HYDROGEOPHYSICAL INVESTIGATION OF THE AQUIFERS OF BRINE FIELD OF AWE AND ENVIRONS, CENTRAL BENUE TROUGH, NIGERIA.

Nuhu Degree Umar[1], Ibrahim Giza Idris[1], Aliyu Itari Abdullahi[1],

[1] Department of Geology, University of Nigeria, Nsukka

Corresponding Author

Ibrahim Giza Idris,

Email: ibgza396@gmail.com

Phone: (+234) 803 414 327 6

Abstract

Geophysical investigations, mainly vertical electrical sounding (VES) using Schlumberger electrode configuration array were performed at 21 locations across the study area. Results of the VES revealed that the study area is characterized by 3, 4 and 5 geo-electrical layers with 9 different curve type signatures. Also, results of the VES show that Awe area has the highest occurrence of saline zone within the central Benue Trough, compared to Keana and Giza saline zones. The study area showed that the saline zones are multi – layered and are characterized by a steep descent from the non-saline to the saline layers. This decrease could be attributed to increase in porosity, hydraulic conductivity, fluid content, and most possibly a high conductivity arising from saline water intrusion. The aquifer protective capacity map of the study area revealed that approximately 40% of the area are covered by poor to weak aquifer protective capacity zone, making the area vulnerable to surface contamination while 60% have moderate to good protective capacities, this area will retard infiltration and minimize surface polluting fluid into the aquifer unit.

Keywords: Awe; Saline Zone; Aquifer; VES; Geo-electric layers; Central Benue Trough

Introduction

Brine is saline or salty water, particularly a highly concentrated solution of common salt (sodium chloride). Naturally, brine occurs as an underground salt lake and is a one of the commercially important source of common salt in the world (Leford and Jacoby, 1983). Saltwater intrusion into aquifers has become a major concern in most of the area around brine fields because it constitutes the commonest of all the pollutants in freshwater (Adeoti et al., 2010). The presence of brine constitutes a serious hydrogeological problem on groundwater. Therefore, understanding of the point of saline intrusion is essential for the management of groundwater in such areas.

The situation analysis of most of the communities within and around the area indicate that portable water supply to the inhabitants of this area has been a very serious problem because of it saltiness due to saltwater intrusion into the aquifers. Therefore, there is the urgent need to formulate sustainable solution to redress the water supply situation. As surface water is exposed to several kinds of contaminations, groundwater remains the only reliable source of water supply that could be developed in response to the established problems.

Electrical resistivity survey, a geophysical survey technique was chosen for this work because it has been proven to be quick and effective for most groundwater and pollution studies in different parts of the world (Loke, 2000). The method can be used to determine the nature, geometry and the thickness of the geological formation (Telford et al 1977 and Oteri, 1988). It has the advantage of non-destructive effect on the environment, cost effective, rapid and quick survey time and less ambiguity interpretations of results when compared to other geophysical survey methods (Todd, 1980).

Many researchers have used the VES technique for groundwater exploration (Anudu et.al 2011), geotechnical investigations (Akintorinwa & Adeusi 2009; Oyedele & Bankole 2009; Fadele, Jatau & Umbughadu 2012; Maduka et. al. 2016; Ameh, Igwe & Ukah 2017; Idris & Igwe 2018), and environmental hazards (Igwe & Egbueri 2018). However, this research will employ the technique for the delineation of saline zone of the aquifers of Awe, and determine the aquifers protective capacity (APC) in order to ascertain its vulnerability to contamination.

2.0 The study area

2.1 Location and climate

Awe is the headquarters of Awe local government area located in the south-eastern part of present Nasarawa state in north-central Nigeria. It lies between longitude 9° 07'E - 9° 09'E and latitude 8° 06'N - 8° 08'N (Fig. 1). The study area is generally accessible through the Lafia-Obi-Awe Trunk A road with some tarred feeder roads and footpaths.

2.2 Physiology and climate

The landforms within the study area include hills, valleys and plains. The hills correspond to outcrops of highly ferrogenised lateritic and sandstone caps that have resisted weathering with elevation ranging from 115m – 165m above mean sea level. They are drained by minor tributaries of the River Benue such as Rivers Tunga, Giza and Keana. The drainage system shows a dendritic pattern generally controlled by the topography and lineaments (where relatively homogeneous rocks have the same resistance to erosion), with minor seasonal stream channels and joining up with major streams in the valleys.

The climatic condition in Awe is made up of two (2) major and distinct seasons: a wet season which usually lasts from March to October and a dry season which lasts from November to February. The annual average rainfall ranges between 1000mm and 1500mm while the mean annual humidity is 70% and relative humidity between 60% and 80%. The annual average temperature is 28.5^0C with annual average sunshine hour of 6.7 per day. A high temperature of 33^0C – 36^0C is experienced in the area during the dry season (Iloeje, 1981).

2.3 Geology

Awe and environs falls within the Cenral Benue Trough, Nigeria and are underlain by the following geological sequence: Asu River Group, Ezeaku, Keana, Awe and Awgu Formations and finally the Lafia sandstone, the youngest. The sedimentary formations listed above are underlain by the Basement Complex rocks of Precambrian age. Detailed discussions on the geology of the area have been presented by many authors notably Offodile (1976, 1983 and 2002), Uma (2003), Nwajide (1990), Obaje (1994), Obaje et al (2006).

2.4 Hydrogeology

Awe area is known to have very difficult hydrogeological situations. These conditions arise from the fact that most of the potential aquifers are either limited in extent, thinly developed with consistent clay and shale interbeddings or even highly indurated that only places with the development of secondary voids created by fractures, joints and solutions channels can attract hydrogeological interest. The stratigraphic sequence shows that the areas are made up of alternate shale and sandstone horizons which are suspected to correspond to the sources of the saline and freshwater respectively.

3.0 Materials and methods

A total of twenty-one (21) vertical electrical sounding (VES) were carried out in the study area. The Schlumberger configuration was adopted with a half current electrode spread (AB/2) of 100m while the half potential electrode separation (MN/2) was maintained between 0.5 and 7.5m using ALLIED OMEGA SAS 300C model Terrameter and its accessories. The VES curves were quantitatively interpreted by partial curve matching and computer iteration techniques based on linear filter theory using IPI2win computer software. The apparent resistivity was computed using equation:

$$\rho a = \frac{\pi L^2}{2l} R = GR \qquad (1)$$

Where,

ρa *is apparent resistivity*

π is $\frac{22}{7}$

G = $\frac{\pi L^2}{2l}$ is geometric factor

R = $\frac{\Delta v}{I}$ is the resistance

L = $\frac{AB}{2}$ is the half current electrodes separation and

L = $\frac{MN}{2}$ is the half potential electrodes separation

The apparent resistivity values obtained from Equation (1) were plotted on bi-log graph against the half current electrode separation spacing. From these plots, qualitative deductions such as the resistivity of the first or top layer, the depth of each layer and the curve signatures or types were made. The initial quantitative interpretations were made using partial curve matching technique in which the field curves produced or generated were matched segment by segment with the appropriate master curves and auxiliary curves. The resistivity and thicknesses of the various layers were improved upon by employing an automatic iterative computer program following the main ideas of Zohdy and Martin (1993). The IPI2win computer software was employed for carrying out the iteration and inversion processes. Each iteration process was conducted for each sounding station until the root mean square (RMS) error of lower than 5% was obtained .

According to Telford et al., (1977) and Philip et al., (1996) the electrical resistivity contrasts existing between lithological sequences in subsurface are often adequate to enable the delineation of geo-electric layers and identification of saline and non-saline layers. In this study, VES locations with no saline layer is designated as having salinity rating of 1 while layers with one, two or three saline layers are designated as having two, three or four salinity rating respectively. Aquifer protective capacity (APC) is the ability of the overburden unit to retard and filter percolating surface polluting fluid into the aquifer unit. Longitudinal conductance (the second order geo-electric parameter) was used to evaluate the APC of each area. Longitudinal conductance had been calculated from the thickness and resistivity (the primary/first order parameters) of the geo-electric subsurface layer in each of the VES station using the relation (Zohdy et al., 1974).

$$S_T = \sum_{i=1}^{n} \frac{h_i}{\rho_i} \quad \ldots\ldots\ldots\ldots\ldots \quad (2)$$

Where

S_T = total longitudinal conductance of the overburden,

ρ_i = layer resistivity,

ISSN 2229-5518

h_i = layer thickness

n = number of layers.

4.0 RESULTS AND DISCUSSION

4.1 Geo-electric characteristics

Table 1 presents the summary of the interpreted electrical resistivity survey. The geo-electric section revealed that the area is characterized by 3- to 6-geo-electric subsurface layers. Eight traverses connecting the twenty VES points were covered and their subsurface geo-electric sections are presented in figure 2. From the figure, the geo-electric subsurface section ranged from 3 to 6 layers with 4-layer type occurring more. The 3-layer geo-electric section is characterized by H curve type (Figure 1a) and is generally made up of top loose soil, laterite/clay and fresh basement rock from top to bottom with varying thicknesses.

Table 2 summarizes the various curve types in the study areas, their frequencies of occurrence and percentages while the classification of the various curve types are as presented in Table 3. The 3-geo-electric subsurface layers are defined by two (2) curve types, namely H-type curve and Q-type curve (Figure 1a). The 4-geoelectric subsurface layers are defined by HK- type curve (Figure 1b), KH- type curve, HA-type curve and QH – type curve. The 5-geo-electric subsurface layers are characterized by HKH – type curve (Figure 1c).

N	1	2	3	4	5
ρ	126.9	480.9	507	43.84	11.5
h	0.2327	0.3517	0.09127	1.843	
d	0.2327	0.5844	0.6757	2.519	
Alt	-0.2327	-0.5844	0.67567	-2.5187	

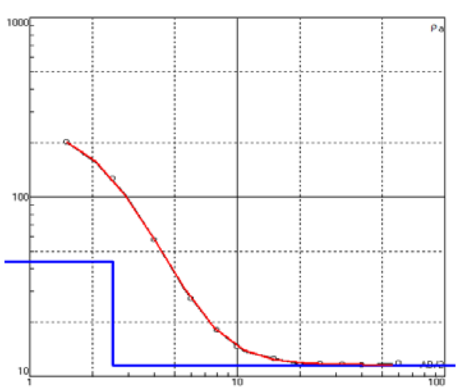


Figure 1a: 3-layered Q-type curve

N	1	2	3	4	5
ρ	126	129	234	4.95	2814
h	1.72	2.79	2.21	4.04	
d	1.72	4.51	6.72	10.8	
Alt	-1.72	-4.51	-6.72	-10.76	

RMS 4.61%

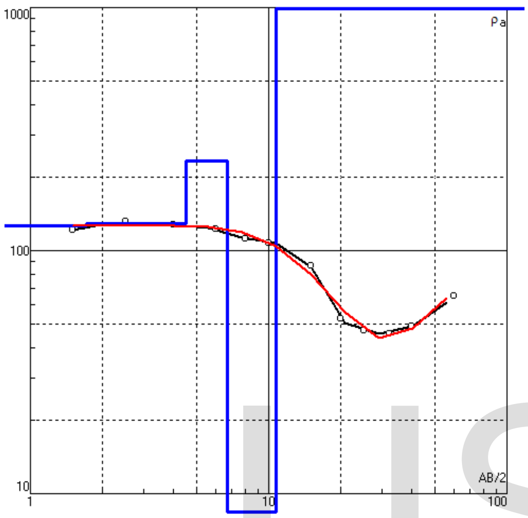
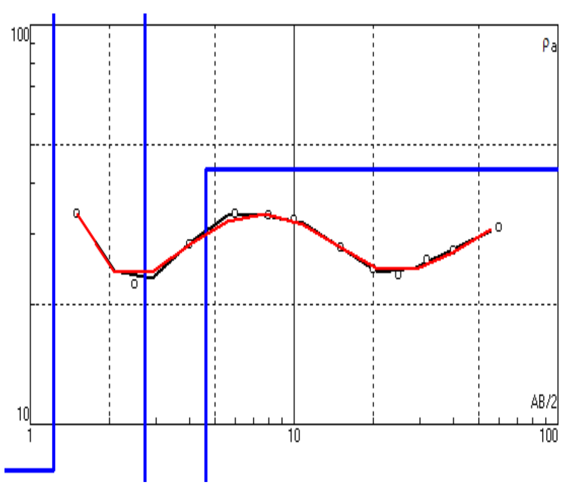


Figure 1b: 4-layered KH-type curve

N	1	2	3	4	5
ρ	112	7.635	155.5	2.926	43.52
h	0.5174	0.708	1.498	1.913	
d	0.5174	1.225	2.724	4.637	
Alt	0.5173[illegible]	-1.2254	-2.7239	-4.6373	

RMS 1.83%



ISSN 2229-5518

Figure 1c: 5-layered HKH-type curve

Table 1. Layers' resistivity, thicknesses and curve types.

VES station	Layer resistivity (Ώ) ρ_1	ρ_2	ρ_3	ρ_4	ρ_5	layer thickness (m) h_1	h_2	h_3	h_4	Curve type
1	146	20	118	40		15.7	15.2	43.3		HK
2	399	31	149	40		5.1	33.6	14.3		HK
3	39	146	26	9		15.8	10.3	35.1		KQ
4	32	8	154	3	43	5.2	7.1	15.1	19.4	HKH
5	83	15	61			4.4	28.9			H
6	61	20	42			5.7	64.8			H
7	54	21	45	63		4.3	31.2	6.6		HA
8	108	21	34			4.7	34.3			H
9	775	24	1357			8.0	10.8			H
10	880	25	128			3.5	23.4			H
11	409	12	283	345		5.0	8.7	28.7		HA
12	825	55	87	19	966	2.0	10.8	7.1	40.1	HKH
13	60	14	35			3.8	17.7			H
14	511	1511	27	77		1.4	3.5	2.1		KH
15	614	163	12	127		0.6	2.3	62.7		QK
16	202	60	8			1.8	2.2			Q
17	595	104	9	617		0.7	17.1			QH
18	185	66	19	42		0.5	4.7			QH
19	378	121	142			5.1	51.8			H
20	2038	720	22	269		0.4	0.7			QH
21	238	19	93			0.2	0.6			H

VES-vertical electrical sounding; ρ-layer resistivity; h-layer thickness, m-meter.

Table 2: Curve types and their frequencies

Curve Type	Frequency	Percentage
H	8	38.10
Q	1	4.76
HA	2	9.52
HK	2	9.52
KH	1	4.76
KQ	1	4.76
QH	4	19.05
HKH	2	9.52

4.2 Geo-electric delineation of saline zone

In this study, all the depth sounding curves interpreted as saline layers are characterized by a steep descent from the non-saline to the saline layers. This decrease could be attributed to increase in porosity, hydraulic conductivity, fluid content, and most possibly a high conductivity arising from saline water intrusion. Examples of such steep descents occur at VES 4 with resistivity contrast of 154.1Ωm and 2.96Ωm (Table 1). The thicknesses of the saline layers/zones and their corresponding resistivities are presented in Tables 1 while the distributions of the saline zones in the areas is presented in Figure 2.

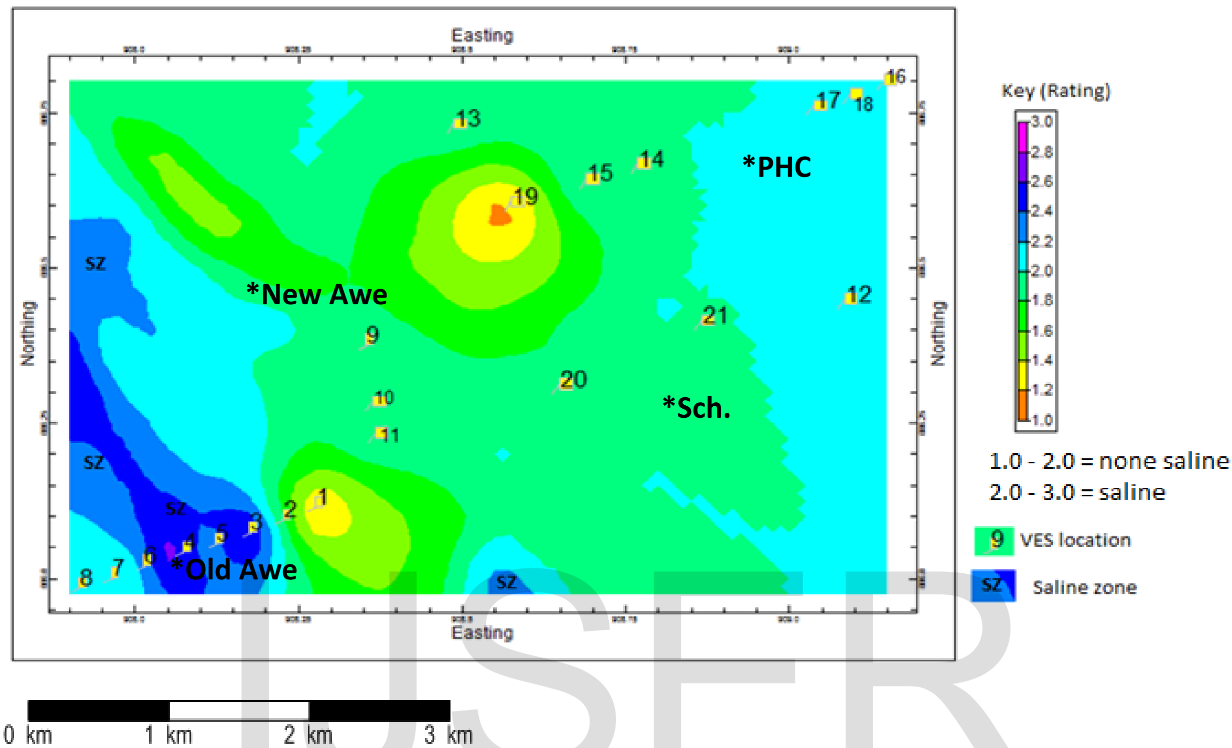


Figure 2: Saline zone distribution map of Awe

Table 3: Classification of curve types

Curve type	Layer's resistivity relationship
H	$P_1>P_2<P_3$
Q	$P_1>P_2>P_3$
HA	$P_1>P_2<P_3<P_4$
HK	$P_1>P_2<P_3>P_4$
KH	$P_1<P_2>P_3<P_4$
KQ	$P_1<P_2>P_3>P_4$
QH	$P_1>P_2>P_3<P_4$
HKH	$P_1>P_2<P_3>P_4<P_5$

4.3 Evaluation of aquifer protective capacity (APC)

Table 4 presents the summary of the computed longitudinal conductance values for the overburden units of the study area. The highest value was observed at VES 9 while the lowest values were observed at VES 1, 2, 6, 11, 14, 17, 19 and 20 (Figure 3).

In order to categorize the aquifer protective capacity of the areas, aquifer protective capacity rating model (Henriet, 1976; Oladapo et al 2004; Okogbue and Omonona, 2013; Table 4) was employed. Five aquifer protective capacity zones: Poor < 0.1mhos; weak 0.1-0.19mhos; moderate 0.2-0.69mhos; good 0.7-4.49mhos; very good 5-10mhos and ‘excellent’ 7-10mhos were delineated. The good and medium aquifer protective capacity zones coincide with zones of appreciable overburden thicknesses with clayey column and low resistivity while the weak and poor zones coincide with zones of shallow or thin overburden thicknesses and high electrical resistivity. Therefore, terrains that retard infiltration would be classified as having good, very good and excellent APC, whereas terrains where contaminant transport is barely restricted are rated as having poor APC.

The aquifer protective capacity map of the study area (Figure 4) revealed that approximately 40% are covered by poor to weak aquifer protective capacity zones. This implies that these areas are vulnerable to surface contamination sources (leakage from underground petroleum storage tanks, infiltration of leachates from decomposing open refuse dumps and diffuse pollution from agricultural activities) in the areas. The rest of the areas have moderate to good protective capacities.

Table 4: Longitudinal conductance/protective rating (after Henriet, 1976; Oladapo, 2004; Okogbue and Omonona, 2013)

Longitudinal Conductance (mhos)	Protective Capacity Rating
>10	'excellent'
5-10	Very good
0.7-4.49	Good
0.2-0.69	Moderate
0.1-0.19	Weak
<0.1	Poor

Adapted from Okogbue and Omonona (2013)

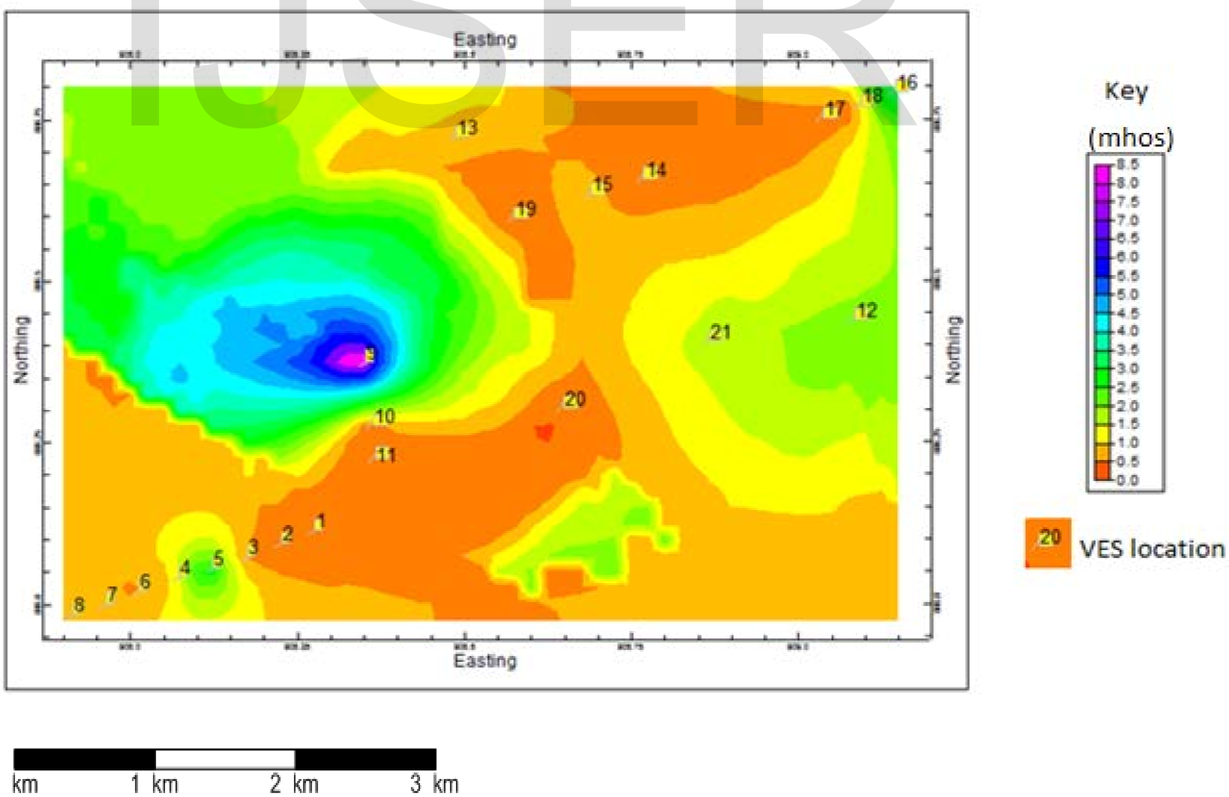


Figure 3: Longitudinal conductance map of Awe

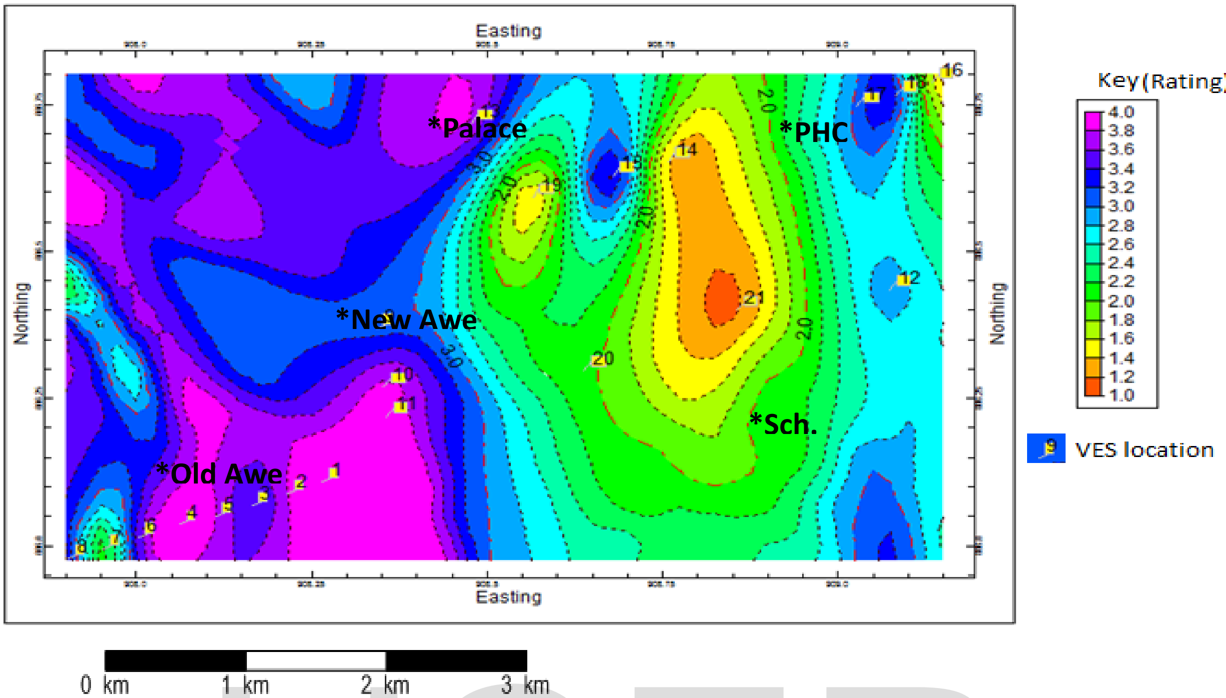


Figure 4: Aquifer protective capacity map of Awe

5.0 Summary and conclusion

Hydrogeophysical investigations were carried out with the objectives of delineating the saline water zones and determining the aquifers protective capacity of the aquifers of Awe brine fields located within the Central Benue Trough. Results of the static water level showed both converging and diverging zones of groundwater corresponding to lower and higher hydraulic heads respectively. Vertical electrical sounding (VES) curves reveal that the study areas are characterized by 3-layers to 5-layers geo-electrical sequences. It also showed that Awe area has the highest occurrence of saline zone within the Central Benue Trough, compared to Keana and Giza saline zones. The study area showed that the saline zones are multi – layered and are characterized by a steep descent from the non-saline to the saline layers. Increase in porosity, hydraulic conductivity, fluid content, and most possibly a high conductivity arising from saline water intrusion could be responsible for the decrease. The aquifer protective capacity map of the study area revealed that approximately 40% are covered by poor to weak aquifer protective capacity zone, making these areas vulnerable to surface contamination, while 60% have moderate to good protective capacities, these areas will retard infiltration.

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