issue at the formational contacts between Ajali and Nsukka Formations while others are caused by sandstone-shale unit contacts within the Nsukka Formation. A valley spring issues between Edem and Nrobo towards the eastern part of the area. (see Figure 4 and Table 1). The discharge of most of the springs range from slightly less than 100ml/s and 2 l/s.

A closer examination of the perched aquifers revealed that they consist of laterites, red sands and gravel and that the thickness range from 3m to 40m. They are usually underlain by clays and shales which stop or redirect percolation. Depth to the water in the hand–dug wells range from 1.5m in the rainy season to 5.2m in the dry season periods.

C. HYDROCHEMISTRY

a. Material and Methods

Physio-chemical parameters were measured in the field using a multi-parameter water quality meter (Sanxin, S×75.1 potable pH/ORP/Conductivity, DO meter). The probe was dipped in the water and measurements of pH, temperature, and conductivity were taken.

Samples drawn from hand-dug wells, and springs were then taken. All the samples were collected using 500ml plastic containers which had been previously rinsed with distilled water. Each container was rinsed with the water to be collected after filtration through 0.45ɥm filter paper. Samples were acidified with the 5ml of 10% HNO3. Analytical techniques of the American Public Health Association as described by Clesceri et al (1998) were used for the determination of cation and anion concentrations.

b. Results and discussion

Table 2 shows the physico-chemical properties of the perched groundwater while table 3 displays the concentration values of major elements in the perched groundwater.

Samples from four hand-dug wells and a total of seventeen spring water samples were analyzed. All the concentration values are given in milligram per litre (mg/l) as shown in table 3. Physical quality analysis shows that the color of the perched waters vary from 5 (five) to 30 (thirty) hazen units. Iyi-Ohee (T.T.C, Nsukka), PGW 6 has a yellowish red or brown colour and has the highest hazen unit of 30. Freeze and Cherry (1979) has shown that such colours arise from biochemical reactions involving organic acids (fulvic and humic acids) and iron.

Both fulvic and humic acids are abundant in organic matter. Organic matter is very abundant in all the perched waters but in the case of Iyi-Alumu, Enugu-Ezike (PGW 14), because the water is in direct contact with decaying organic matter.

The pH values for perched waters vary from 3.16 (at Iyi-Alumu, Enugu-Ezike) to 6.0 (hand-dug well, HW4, PGW 20). The redox potential Eh which is a measure of the tendency of the water to oxidize or to reduce dissolve constituents range from 189mv (PGW 12) to 389mv (PGW 14). All the Eh values fall within the positive range and indicate the waters to be reactive. Alkalinity is mainly due to the bicarbonate ion (HCO^-) except at the Ogurugu Shallow well (PG 12) where the carbonate ion $CO3^{2-}$ contributes 36.4% of the total alkalinity.

Sulphate (SO_4^{2-}) values range from 2.0mg/l (PGW 16) to 77mg/l (PGW 12). At Ogurugu Shallow well, an anomalous value of 77mg/l was recorded. High SO_4^{2-} are also known in Iyi-Ajie (PGW 4). Although the major source of SO_4^{2-} in fresh water is gysum, the most probable source of the anion in Nsukka is decaying organic matter. Hem (1989) stated that SO_4^{2-} concentrations exceeding 30ppm imply that the groundwater is in contact with gypsum-bearing rocks. Since there are no reported evaporate deposits in the Nsukka or Ajali Formations and whereas $SO^{2-}4$ is not appreciably affected by absorption of ion-exchange processes, the only remaining possible sources of the sulphate ion would be the reactions arising from the interaction of decaying organic matter, atmospheric precipitation and ferrous sulphides like pyrite.

Chloride concentration varies from 0.71mg/l (PGW 17) to 27mg/l (PGW 12). They are generally low. Hem (1989) has suggested the source of Cl^- ion in groundwater may be known by determining the values of the ionic ratios of Na^+/Cl^- (see Table 4). A ratio of unity implies that the source of the Cl^- may be due to other sources. The ionic ratio calculations given in table 4 shows that most of the perched waters have other sources of chloride other than the common salt (NaCl). The very low chloride value is a sign that the perched aquifers are well flushed and that the chloride (Cl^-) may be due to atmospheric precipitation.

The study of Na/Cl ratios of perched waters indicate that the ratios range from 0.0 to 2.13. Davis and Dewiest (1966) suggest that ratios exceeding unity may be attributed to negative ion exchange where sodium replaces calcium or magnesium in cases where groundwater is in contact with clay minerals. This is the case in Iyi-Agbo (PGW 2), Iyi-Ajie (PGW 4), Iyi-Ohee (PGW 6), Iyi-Oku (PGW 8), Iyi-Ezi (PGW 9), and Ogurugu shallow well (PGW 12), where the Na/Cl ratios exceed the value of one. At the hand-dug wells (HW 1, HW 4 HW 6) and Iyi-Oji, Ibagwa-Ani the Na/Cl ratio is equal to unity. The rest of the perched water have values less than the seawater range (0.876 ± 0.1) which is indicative of the exchange of sodium from the water against magnesium in the aquifer (Table 4). This is an indication of cation exchange reactions in the clay minerals in the host aquifer. Mg/Ca ratios are also given in Table 4. They range from 1.49 for hand-dug well (HW 4, PGW 20) to 16.57 (Iyi-Ikwoka, PGW 10). Hem (1989) has shown that when the Mg/Ca ratio is 0.9, it is indicative of freshwater from silicate aquifers while Davis (1973) suggests that they indicate the admixture of seawater or of brines. From table 4 it is considered that the ratios represent freshwater from a silica rich aquifer. There is no evidence of brines in the area.

Nitrate values vary from 0.7mg/l in Opi, Uhere (PGW 13) and Iyi-Ayata, Okpuje (PGW 17) to 19.1mg/l in hand-dug well, HW 4 (PGW 20), Nsukka.

Atmospheric precipitation provides small initial values of NO^-_3 for the perched water system. They originate from the oxidation of atmospheric nitrogen by electric discharges. Their high content in the perched water bodies is probably due to the oxidation of organic matter by aerobic bacteria in the following sequence: organic matter –NH_3 (gaseous ammonia) –NH^+_4 (ammonium ion) –NO^-_2 (nitrite ion) –NO^-_3 (nitrate ion). The sources of NO^-_3 in the perched water therefore are due to atmospheric precipitation and the decay of organic matter.

An examination of cation concentrations reveals interesting trends. Ca^{2+} varies from 0.0mg/l to 8.02mg/l while $Mg2^+$ ions range from 2.43 to 48.6mg/l. Mg^{2+}/Ca^{2+} ratios for most natural waters are expected to be less than unity.

Sodium (Na^+) values in the perched groundwater range from 0.0mg/l to 22.26mg/l. These are the values in PGW 13, 15, 17, 18 and 12 respectively. K^+ varies from 0.0mg/l (PGW 8, 15, 17, 19 -22) to 55mg/l (PGW 12). The abundance of K^+ ions in some of the perched waters probably indicate that the clay minerals in the aquifers do not absorb K^+ ions but where the clay mineral in the aquifer is of kaolinite composition, a high value of K^+ would be expected.

Total iron content ranges from 0.06mg/l (PGW 2) to 19.0mg/l (PGW 19) which is very high and is due to dissolved ferrous ion (Fe^{2+}) in the water. Hem (1989) states that high concentration of dissolved ferrous iron can occur in solution at sites of either reduction of ferric oxyhydroxides or oxidation of ferrous sulphides. In the case of the oxidation of ferrous sulphides, sulphur is attacked first and then altered to sulphate thus releasing the ferrous iron.

The high iron levels in the waters mainly may be due to the presence of organic matter and subordinately to reduction of ferric oxhydroxides. Most of the waters have the sum of magnesium (Mg^{2+}) and bicarbonate (HCO_3^-) exceeding 50% of the total ionic concentration. This indicates that such waters are magnesium bicarbonate type. Table 5 shows the classification of perched aquifer waters on the basis of major ion percentages.

From table 5 it is clear that Iyi-Asho, Iyi-Ajie, Iyi-Ngwo, Ogurugu shallow well, Iyi-Amila in Ibagwa ani and hand-dug well, HW 1 Nsukka all show variations in their anion concentrations. SO_4^{2-} predominates over HCO_3^- in Iyi-Amila and Ogurugu shallow well and is also the principal anion in HW 1. Iyi-Asho (PGW 3) has a mixed anion population where there is no clear dominant ion between HCO_3^-, Cl^- and SO_4^{2-}. In Iyi-Ajie Cl^- predominates over HCO_3^-.

D. CONCLUSION

These perched aquifers of the Nsukka Formation not only help to recharge various springs in the area but they are also responsible for iron enrichment of the spring waters. This is because they consist of laterites, red sands and gravels. Organic matter is also another important contributor to the overall concentration of iron in the area. Again, the Na^+/Cl- ratio shows the aquifers to be well flushed. The Mg^{2+}/Ca^{2+} indicate that cation exchange reactions might be very important for establishing cation concentrations.

An important reaction within the perched aquifer is the reduction of ferric oxhydroxides which effectively releases more iron into the water.

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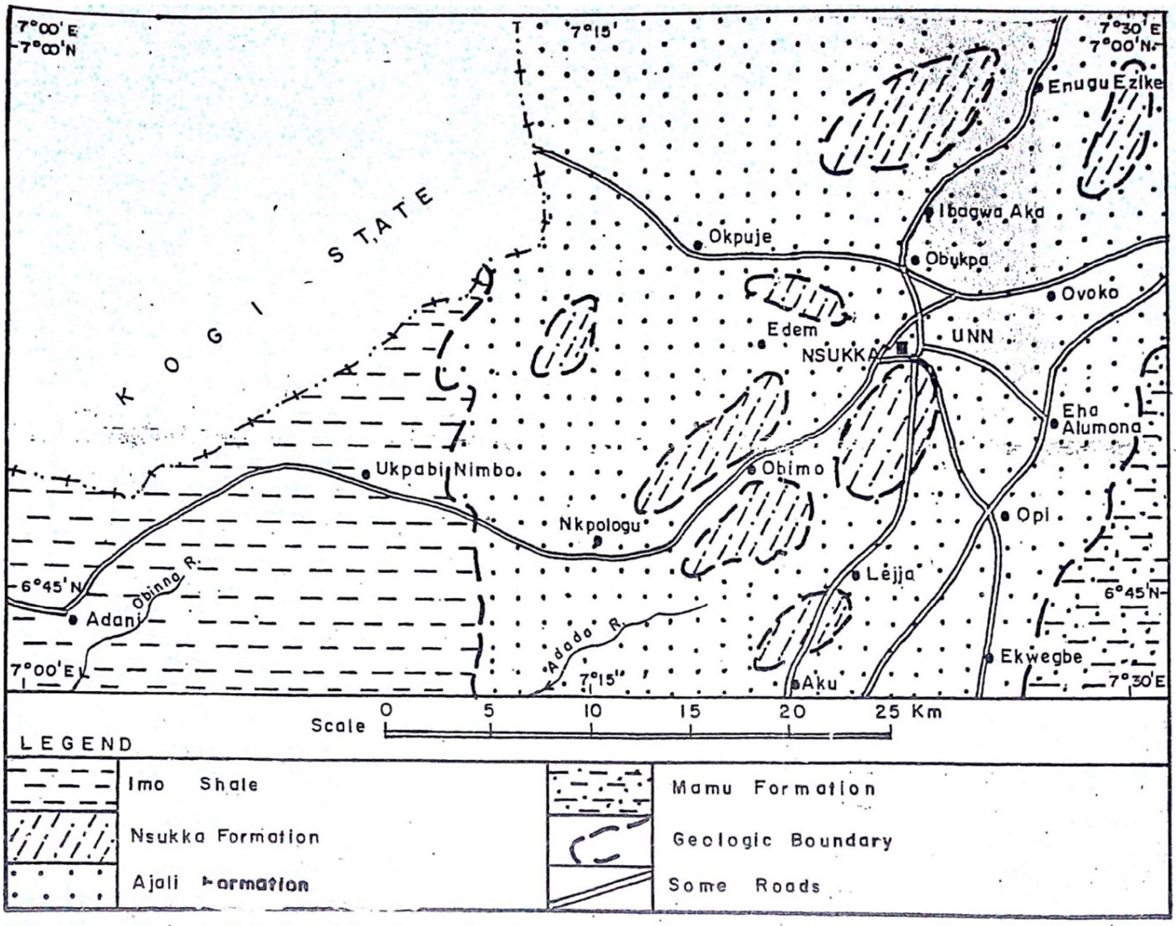

Fig. 1 GEOLOGIC MAP OF THE STUDY AREA.

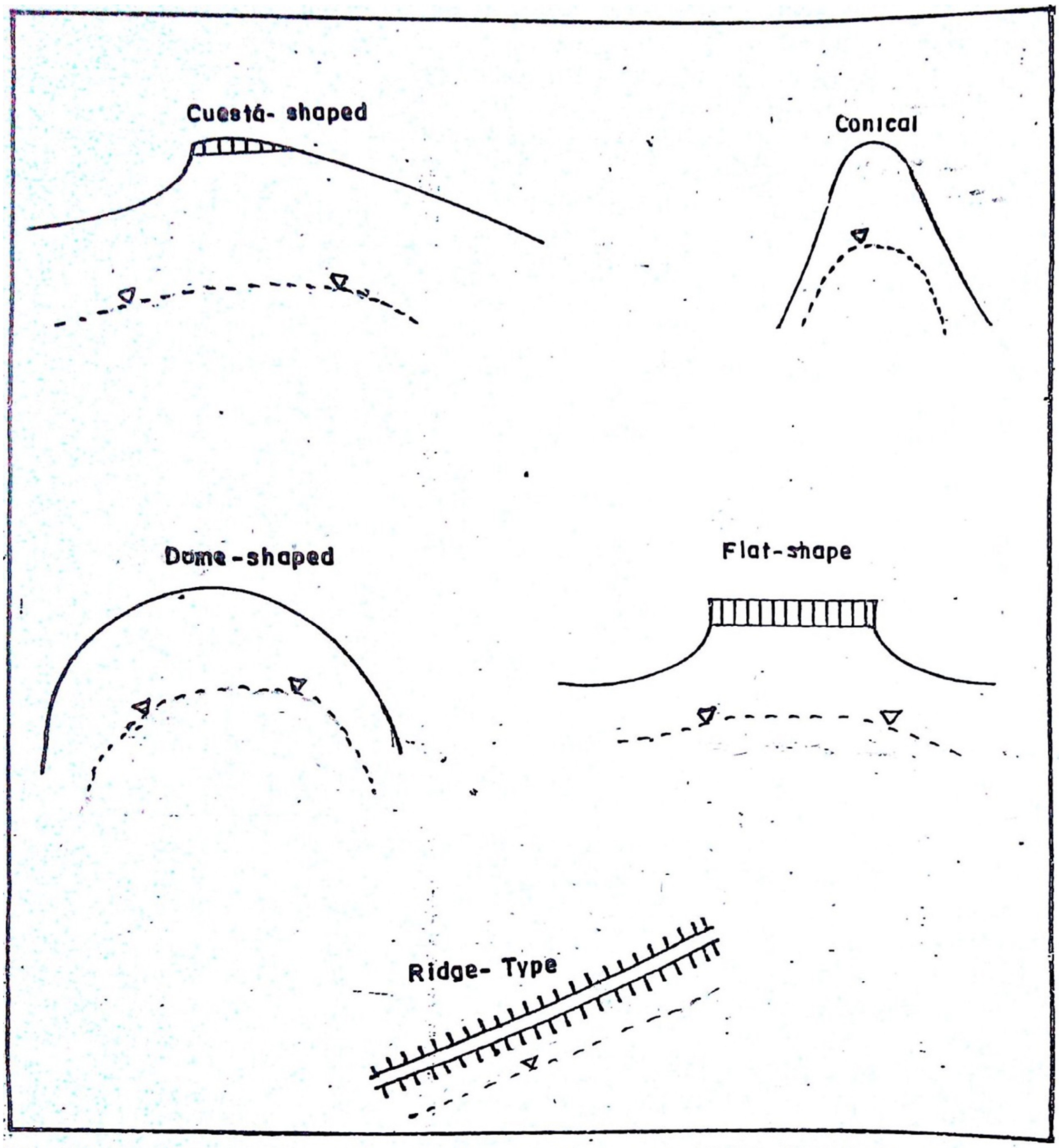

Fig. 2 : SHAPES OF OUTLIERS OF THE NSUKKA FORMATION AND THEIR IMPACT ON THE PERCHED WATER TABLES (Modified from Ofomata, 1978b)

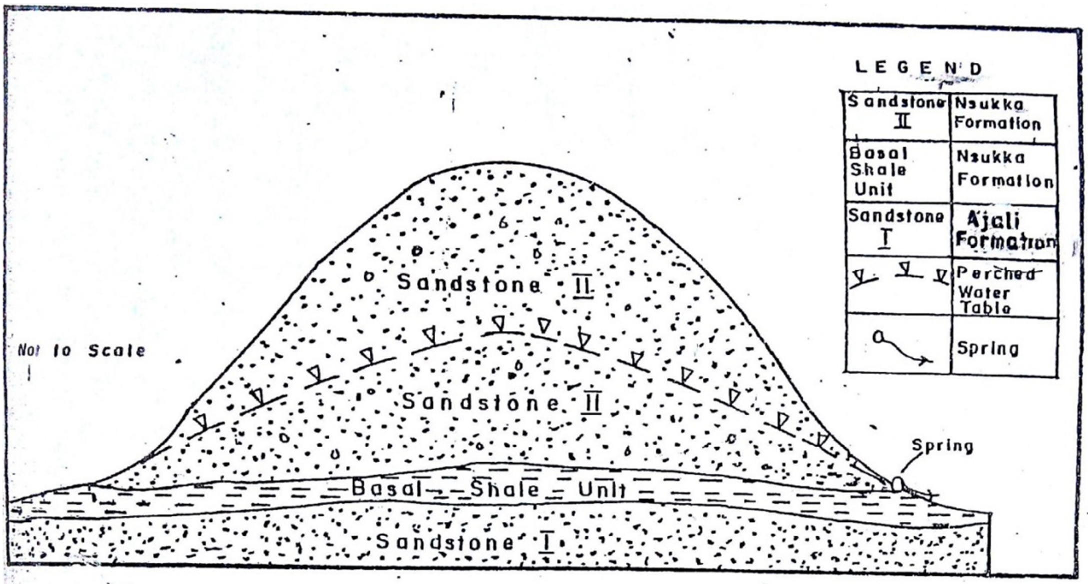

Fig 3 : PERCHED AQUIFER : THEIR RELATIONSHIP WITH SPRINGS:

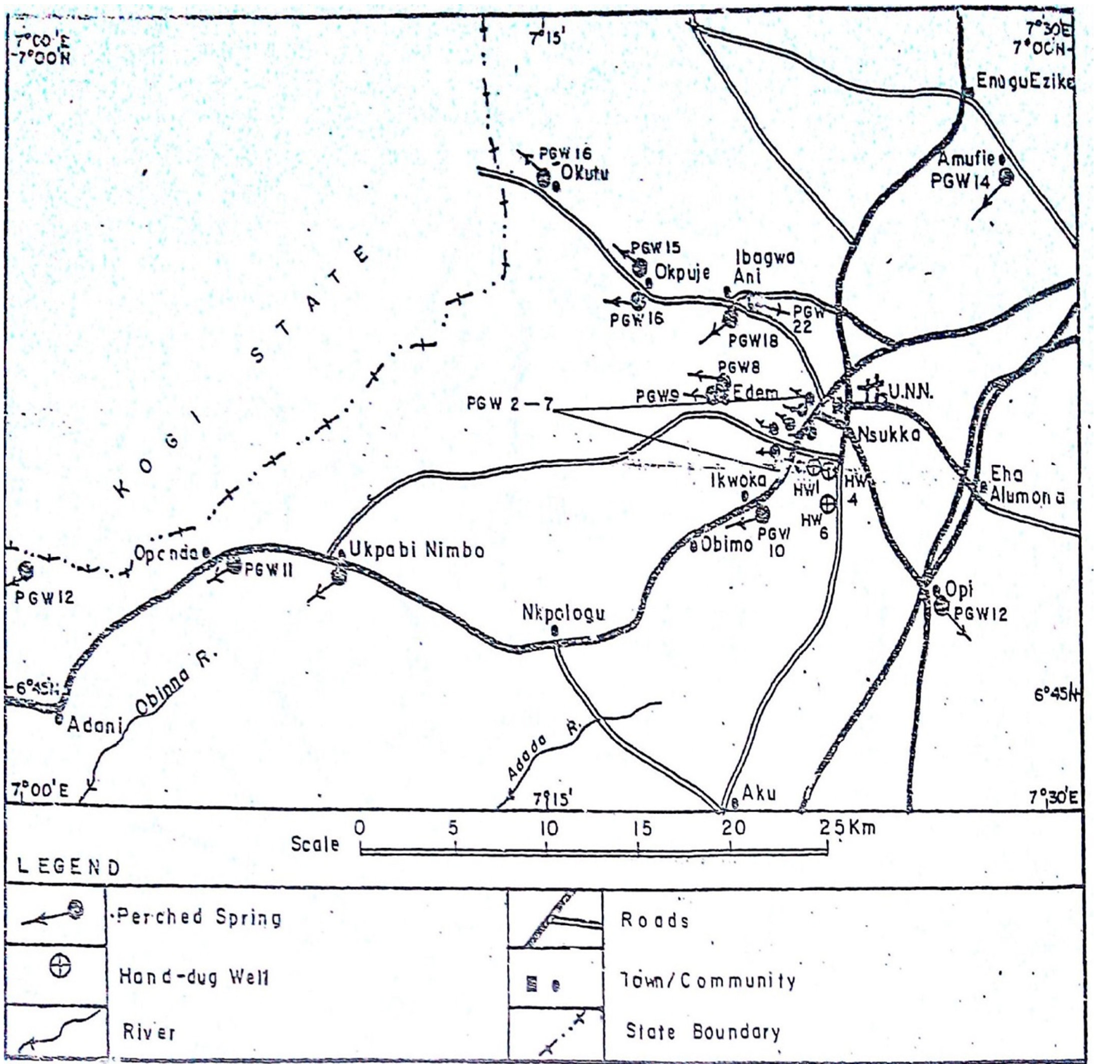

Fig. 4 : LOCATION MAP OF SOME SPRINGS AND HANDDUG WELLS.

TABLE 1: SPRINGS AND HAND-DUG WELL LOCATIONS IN THE AREA.

S/n	Name of spring and location	Spring No	Elevation
1.	Iyi-Agbo, Odoru	PGW 2	360m
2	Iyi-Asho, Onuiyi	PGW 3	396m
3	Iyi-Ajie, Edem	PGW 4	380m
4	Iyi-Ngwo, Edem	PGW 5	390m
5	Iyi-Ohu, T.T.C	PGW 6	390m
6	Iyi-Adaoka, Obimo	PGW 7	378m
7	Iyi-Oku, Edem	PGW 8	390m
8	Iyi-Ezi, Edem	PGW 9	390m
9	Iyi-Ikwoka, Obimo	PGW 10	378m
10	Opanda-Nimbo Well	PGW 11	250m
11	Ogurugu Shallow well	PGW 12	120m
12	Uhere Stream	PGW 13	480m
13	Iyi-Alumu,Enugu-Ezike	PGW 14	300m
14	Iyi-Ezeri, Okpuje	PGW 15	350m
15	Iyi-Okutu, Okutu	PGW 16	350m
16	Iyi-Ayata, Okpuje	PGW 17	350m
17	Iyi-Amila, Ibagwa-Ani	PGW 18	335m
18	Hand-dug well, Anglican Road	HW 1 PGW 19	380m
19	Hand-dug well, Anglican Road	HW 4 PGW 20	380m
20	Hand-dug well, Anglican Road	HW 6 PGW 21	380m
21	Iyi-Oji, Ibagwa-Ani	HW 6 PGW 22	335m

TABLE 2: PHYSICO-CHEMICAL PARAMETERS OF SPRINGS AND HAND-DUG WELLS IN NSUKKA

S/n	Name and location of Spring/Hand dug well	Temp. ^0C	H_2S (aq)	Diss. Oxy	Elect. Cond.	Eh mV	pH
1.	Iyi-Agbo (PGW 2)	26.3	-	6.20	37.5	255	5.05
2	Iyi-Asho (PGW 3)	24.7	1.60	6.40	31.8	295	4.78
3	Iyi-Ajie (PGW 4)	25.6	0.00	4.50	91.3	284	4.30
4	Iyi-Ngwo (PGW 5)	24.6	0.00	5.40	9.2	275	5.56
5	Iyi-Ohee (PGW 6)	26.9	1.20	5.50	41.2	226	4.60
6	Iyi-Adaoka (PGW 7)	25.3	1.00	5.30	7.11	302	4.96
7	Iyi-Oku (PGW 8)	26.2	0.80	5.60	5.1	300	5.38
8	Iyi-Ezi (PGW 9)	28.1	0.00	5.90	7.8	331	5.58
9	Iyi-Ikwoka (PGW 10)	30.0	0.00	4.90	7.3	289	5.76
10	Opanda-Nimbo Spring (PGW 11)	27.3	0.00	5.10	15.8	280	5.75
11	Ogurugu Shallow well (PGW 12)	27.3	0.00	5.70	188.8	189	5.67
12	Uhere Stream Opi (PGW 13)	27.2	0.00	5.90	10.0	243	5.40
13	Iyi-Alumu,Enugu-Ezike (PGW 14)	28.0	0.40	6.80	155.0	389	3.16
14	Iyi-Ezeri, Okpuje (PGW 15)	25.0	0.00	6.20	6.2	298	5.47
15	Iyi-Okutu, (PGW 16)	24.3	0.00	6.20	23.0	261	5.50
16	Iyi-Ayata, Okpuje (PGW 17)	0.71	25.6	0.00	5.00	300	5.4
17	Iyi-Amila, Ibagwa-Ani (PGW 18)	25.3	0.00	2.30	13.5	289	5.15
18	Hand-dug well (HW 1) (PGW 19)	28.3	1.0	-	-	-	6.0
19	Hand-dug well (HW 4) (PGW 20)	27.8	19.10	1.00	-	-	6.00
20	Hand-dug well (HW 6) (PGW 21)	28.5	1.60	-	-	-	5.60
21	Iyi-Oji, Ibagwa-Ani (HW 6) (PGW 22)	26.5	0.4	-	-	-	5.20

TABLE 3: RESULTS OF THE CHEMICAL ANALYSIS OF PERCHED AQUIFER WATERS (IN MILLIGRAM PER LITRE)

S/n	Name and location of (HCO_3^-) SO_4^{2-} NO_3^- Spring/Hand dug well	Ca^{2+}	Mg^{2+}	Na^+	K^+	Fe^{Total}	SiO_2	Cl^-
1.	Iyi-Agbo (PGW 2) 10.00 3.8 9.53	1.60	7.30	5.10	0.50	0.06	0.20	6.00
2	Iyi-Asho (PGW 3) 10.00 7.80 0.25	1.60	7.30	1.00	0.17	1.60	0.40	6.00
3	Iyi-Ajie (PGW 4) 10.00 5.80 3.68	1.60	7.30	11.28	0.50	0.16	0.40	8.00
4	Iyi-Ngwo (PGW 5) 10.00 7.80 2.66	0.00	9.70	0.89	0.33	1.32	0.40	4.00
5	Iyi-Ohee (PGW 6) 20.00 11.60 1.64	2.40	12.20	2.25	1.16	2.87	0.20	2.00
6	Iyi-Adaoka (PGW 7) 16.00 3.80 1.64	0.80	7.30	1.34	0.33	1.60	0.20	3.00
7	Iyi-Oku (PGW 8) 36.00 3.80 1.64	1.60	7.30	1.93	0.00	0.16	0.20	2.00
8	Iyi-Ezi (PGW 9) 84.00 5.80 1.64	1.60	7.30	3.12	0.33	0.16	0.20	3.00
9	Iyi-Ikwoka (PGW 10) 48.00 3.80 1.64	1.60	17.00	2.37	0.33	0.16	0.20	3.00
10	Opanda-Nimbo Spring (PGW 11) 16.00 7.60 2.66	3.20	7.30	0.30	0.17	3.00	0.30	2.00
11	Ogurugu Shallow well (PGW 12) 27.00 70.00 77.00 6.20	3.20	48.60	22.26	55.00	0.36	0.40	
12	Uhere Stream Opi (PGW 13) 30.00 3.80 0.71	1.60	4.90	0.00	0.33	0.16	0.30	2.00
13	Iyi-Alumu,Enugu-Ezike (PGW 14) 46.00 9.60 1.11	1.60	7.30	0.74	0.66	0.80	0.60	3.00
14	Iyi-Ezeri, Okpuje (PGW 15) 20.00 3.80 1.11	1.60	4.90	0.80	6.00	0.36	0.30	1.00
15	Iyi-Okutu, (PGW 16) 54.00 2.00 1.11	1.60	7.30	0.30	0.00	0.60	0.30	2.00
16	Iyi-Ayata, Okpuje (PGW 17) 0.71 36.0 5.80	-	0.80	4.90	0.00	0.00	0.36	0.30
17	Iyi-Amila, Ibagwa-Ani (PGW 18) 24.00 20.00 6.2	2.40	7.30	0.00	0.33	19.00	0.20	2.00
18	Hand-dug well (HW 1) (PGW 19) 58.0 15.60 4.30	4.01	9.73	4.90	-	0.34	1.25	7.50
19	Hand-dug well (HW 4) (PGW 20) 17.49 52.0 17.49 3.80	8.02	7.30	11.30	-	0.06	0.75	
20	Hand-dug well (HW 6) (PGW 21) 53.00 3.80 3.20	6.41	9.13	4.20	-	0.38	0.50	6.50
21	Iyi-Oji, Ibagwa-Ani (HW 6) (PGW 22) 65.00 3.80 1.33	2.40	2.43	3.24	-	0.38	0.30	5.00

TABLE 4: ***Na^{+}/Cl^{-} AND Mg^{2+}/Ca^{2+}*** **RATIOS FOR PERCHED WATER IN NSUKKA AREA.**

S/n	Location	Spring No.	Na/Ca	Mg/Ca
1.	Iyi-Agbo	PGW 2	1.29	7.69
2	Iyi-Asho	PGW 3	0.23	7.69
3	Iyi-Ajie	PGW 4	2.13	7.69
4	Iyi-Ngwo	PGW 5	0.36	-
5	Iyi-Ohee	PGW 6	1.83	8.3
6	Iyi-Adaoka	PGW 7	0.75	14.29
7	Iyi-Oku	PGW 8	1.33	7.69
8	Iyi-Ezi	PGW 9	1.75	7.69
9	Iyi-Ikwoka	PGW 10	1.25	16.67
10	Opanda-Nimbo	PGW 11	0.17	3.70
11	Ogurugu Shallow well	PGW 12	1.28	25
12	Opi-Uhere	PGW 13	0.0	5
13	Enugu-Ezike (Iyi-Alumu)	PGW 14	0.375	7.69
14	Iyi-Ezeri, Okpuje	PGW 15	0.0	10
15	Iyi-Okutu	PGW 16	0.17	7.69
16	Iyi-Ayata, Okpuje	PGW 17	0.0	10
17	Iyi-Amila, Ibagwa-Ani	PGW 18	0.0	5
18	Hand-dug well HW 1	PGW 19	1.0	4
19	Hand-dug well HW 4	PGW 20	1.0	1.49
20	Hand-dug well HW 6	PGW 21	1.0	2.5
21	Iyi-Oji, Ibagwa-Ani	PGW 22	1.0	1.67

*These ratios were calculated from milliequivalents per litre units.

TABLE 5: CLASSIFICATION OF PERCHED/AQUIFER WATERS ON THE BASIS OF THEIR MAJOR ION PERCENTAGES

S/n	Location	Spring No.	Maj. Cation Type	Maj. Anion Type	Remarks
1.	Iyi-Agbo	PGW 2	*Mg^{2+}*	*HCO_3^-*	*Mg^{2+} HCO_3^- type*
2	Iyi-Asho	PGW 3	*Mg^{2+}*	*mixed*	*HCO_3^-, Cl^- and SO_4^{2-} are almost equal*
3	Iyi-Ajie	PGW 4	*Mg^{2+}*	*Cl^-/ HCO_3^-*	*Cl^- Predominates overHCO_3^-*
4	Iyi-Ngwo	PGW 5	*Mg^{2+}*	*HCO_3^-/SO_4^{2-}*	*HCO_3^- predominates over SO_4^{2-}*
5	Iyi-Ohee	PGW 6	*Mg^{2+}*	*HCO_3^-*	*Mg^{2+} HCO_3^- type*
6	Iyi-Adaoka	PGW 7	*Mg^{2+}*	*HCO_3^-*	”
7	Iyi-Oku	PGW 8	*Mg^{2+}*	*HCO_3^-*	”
8	Iyi-Ezi	PGW 9	*Mg^{2+}*	*HCO_3^-*	”
9	Iyi-Ikwoka	PGW 10	*Mg^{2+}*	*HCO_3^-*	”
10	Opanda-Nimbo	PGW 11	*Mg^{2+}*	*HCO_3^-*	”
11	Ogurugu Shallow well	PGW 12	*Mg^{2+}*	*SO_4^{2-}/ HCO_3^-*	*SO_4^{2-} predominatesover HCO_3^-*
12	Opi-Uhere	PGW 13	*Mg^{2+}*	*SO_4^{2-}/ HCO_3^-*	*type*
13	Enugu-Ezike (Iyi-Alumu)	PGW 14	*Mg^{2+}*	*HCO_3^-*	”
14	Iyi-Ezeri, Okpuje	PGW 15	*Mg^{2+}*	*HCO_3^-*	”
15	Iyi-Okutu	PGW 16	*Mg^{2+}*	*HCO_3^-*	”
16	Iyi-Ayata, Okpuje	PGW 17	*Mg^{2+}*	*HCO_3^-*	”
17	Iyi-Amila, Ibagwa-Ani	PGW 18	*Mg^{2+}*	*SO_4^{2-}/ HCO_3^-*	*SO_4^{2-} preominates over HCO_3^-*
18	Hand-dug well HW 1	PGW 19	*Mg^{2+}*	*SO_4^{2-}*	*SO_4^{2-} is the dominant anion*
19	Hand-dug well HW 4	PGW 20	*Mg^{2+}*	*HCO_3^-*	*Mg^{2+} HCO_3^- type*
20	Hand-dug well HW 6	PGW 21	*Mg^{2+}*	*HCO_3^-*	*Mg^{2+} HCO_3^- type*
21	iyi-Oji, Ibagwa-Ani	PGW 22	*Mg^{2+}*	*HCO_3^-*	”