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Assessment of Recharge and Discharge Areas in Abakiliki and Environs Using Hydrologic Parameters in Shallow Wells

B. E. B. Akudinobi[1], P. N. Obasi[2] and O. C. Akakuru[1*]

[1]Department of Geological Science, Nnamdi Azikiwe University, Awka, Nigeria.
[2]Department of Geology, Ebonyi State University, Abakaliki, Nigeria.

Authors' contributions

This work was carried out in collaboration between all authors. Author BEBA designed the study, performed the statistical analysis, wrote the protocol and first draft of the manuscript. Authors PNO and OCA managed the analyses of the study. Authors BEBA and OCA managed the literature searches. All authors read and approved the final manuscript.

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ABSTRACT

This research assessed the recharge and discharge areas in Abakiliki and environs to determine the direction of groundwater movement. Three major stages of procedures were used in this research: data collection, processing, and interpretation. With the aid of a water level indicator, the static water level in hand-dug wells was measured and recorded. The Global positioning system (GPS) was used to measure the longitude, latitude and the surface elevations concerning the mean sea level to the lowest surface of the earth. The surface elevation at different points varied considerably. The data were collected from one hundred and forty-three (143) wells at different locations in the mapped area which are: Kpirikpiri, Abakaliki, Agbaja, ObubraAmachi, Nkwagu, Azuiyiokwu, Ekaeru Inyimagu and were contoured. From the result, groundwater moves from points P1 to P3 with highest hydraulic head or elevation in South of the study area comprising: Abakaliki, Agbaja, and Umuoghara and flows from point D1 to D3 Northeastward of the study area passing through Azuiyiokwu ,Ekaeru - Inyimagu and Ndiechi - Igbeagu. The study recommends among others, that

**Corresponding author: E-mail: obyzmagma@yahoo.com;*

boreholes for potable water supply should be sited in the Southern or Northwestern region of the area, since they are the recharge areas and not within the Northeastern part of the region, since they are the discharge areas; also that dumpsites should be sited within the Northeastern part of the region since contaminant moves in the direction of groundwater flow and not in the Southern or Northwestern part of the regions in order to minimize groundwater contamination by dumpsites.

Keywords: Recharge and discharge areas; shallow wells; hydrologic parameters; water table.

1. INTRODUCTION

Water is of fundamental importance to plants and animals particularly humans. It is very vital in maintaining life processes and growth [1]. Groundwater is commonly understood to mean water occupying all the voids within a geologic stratum [2]. It is not usually static but flows through the rock. The ease with which water can flow through a rock mass depends on a combination of the size of the pores and the degree to which they are inter-connected [3]. Most local groundwater supply in Abakaliki and its environs comes from the fractured shale aquifer. These rocks are very porous but poorly permeable. The depth to water table can be determined by digging a hole progressively deeper into the ground, the depth at which groundwater begins to seep into the hole indicates that the surrounding material is saturated with water and this marks the height of the local water (water table) where there is no surface water [4]. The water table varies in depth according to local topography and prevailing climate.

The depth is established by a long-term balance between recharges despite seasonal climatic fluctuations. The water table is not flat as its name implies. It is the top of the water surface in the saturated part of an aquifer. It has peaks and valleys that echo the shape of the land above it. Groundwater usually flows toward, and eventually drains into stream, rivers, lakes, creeks, ponds and boreholes [5]. The flow of groundwater in aquifer does not always reflect the flow of water on the surface. It is, therefore, necessary to have knowledge of the direction of groundwater flow and take steps to ensure that land use activities in the recharge area will not pose a threat to the quality of the groundwater [6]. Furthermore, it is also important to know if the groundwater system is a recharge or discharge system (gaining type or losing type) because the quality of water is affected by the quality of groundwater entering the system of water supply in the borehole [7]. This is because the water table elevation is approximately the same as the gaining borehole surface elevation; both elevations may be used to construct water table maps (contour) and to predict groundwater flow direction. The need thus arises for this study, to assess the recharge and discharge areas in Abakaliki using shallow wells hydrologic flow parameter. This work is very useful as it will delineate groundwater recharge and discharge areas using the flow direction and groundwater flow pattern to can be used to predict possible movement of hydrological contaminant in the study area.

1.1 Aim and Objectives

This study aims to assess the recharge and discharge areas in Abakiliki and environs using hydrologic (flow) parameters in shallow wells, to achieve this aim, the following objectives were set:

1. To measure the depth from the surface of the earth to the water level in the hand-dug well (Direct Bore hole logging);
2. To measure the surface elevation with respect to the mean sea level and determine the static water level;
3. To determine the direction of groundwater movement in the study area.

2. BRIEF GEOLOGY AND PHYSIOGRAPHY

Geologically, the Abakaliki area is located within the Abakaliki Anticlinorium in the southern tip of the Benue Trough (Reyment, 1965). The area is underlain by Albian Asu River Shale. It composed of shales, mudstone, ironstones and thin beds of limestone and sandstone. The shales vary from dark grey to light grey in colour and are very fissile. The shales are often very hard, calcareous and pyritic. The rocks are extensively fractured, folded and faulted following the Santonian epirogeny which strongly affected the area. This Sontonian event also accounts for the pyroclastics intrusions and mineralization of the area (Kogbe, 1987). The occurrences of these hard rocks and mineralized veins lead to

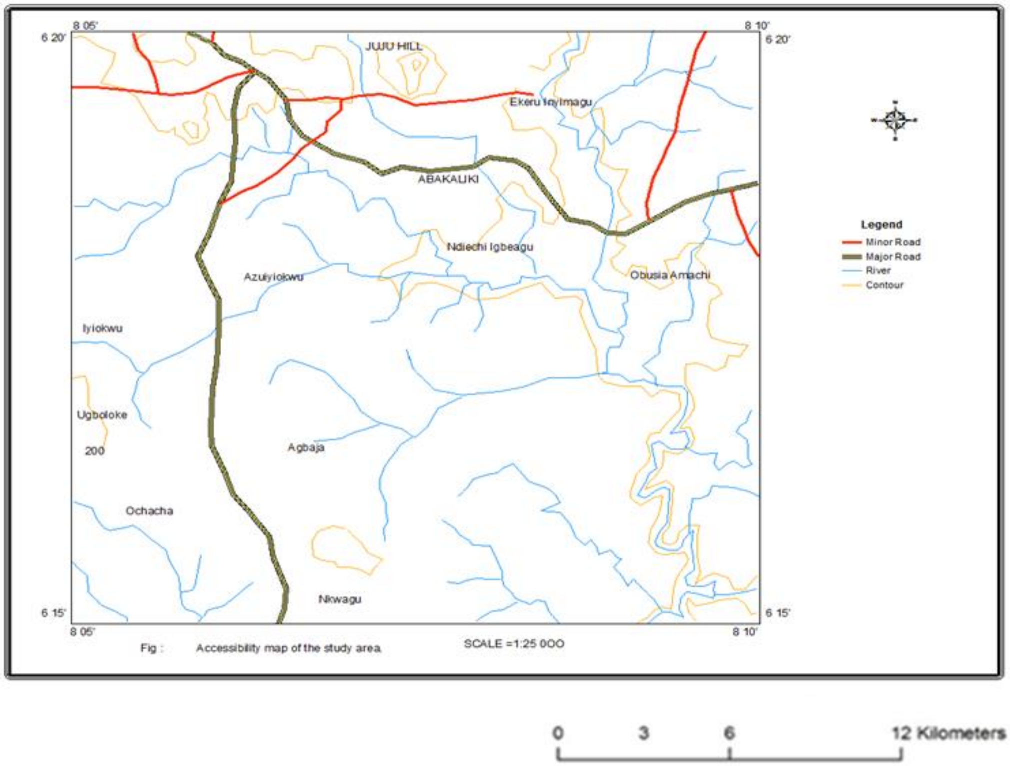

Fig. 1. Map of Abakaliki and its environs showing accessibility and drainage

the establishment of quarries in the area, which in turn has caused serious environmental degradation in the area.

The relief of the area is generally lowland with the Juju hill (about 400 m) as the major relief structure in the area. No trend has been established of these conical shaped hills and other residual hills that spread sporadically within the area [8]. The shale lithofacies has favored the low erodability of the area, resulting in absence or near absence of deep cut valleys and erosion channels. The drainage system of the area is dendritic in pattern, as a function of lithology control. The study area is mainly drained by Iyiokwu River, Iyiudene River and Ebonyi River with few minor drainage flows. All these rivers contribute to the drainage system which flows eastward to join the Cross River (see Fig 1).

3. DETERMINATION OF GROUNDWATER FLOW DIRECTION

3.1 Methodology

The most direct and accurate method of determining the direction of groundwater movement is by measuring the elevation of groundwater at multiple locations over the aerial extent of an aquifer was done during the wet season (between May-July). Three major stages of procedures were used in this research: data collection, processing and interpretation. With the aid of a water level indicator, the static water level in the hand dug wells were measured and recorded. The Global positioning system (GPS) was used to measure the longitude, latitude and the surface elevations with respect to the mean sea level to the lowest surface within the earth. The surface elevation at different point, varied. This uniform water level coincided with static water level in the case of an unconfined aquifer while it was the piezometric surface if the aquifer was confined [9], the contouring was done using Surfer 9.0 software.

Let:

DHDW = depth from the surface level to the water level in the hand-dug well (Direct Bore hole logging)

E = surface elevation with respect to the mean sea level

Swl = true or uniform water level otherwise known as the static water level in the case of an unconfined aquifer

Swl =E - DHDW (1)

The values of the static water levels were contoured on the map of Abakaliki and its environ. These lines represented the water table contours. According to [4], groundwater would flow from the highest values of contour lines to the lowest values in a direction perpendicular to the contour lines.

3.2 Data Collected and Presentation

The data were collected from one hundred and forty three wells on different location in the mapped areas which are Kpirikpiri, Abakaliki, Agbaja, ObubraAmachi, Nkwagu, Azuiyiokwu, Ekaeru Inyimagu. The data are presented below:

Table 1. Static water levels of wells and their locations

S/N	Latitude	Longitude	Water level	Static water level(SWL)
1.	N06^{0}19’51.5”	E008^{0}06’60.1”	2.8 m	72.2m
2.	N06^{0}19’51.1”	E008^{0}05’59.2”	3.41 m	72.6 m
3.	N06^{0}19’50.8”	E008^{0}05’58.7”	6.00 m	74.2 m
4.	N06^{0}19’50.9”	E008^{0}05’58.4”	6.28 m	70.22 m
5.	N06^{0}19’50.3”	E008^{0}05’57.1”	5.73 m	70.27 m
6.	N06^{0}19’51.4”	E008^{0}05’55.9”	4.87 m	72.4 m
7.	N06^{0}19’44.6”	E008^{0}05’26.8”	5.6 m	68.4 m
8.	N06^{0}19’43.9”	E008^{0}05’27.3”	2.74 m	71.1 m
9.	N06^{0}20’14.9”	E008^{0}04’12.0”	5.36 m	79.3 m
10.	N06^{0}16’02.5”	E008^{0}06’21.7”	3.04 m	58.9 m
11.	N06^{0}15’58.7”	E008^{0}06’25.4”	2.1 m	50.8 m
12.	N06^{0}15’52.3”	E008^{0}06’23.4”	4.8 m	54.7m
13.	N06^{0}15’45.3”	E008^{0}06’19.7”	5.1 m	37.7 m
14.	N06^{0}15’43.2”	E008^{0}06’32.4”	4.7 m	57.5 m
15.	N06^{0}15’58.2”	E008^{0}06’27.7”	3.9 m	59.8 m
16.	N06^{0}16’03.4”	E008^{0}06’21.9”	2.3 m	60.2 m
17.	N06^{0}15’27.1”	E008^{0}06’37.8”	3.26 m	50.44 m
18.	N06^{0}15’19.2”	E008^{0}06’34.2”	4.17 m	59.7 m
19.	N06^{0}15’05.7”	E008^{0}06’36.6”	15.2 m	55 m
20.	N06^{0}17’18.1”	E008^{0}05’55.3”	5.9 m	56.2 m
21.	N06^{0}17’28.4”	E008^{0}05’57.9”	7.5 m	64.5 m
22.	N06^{0}17’30.1”	E008^{0}06’02.9”	6.3 m	41.1 m
23.	N06^{0}17’31.4”	E008^{0}06’06.0”	2.1 m	46.5 m
24.	N06^{0}17’32.4”	E008^{0}06’03.8”	3.35 m	39.6 m
25.	N06^{0}17’37.5”	E008^{0}06’03.3”	2.07 m	44.03 m
26.	N06^{0}18’52.1”	E008^{0}06’33.1”	3.9 m	25.9 m
27.	N06^{0}18’52.5”	E008^{0}06’32.7”	3.9 m	44.3 m
28.	N06^{0}18’52.8”	E008^{0}06’32.8”	5.86 m	44.8 m
29.	N06^{0}18’52.8”	E008^{0}06’34.1”	1.9 m	46.3 m
30.	N06^{0}18’56.9”	E008^{0}06’36.3”	1.52 m	53.7 m
31.	N06^{0}18’54.2”	E008^{0}06’37.5”	3.5 m	56.5 m
32.	N06^{0}18’37.8”	E008^{0}06’41.7”	6.1 m	45.9 m
33.	N06^{0}18’34.8”	E008^{0}06’45.3”	2.7 m	48.7 m
34.	N06^{0}18’36.1”	E008^{0}06’44.4”	5.2 m	46 m
35.	N06^{0}18’40.2”	E008^{0}06’47.3”	3.75 m	51.1 m
36.	N06^{0}18’36.7”	E008^{0}06’31.0”	4.2 m	51.9 m
37.	N06^{0}18’45.6”	E008^{0}06’34.4”	1.7 m	44.2 m
38.	N06^{0}18’49.6”	E008^{0}06’35.8”	1.31 m	61.69 m
39.	N06^{0}18’52.5”	E008^{0}06’25.3”	4.6 m	85.4 m
40.	N06^{0}18’54.3”	E008^{0}06’25.4”	3.96 m	51.7 m
41.	N06^{0}18’52.5”	E008^{0}06’23.1”	3.8 m	54.9 m
42.	N06^{0}18’52.2”	E008^{0}06’22.4”	3.8 m	49.3 m
43.	N06^{0}18’51.1”	E008^{0}06’22.1”	3.9 m	39.1 m
44.	N06^{0}18’54.9”	E008^{0}06’20.1”	3.1 m	46.9 m

S/N	Latitude	Longitude	Water level	Static water level(SWL)
45	N06^{0}18'56.9"	E008^{0}06'19.1"	4.4 m	40.9 m
46	N06^{0}18'59.2"	E008^{0}06'20.8"	5.1 m	53.5 m
47	N06^{0}18'58.4"	E008^{0}06'20.1"	5.3 m	49.3 m
48	N06^{0}19'01.4"	E008^{0}06'19.5"	5.4m	53.1 m
49	N06^{0}18'53.9"	E008^{0}06'14.4"	2.1 m	56.4 m
50	N06^{0}18'51.8"	E008^{0}06'17.6"	2.6 m	61.1 m
51	N06^{0}18'51.1"	E008^{0}06'11.1"	3.2 m	46 m
52	N06^{0}18'45.7"	E008^{0}06'15.0"	2.8 m	71.3 m
53	N06^{0}18'30.7"	E008^{0}09'39.3"	4.02 m	48.3 m
54	N06^{0}18'33.8"	E008^{0}09'51.9"	5.7 m	43.3 m
55	N06^{0}18'29.3"	E008^{0}09'53.7"	1.8 m	42.5 m
56	N06^{0}18'41.4"	E008^{0}09'46.5"	7.4 m	38.3 m
57	N06^{0}18'41.6"	E008^{0}09'40.3"	6.5 m	36.5 m
58	N06^{0}18'49.2"	E008^{0}09'49.1"	7.01 m	45.7 m
59	N06^{0}18'93.9"	E008^{0}10'37.2"	8.2 m	45.4 m
60	N06^{0}19'17.3"	E008^{0}10'84.4"	53.3 m	5.7 m
61	N06^{0}19'09.4"	E008^{0}10'64.4"	50.6 m	6.5 m
62	N06^{0}18'97.4"	E008^{0}10'69.3"	9.5 m	51.6 m
63	N06^{0}18'97.9"	E008^{0}10'66.0"	5.6 m	55.4 m
64	N06^{0}19'84.2"	E008^{0}10'77.1"	2.4 m	57.6 m
65	N06^{0}19'94.2"	E008^{0}10'64.7"	3.6m	57.4 m
66	N06^{0}19'97.6"	E008^{0}10'50.6"	4.9 m	57.1 m
67	N06^{0}19'90.1"	E008^{0}10'34.1"	5.1 m	50.7 m
68	N06^{0}19'91.9"	E008^{0}10'17.8"	3.9 m	52.1 m
69	N06^{0}19'91.9"	E008^{0}10'01.9"	6.7 m	50.3 m
70	N06^{0}19'44.5"	E008^{0}09'95.2"	4.9 m	56.5 m
71	N06^{0}19'39.1"	E008^{0}09'83.6"	5.0 m	50 m
72	N06^{0}19'07.9"	E008^{0}09'04.1"	4.17 m	43.1 m
73	N06^{0}19'05.4"	E008^{0}08'58.1"	7.4 m	37.8 m
74	N06^{0}19'14.1"	E008^{0}09'13.2"	6.8 m	31.8 m
75	N06^{0}19'13.5"	E008^{0}09'18.8"	5.3 m	42.3 m
76	N06^{0}19'12.1"	E008^{0}09'18.1"	8.3 m	25.5 m
77	N06^{0}19'11.4"	E008^{0}09'16.2"	6.7 m	34.9 m
78	N06^{0}19'13.1"	E008^{0}09'20.9"	40.4 m	3.6 m
79	N06^{0}19'10.3"	E008^{0}09'20.0"	7.8 m	36.3 m
80	N06^{0}19'10.2"	E008^{0}09'18.9"	39.5 m	5.06 m
81	N06^{0}19'10.6"	E008^{0}09'15.3"	4.5 m	42.5 m
82	N06^{0}19'38.3"	E008^{0}07'07.8"	2.8 m	74.3 m
83	N06^{0}20'00.1"	E008^{0}07'05.1"	1.4 m	48.4 m
84	N06^{0}20'05.5"	E008^{0}07'08.9"	2.1 m	59 m
85	N06^{0}19'38.1"	E008^{0}07'08.6"	2.8 m	61.1 m
86	N06^{0}19'37.8"	E008^{0}07'09.2"	5.3 m	77.5 m
87	N06^{0}19'39.6"	E008^{0}07'10.5"	3.2 m	66.8 m
88	N06^{0}19'39.5"	E008^{0}07'12.9"	3.8 m	68.5 m
89	N06^{0}19'39.6"	E008^{0}07'10.5"	3.6 m	40 m
90	N06^{0}19'47.3"	E008^{0}07'08.3"	6.8 m	48.2 m
91	N06^{0}19'53.0"	E008^{0}07'15.3"	1.7 m	75.7 m
92	N06^{0}19'49.3"	E008^{0}07'15.7"	5.9 m	62.6 m
93	N06^{0}19'47.2"	E008^{0}07'15.9"	7.4 m	83.7 m
94	N06^{0}19'43.4"	E008^{0}07'15.7"	4.8 m	77 m
95	N06^{0}19'34.8"	E008^{0}07'08.6"	3.4 m	60.6 m
96	N06^{0}19'33.0"	E008^{0}06'57.3"	3.1 m	55.5 m
97	N06^{0}19'35.7"	E008^{0}06'56.9"	4.9 m	63.2 m
98	N06^{0}19'35.6"	E008^{0}06'57.2"	6.0 m	60.2 m
99	N06^{0}19'38.6"	E008^{0}06'56.6"	2.2 m	61.7 m
100	N06^{0}19'39.2"	E008^{0}06'56.9"	1.7 m	71.3 m

S/N	Latitude	Longitude	Water level	Static water level(SWL)
101	N06^{0}19’36.4”	E008^{0}06’43.2”	1.7 m	65.3 m
102	N06^{0}19’37.0”	E008^{0}06’54.2”	3.3 m	61.8 m
103	N06^{0}19’35.3”	E008^{0}06’45.3”	2.2 m	61.6 m
104	N06^{0}19’34.2”	E008^{0}06’40.1”	2.6 m	70.3 m
105	N06^{0}19’33.2”	E008^{0}06’41.2”	6.4 m	57.1 m
106	N06^{0}19’32.9”	E008^{0}06’29.2”	5.8 m	59.3 m
107	N06^{0}19’36.5”	E008^{0}06’51.2”	3.9 m	55.8 m
108	N06^{0}19’38.6”	E008^{0}06’50.3”	4.7 m	74.7 m
109	N06^{0}19’36.0”	E008^{0}06’50.8”	2.6 m	68.8 m
110	N06^{0}19’51.7”	E008^{0}06’54.3”	7.1 m	75.8 m
111	N06^{0}19’54.4”	E008^{0}06’52.6”	9.7 m	69.7 m
112	N06^{0}18’24.9”	E008^{0}06’01.0”	5.1 m	50.1 m
113	N06^{0}18’26.1”	E008^{0}06’00.2”	3.9 m	61 m
114	N06^{0}18’28.1”	E008^{0}06’00.4”	4.4 m	59.4 m
115	N06^{0}18’27.8”	E008^{0}06’01.0”	7.4 m	65.6 m
116	N06^{0}18’27.8”	E008^{0}05’59.3”	4.3 m	64.2 m
117	N06^{0}18’27.1”	E008^{0}05’59.4”	3.6 m	69.6 m
118	N06^{0}18’26.5”	E008^{0}05’57.1”	2.8 m	57.6 m
119	N06^{0}18’25.5”	E008^{0}05’57.8”	5.1 m	63.7 m
120	N06^{0}18’22.4”	E008^{0}05’55.1”	7.1 m	69.9 m
121	N06^{0}18’23.5”	E008^{0}05’54.7”	6.2 m	58.9 m
122	N06^{0}18’25.1”	E008^{0}05’51.0”	4.3 m	58.3 m
123	N06^{0}18’25.8”	E008^{0}05’50.3”	4.8 m	36.4 m
124	N06^{0}18’23.2”	E008^{0}05’47.3”	4.8 m	75.9 m
125	N06^{0}18’18.3”	E008^{0}05’46.5”	3.96 m	45.3 m
126	N06^{0}18’14.0”	E008^{0}05’44.7”	6.3 m	63 m
127	N06^{0}18’10.8”	E008^{0}05’41.8”	6.7 m	59.6 m
128	N06^{0}18’09.2”	E008^{0}05’42.1”	7.5 m	58 m
129	N06^{0}18’10.2”	E008^{0}05’43.5”	5.9 m	72.8 m
130	N06^{0}18’07.3”	E008^{0}05’41.2”	6.7 m	70.8 m
131	N06^{0}19’50.3”	E008^{0}04’52.1”	2.2 m	38.9 m
132	N06^{0}19’49.3”	E008^{0}04’51.1”	2.4 m	69.9 m
133	N06^{0}19’51.7”	E008^{0}04’50.2”	2.1 m	78.5 m
134	N06^{0}19’48.8”	E008^{0}04’49.3”	1.5 m	77 m
135	N06^{0}19’57.9”	E008^{0}04’59.9”	3.4 m	73.9 m
136	N06^{0}19’46.7”	E008^{0}04’50.9”	4.2 m	74.7 m
137	N06^{0}19’05.6”	E008^{0}09’21.9”	10.5 m	48.4 m
138	N06^{0}19’14.4”	E008^{0}09’12.8”	7.4 m	45.9 m
139	N06^{0}19’00.9”	E008^{0}09’11.7”	7.01 m	46 m
140	N06^{0}18’92.1”	E008^{0}09’24.1”	8.3 m	42.7 m
141	N06^{0}18’70.2”	E008^{0}09’15.2”	5.3 m	40.7 m
142	N06^{0}18’44.4”	E008^{0}09’05.6”	4.2 m	43.8 m
143	N06^{0}18’42.6”	E008^{0}08’98.5”	4.5 m	42.5 m

4. RESULT

Measurements were plotted on a map of the area and lines are drawn to connect points of equal elevation. These lines represent equal pressure between connected points and are called equipotential lines. The equipotential lines and map together are called an equipotential surface map. Groundwater moves along a flowpath perpendicular to equipotential lines and the direction of movement is from lines of higher value to lines of lower value (i.e., higher to lower elevation or pressure). Groundwater flow paths are usually shown by arrows on equipotential surface maps pointing in the direction of groundwater flow as in Fig. 2.

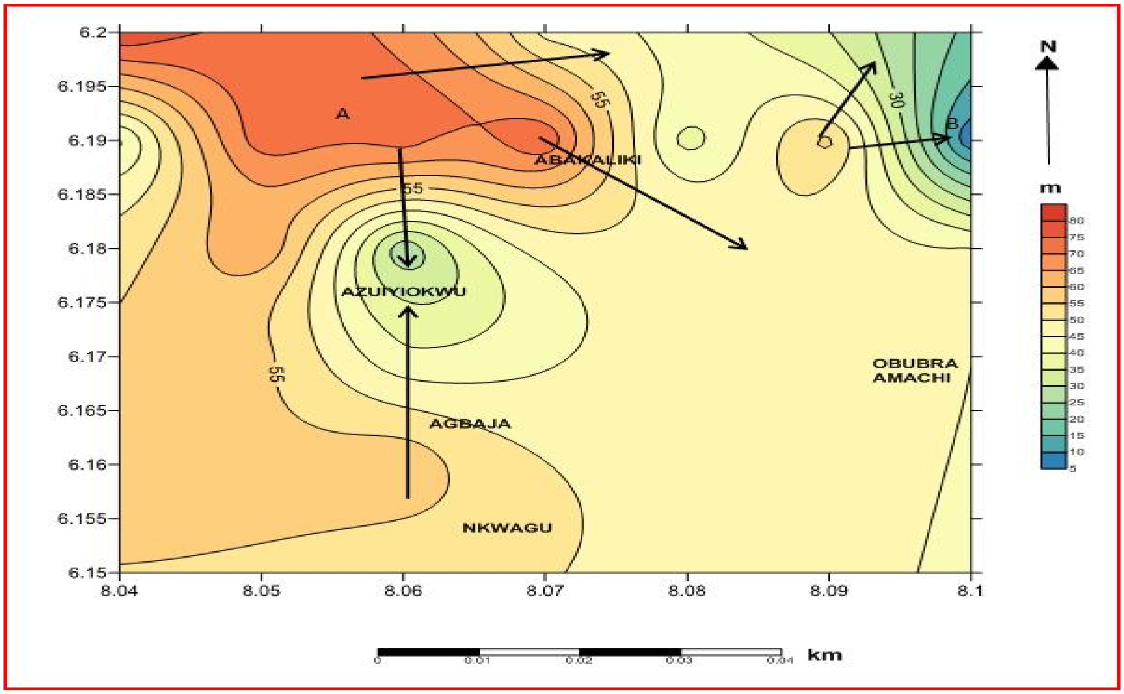

Fig. 2. Contoured static water level map of Abakaliki and its environs showing groundwater flow direction (A-Recharge, B-Discharge)

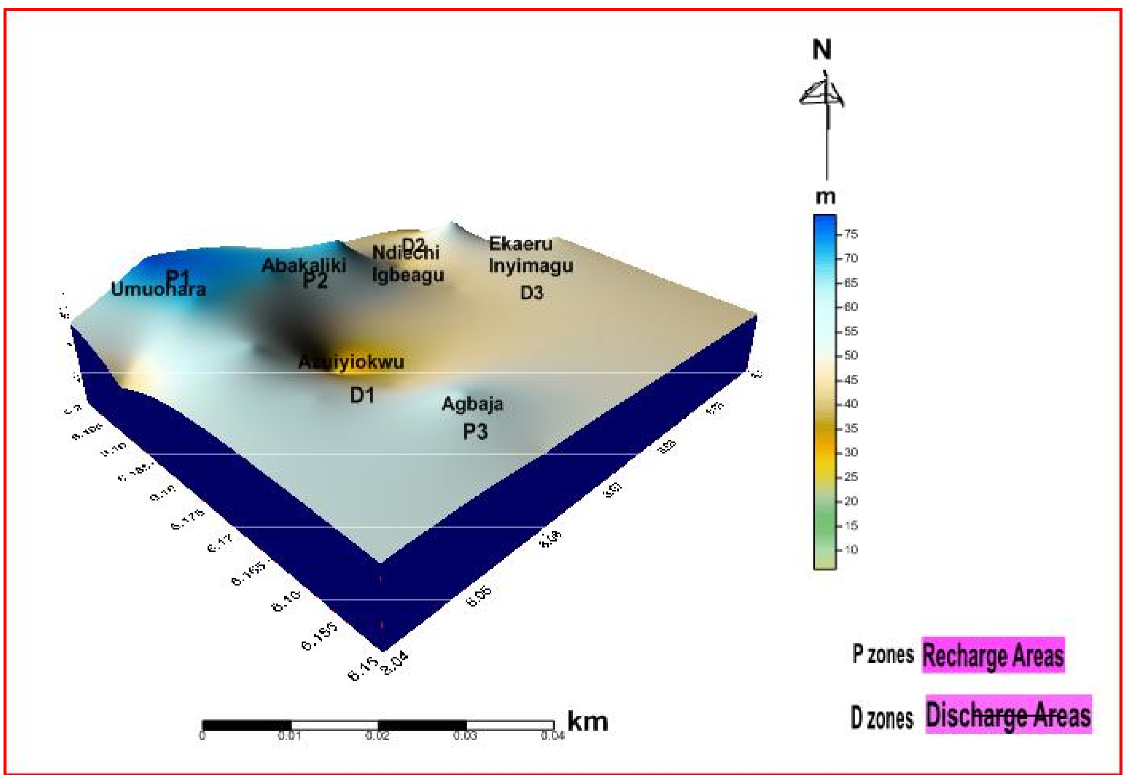

Fig. 3. 3D Contoured static water level map of Abakaliki and its environs showing Groundwater flow direction

5. DISCUSSION AND INTERPRETATION

Groundwater movement follows two main rules: first, ground water flows from higher hydraulic head to lower hydraulic head; second, the direction of groundwater flow is perpendicular to contour lines [10]. The distribution of hydraulic heads in the saturated zone determines the direction in which the water will flow [11]. As shown in Fig. 2 and Fig. 3, groundwater moves from points P1 to P3 with highest hydraulic head or elevation in south of the study Area in encompassing Abakaliki, Agbaja and Umuoghara and flows from point D1 to D3 northeastward of the study area passing through Azuiyiokwu, Ekaeru – Inyimagu, and Ndiechi - Igbeagu. The groundwater flow is perpendicular to the contour lines west to southwest of the study area. Studies have shown that groundwater moves down from the recharge areas to discharge areas. This is applicable in the Southern parts of the area as they form the recharge areas while the Northern part forms the discharge area.

6. CONCLUSION AND RECOMMENDATIONS

The water elevation contour map of Abakaliki and it's environ revealed that groundwater flow direction is from Umuoghara, Agbaja and Abakaliki (which are the recharge area and are located in the South and Northwestern part of the region) to Azuiyiowu, Ekaeru - Inyimagu and Ndiechi - Igbeagu located in the Northeastern part of the region (which are the discharge areas). Based on the flow pattern of the aquifer system, it was therefore recommended that:

1. dumpsites should be sited within the Northeastern part of the region since contaminant moves in the direction of groundwater flow and not in the Southern or Northwestern part of the regions in order to minimize groundwater contamination by dumpsites;
2. borehole for potable water supply should be sited in the Southern or Northwestern region of the area since they are the recharge areas and not within the Northeastern part of the region since they are the discharge areas;
3. an operating agency with adequate power should be available to manage groundwater recharge sites so as to provide quality and adequate water for public supply; and
4. detailed management studies should be done in areas like Abakaliki, Agbaja and Umuohara in order to formulate the most economic plan for operating groundwater basin in coordination with surface water storage and transmission facilities to meet the growing and fluctuating water demands of the area; to conserve the maximum amount of locally available water; and minimize the undesirable effects of overdraft.

COMPETING INTERESTS

Authors have declared that no competing interests exist.

REFERENCES

1. Akakuru OC, BEB Akudinobi. Qualitative characterization of groundwater sources around Nigeria national petroleum cooperation oil depot Aba, using multiple linear regressions modelling. Int. J. Adv. Geosci. 2018;6:57-64.
2. Akakuru O, Akudinobi B, Okoroafor P, Maduka E. Application of geographic information system in the hydrochemical evaluation of groundwater in parts of Eastern Niger Delta Nigeria. Am. J. Environ. Policy Manage. 2017;3:39-45.
3. Oseji JO. Thermal gradient in vicinity of kwale/okpai gas plant, Delta State, Nigeria. Preliminary Observations. The Environmentalist, Springer Science + Business Media. 2007;27:311–314.
4. Deborah chapman water quality assessment. UNESCO/WHO/UNEP; 1996.
5. Neilson DM. Ground water monitoring. Lewis Publishers, Chelsea, Michigan. 1991;717.
6. Buddermeier RW, Schloos JA. Groundwater Storage and Flow; 2000.
7. Freeze RA, Cherry JA. Groundwater" Prentice-Hall, Englewood cliffs New Jersey. 2002;604.
8. Shwille, F. Groundwater pollution in porous media by fluids immiscible with water. Quality of Groundwater, Proceedings of an International Symposium. Langley R.B. "Why is the GPS Signal so Complex" GPS world. 2000;1(3):56-59.
9. Shanker RK. Selected chapters in geology. Shell petroleum development company, Warri. 1994;10–148.

10. Huisman L. Groundwater in Deltas in scientific problems of the humid tropical zone Deltas and their implications Pro. Dacca Symp. 1966;157-168.

11. Ofoegbu CO, Amajor LC. A geochemical comparison of the pyroclastic rocks from Abakaliki and Ezillo, southeastern Benue Trough, Nigeria. J Min Geol. 1987;23(1-2): 45-52.

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