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INVESTIGATION OF SUBSURFACE GROUNDWATER USING THE VES METHOD AROUND DENDAM LAKE, BENGKULU CITY, INDONESIA

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ABSTRACT

Concerns have been raised over the availability of water in the Dendam Lake neighborhood of Bengkulu City and the areas surrounding it. The location is characterized by a number of unsuccessful water wells. These issues are the direct and indirect results of the geological formations that are present in the region, specifically Aluvium (which consists of boulders, clasts, sand, silt, mud, and clay). A MAE X-612 EM resistivity meter was utilized in order to get a total of twenty Vertical Electric Sounding (VES) measurement points. Using the software programs Progress and Surfer, the data that was gathered was plotted on a two-log graph. The geoelectric layer and layer parameter maps that were made were prepared with the use of quantitative and qualitative interpretations. It was determined that there were between three and five geoelectric layers. It has been demonstrated that the resistivity of the subsurface shallow groundwater zone ranges from 10 to 20 Ωm at a depth of 4 to 15 meters. According to the findings of this research project, employing the VES geo-electrical exploration approach is likely capable of effectively outlining the subsurface and shallow groundwater. In addition, there is no information available regarding the precise depth of the groundwater table in the region. On the other hand, the underground groundwater at this location has a depth that is shallower than the norm.

Keywords: Dendam Lake, resistivity, shallow groundwater, vertical electrical sounding

INTRODUCTION

According to previous study [1], "ensuring availability and sustainable management of water and sanitation for all," having access to clean water is crucial to people's well-being and economic growth. There is a substantial amount of variation, both in terms of position and time, in the distribution of freshwater that is available throughout an area. Therefore, gaining access to freshwater presents difficulties for each alternative source (that is, surface water and groundwater). Since the beginning of this decade, residents of the Dendam Lake region, Bengkulu City, and the neighboring areas have been dealing with concerns with the quality of the water that can be used. This has sometimes led to communities using more PDAM water, which is also occasionally of lesser quality. This has sometimes led to communities using more PDAM water. Institutions and the general population in the Bengkulu municipality, particularly in and around Dendam Lake, have been negatively impacted as a result of the low water quality.

Because of this, the settlements that are located around Dendam Lake have the option of using surface water. The Indonesian government employed groundwater resources to find other ways to give water to the citizens of the region in order to solve this issue and put an end to the water shortage. In light of the community's past experiences with unproductive well drilling, which involved the arbitrary selection of drilling sites without the aid of geophysical exploration, we made the decision to undertake a comprehensive geophysical survey. The objective of this survey was to identify optimal drilling locations capable of yielding a substantial volume of water, thereby ensuring a sustainable water supply and consequently enhancing the success rate of drilling endeavors. Considering these factors, the vertical electrical sounding (VES) method was chosen as the optimal geophysical technique due to its cost-effectiveness per unit length, enhanced sensitivity to vertical and horizontal electrical structures compared to other one-dimensional methods like electromagnetic, and crucial ability to detect subsurface aquifers [2].

In the previous research [3], geoelectric resistivity techniques are also utilized to show structural factors and detect polluted groundwater zones, which is an essential factor. According to Verma and colleagues' (1980) [4] research, the resistivity approach can be utilized for groundwater investigations in situations in which there is a significant difference in the electrical resistivity of the water-bearing formation and the rock that lies beneath it. When the method is proposed with a comprehensive understanding of the geology, geomorphological, and hydrogeological settings, as well as the conditions of the groundwater table and the topography at a particular site [5,6], accurate and dependable findings have been obtained. Groundwater issues can be resolved with the use of the electrical resistivity method by overcoming issues with power and economic feasibility. The electrical resistivity method can be used to look at a variety of lithological formations, figure out how bedrock is set up, find the depth to the water table or saturated formation zone, measure the thickness of weathered zones, find fissures, fractures, and fault zones, and figure out the depth, consistency, and lateral extent of aquifers. Lawal et al. (2020) [7] conducted a study wherein they identified several crucial factors that warrant consideration. These factors include the direction of groundwater flow, the presence of valley fills, the depth of the basement in hard rock formations, the presence of freshwater and saltwater intrusion, the identification of potential groundwater zones for ore resource exploration, and the need to do archaeological investigations.

Numerous researchers have investigated this topic from a variety of angles in the past. Groundwater data are combined with Schlumberger electrode designs to detect subsurface features and water locations [8-11]. It has been shown that the VES technique can be a superior tool for understanding hydrogeological problems. The electrical resistivity techniques were used to determine where the groundwater zones in the research region were located. Today's geophysical designs are able to deliver more significant information about the geology of the subsurface. There is a relationship between geoelectric methods, aquifer hydraulic features, and geophysics variables (hydraulic resistance and transmissivity), particularly lateral conductivity and lateral resistivity [9,12]. This relationship exists because geoelectric methods measure aquifer hydraulic features.

Continuous evaluations of the quantity and quality of groundwater have traditionally relied on geophysical approaches, in particular those that measure electrical resistivity [13]. The VES method's ease of use has contributed to its widespread adoption in engineering investigations and the search for groundwater resources [14]. The electrical resistivity approach is helpful in determining the depth, thickness, and production capacity of various waters found in the subsurface [15]. The geophysical techniques also identify and evaluate groundwater viewpoints in order to gain an understanding of subsurface geology [16].

The VES is employed here as an investigation tool with the purpose of determining the potential locations of subsurface zones containing shallow groundwater. In addition, the purpose of this study was to investigate the viability of the VES approach as a method for determining the possible zones of shallow subsurface groundwater in the region of Dendam Lake, which is located in Bengkulu City, Indonesia. The difference between earlier studies that were carried out utilizing VES and the study that is currently being presented is that the current study is centered on identifying probable subterranean groundwater zones and studying groundwater quality in relation to the prospective influence of seepage from water bodies.

METHOD

In accordance with the conventional method of geophysical surveying and in correlation with the geological field mapping found in the region, Vertical Electrical Sounding (VES) was utilized. An MAE X-612EM, a multimeter, a hammer, electrodes, and cable reels were all part of the assortment of tools that were utilized. We employed the Schlumberger electrode configuration, which consists of pairs of current and potential electrodes with the same center point but variable distances between adjacent electrodes (see FIGURE 2 for further details). A maximum distance of one hundred meters was allowed to pass between the current electrodes (AB/2) and the twenty sounding locations that were dispersed around the Dendam Lake region (FIGURE 1).

The data acquisition sequence number around Dendam Lake labels the data acquisition points from VES1 to VES20. Each sounding point has a 200-meter track, and the Schlumberger electrode configuration ensures that current and potential electrode spacing are always the same. Of course, sounding locations are evenly distributed among surrounding geological structures. The state of developed land, especially for residential, industrial, and other buildings, made it difficult to identify a maximum stretch. Researchers detected these impediments during data gathering at several sounding stations. Road-developed terrain at the measuring site makes collecting geoelectric data difficult due to blocks and stones.

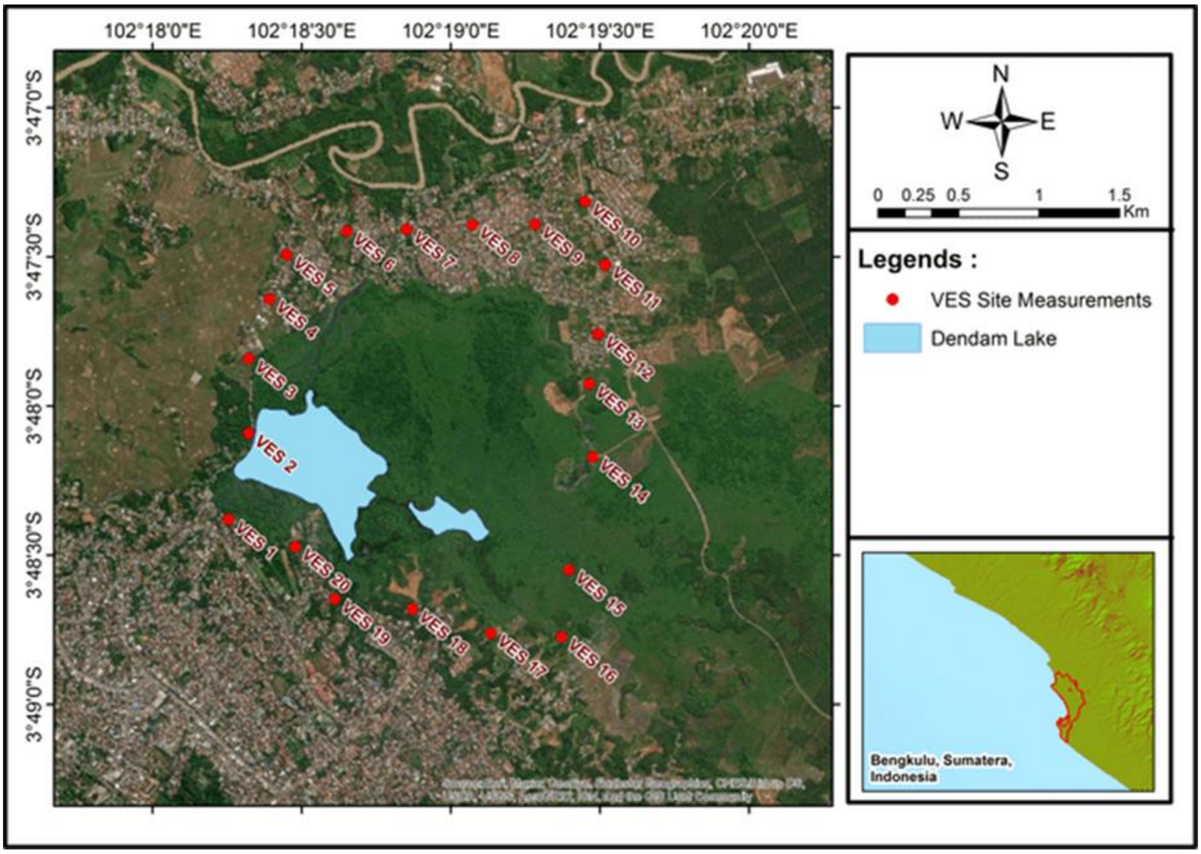

FIGURE 1. VES site measurements in the study area

Reference electrical resistivity values were established beforehand, and Telford et al. (1990) [17] discovered that variances in electrical resistivity enabled the identification of important subsurface heterogeneities and resistivity ranges (Ohm/m) associated with geoelectrical layers. The primary goal of this research was to determine if there was any potential for subsurface groundwater in the area surrounding Dendam Lake using the vertical electrical sounding method. Changing the lithology of the sediment, particle size, or water content can all affect the results of a VES analysis, as is well known. In the VES method, two current electrodes are used to inject a direct current (DC) electric current into the ground, and the resulting potential difference is then measured. To determine the apparent resistivity of the subsurface formation at a given depth, one must be familiar with the magnitude of the injected electric current, the magnitude of the potential difference, and the array's configuration factor [18].

The data on the final computed apparent resistivity were transferred to the Progress 1D software for processing in order to obtain the 1D model of the sounding curve. Layer resistivity, thickness, and occurrence depths were all gleaned through a study of the full one-dimensional resistivity model. The 1D VES models were then used to infer the geological model. The analysis was conducted while ensuring that the root mean square error (RMS) values for the data fit were within a manageable range of 5-12%. After the human adjustment for optimum fit, the root mean square measures how well the theoretical curves match the observed field curves [2].

The fundamental idea behind this approach is expressed through the following formula [17]:

$$K = \pi \frac{(AB/2)^2 - (MN/2)^2}{MN} \frac{\Delta V}{I} \tag{1}$$

$$\rho_a = K \frac{\Delta V}{I} \tag{2}$$

Where AB/2 = half current electrodes spacing (m), MN/2 = half potential electrodes spacing (m), ΔV = potential difference measured between the potential electrodes M and N, I = electric current injected into the ground by the current elctrodes A and B, ρ_a = apparent resistivity measured (Ωm).

The Schlumberger configuration is utilized for subsurface data gathering, which is a technique that is less complicated, less labor intensive, and saves both time and labor [19]. Several authors [17-19] have discussed the Schlumberger Configuration Survey principles. When compared to other arrays, such as the Wenner array, the Schlumberger array has a number of advantages that led to its selection. Keary and Brooks (1984) [23] state that these benefits include higher resolution, deeper probing, and the need to relocate fewer electrodes with each sounding. However, at least three people are needed to collect data from the array. There are four collinear electrodes in the Schlumberger array, and they are all separated by a specific distance. The two outer electrodes are the current electrodes, while the two inner electrodes are the potential electrodes [2].

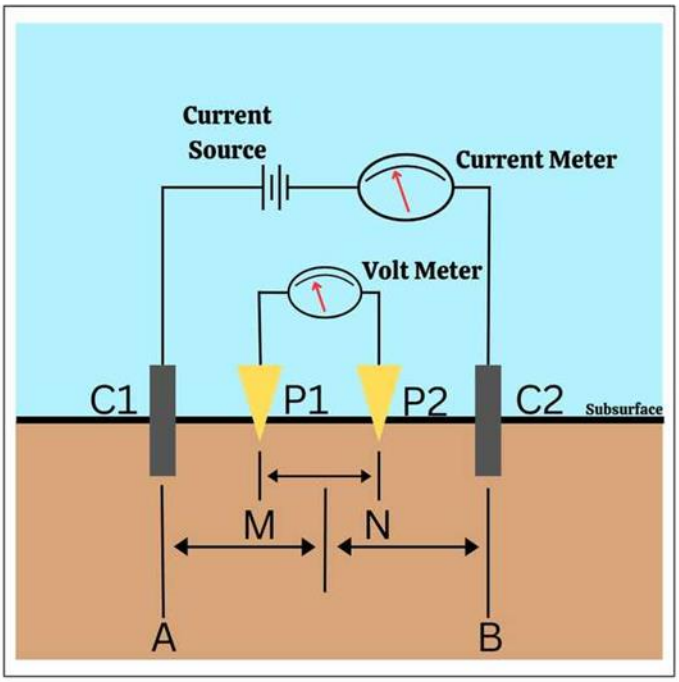

FIGURE. 2. Schlumberger electrode configuration array

These findings will be utilized in the creation of iso-contour maps, which will show the genuine resistivity, thickness, and expected depth of the subsurface groundwater deposits. The data from the interpreted VES curves were used to produce geo-electrical cross sections that traversed the area in a northeast-southwest direction. These cross sections were created. This section gives in-depth information on the lateral and vertical extent of the groundwater deposits that lie under the surface

RESULT AND DISCUSSION

After the data collected during the survey were analyzed, a graph of the subsurface lithology was obtained and projected using Progress 1D software. On the graph, the apparent resistivity values of the different VES locations were plotted against half the electrode spread (AB/2). A description of the lithology was also shown. Based on the varying apparent resistivities against depth, the program segments the subsurface into layers. In the end, the modeling results were iterated until the root mean square (RMS) error percentage was reduced to its minimum. The modeling of the geoelectric layers is accomplished by the use of geoelectric correlations. The model that was acquired from the resistivity program (Progress) illustrates layers that are notably distinct from one another in terms of the resistance that they present to the flow of electric current. The resistivity values in the area have been measured to show variances that vary from low to high, with the lowest value being 3.71 m and the highest value being 187.3 m. The subsurface is segmented into distinct layers by the program in accordance with the various resistivities that are plotted against depth in TABLE 1.

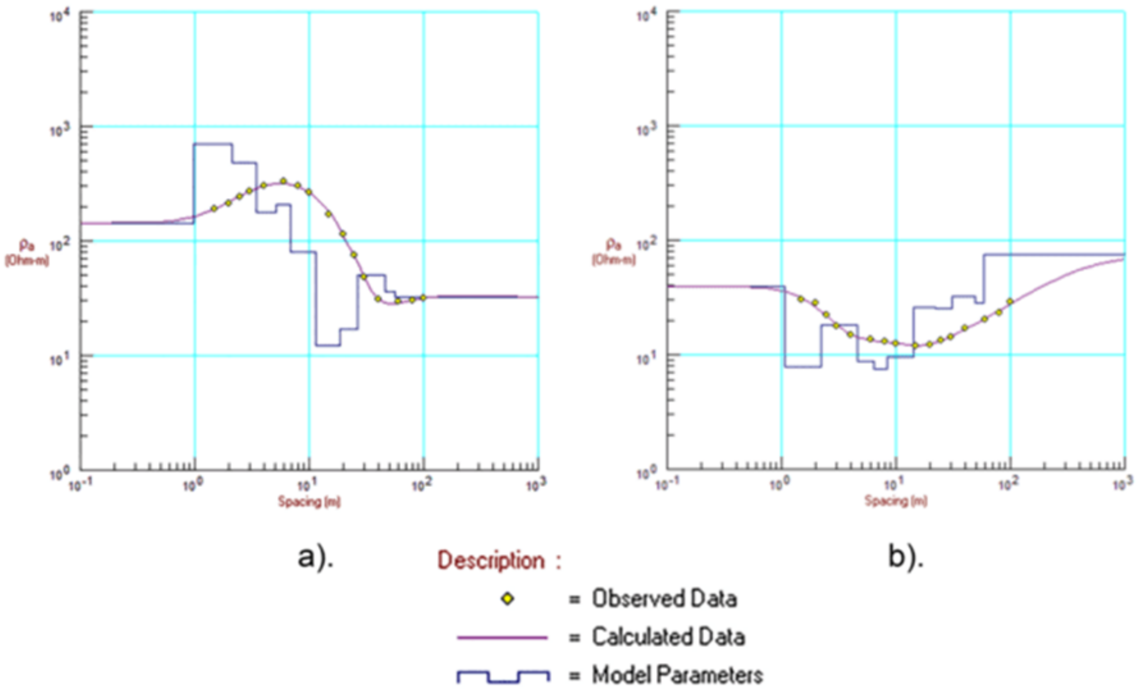

FIGURE 3. VES curve at: a) VES 1 and b) VES 2

The difference in resistivity readings that are measured and those that are estimated can have a root mean square (rms) inaccuracy of anywhere from 1.04% to 3.97%. In Figure 3, we see two examples of models that were derived at measurement locations VES 1 and VES 2, where there is a good agreement between the model responses (purple lines) and the measured data (yellow circles).

TABLE 1. VES point thickness, depths, resistivity, and interpreted lithology data

VES Site	Thickness (m)	Depth (m)	Resistivity (Ωm)	Interpreted Lithology
VES 1	23.7	0-23.7	156	Sandy Gravel
	18.5	23.7-42.2	64.6	Alluvium
	18.8	42.2-61	55	Gravelly Sand
	10.8	61-71.8	28.5	Clay
	8.2	71.8-80	15.8	Groundwater
VES 2	2.2	0-2.2	3.71	Clay
	17.8	2.2-20	15.8	Groundwater
	9	20-29	30.4	Clay
	6	29-35	52.2	Gravelly Sand
	31	35-66	127.7	Sandy Gravel
	14	66-80	33	Clay
VES 3	1.5	0-1.5	68.1	Alluvium
	1.66	1.5-3.16	34.9	Clay
	15.84	3.16-19	13.3	Groundwater
	7	19-26	29.2	Clay

VES Site	Thickness (m)	Depth (m)	Resistivity (Ωm)	Interpreted Lithology
	13	26-39	51.6	Gravelly Sand
	41	39-80	114	Sandy Gravel
VES 4	3	0-3	64	Alluvium
	1.3	3-4.3	26.4	Clay
	30.7	4.3-35	16.7	Groundwater
	9	35-44	25.9	Clay
	9	44-53	52.1	Gravelly Sand
	27	53-80	135	Sandy Gravel
VES 5	2	0-2	64	Clay
	7.67	2-10.33	26.4	Groundwater
	4.67	10.33-15	16.7	Clay
	27	15-42	25.9	Gravelly Sand
	38	42-80	52.1	Sandy Gravel
VES 6	2.8	0-2.8	23.7	Gravelly Sand
	1.2	2.8-4	15.4	Clay
	19	4-23.	10.1	Groundwater
	12	23-35	14.7	Clay
	21	35-56	22.5	Gravelly Sand
	24	56-80	42	Sandy Gravel
VES 7	8	0-8	16.2	Clay
	32.7	8-41.3	12.5	Groundwater
	9	41-50	15.3	Clay
	23	50-73	25.7	Gravelly Sand
	7	73-80	40.4	Sandy Gravel
VES 8	10	0-10	22.9	Gravelly Sand
	13.7	10-23.7	48.2	Sandy Gravel
	8.3	23.7-32	17.4	Clay
	27	32-59	11.6	Groundwater
	21	59-80	45	Sandy Gravel
VES 9	5	0-5	41.6	Sandy Gravel
	24.5	5-29.5	25.3	Gravelly Sand
	8.5	29.5-38	16.3	Clay
	37	38-75	9.66	Groundwater
	5	75-80	14.5	Clay
VES 10	6	0-6	23.7	Gravelly Sand
	4.1	6-11.9	15.4	Clay
	38.1	11.9-50	10.5	Groundwater
	30	50-80	52.2	Sandy Gravel
VES 11	18.7	0-18.7	37.3	Gravelly Sand
	13.3	18.7-32	19.3	Clay
	34	32-66	7.2	Groundwater

VES Site	Thickness (m)	Depth (m)	Resistivity (Ωm)	Interpreted Lithology
	14	66-80	13.9	Clay
VES 12	3	0-3	42.8	Gravelly Sand
	3.2	3-7.8	18.3	Clay
	49.2	7.8-57	7	Groundwater
	23	57-80	15	Clay
VES 13	15	0-15	139	Sandy Gravel
	10	15-25	37.3	Gravelly Sand
	7	25-32	15.4	Clay
	18	32-50	5.7	Groundwater
	30	50-80	16.8	Clay
VES 14	15	0-20	48.8	Gravelly Sand
	10	20-24	19	Clay
	7	24-60	8.6	Groundwater
	20	60-80	17	Clay
VES 15	2	0-2	40.5	Gravelly Sand
	6.2	2-8.2	6.2	Groundwater
	13.8	8.2-22	18.8	Clay
	46	22-68	8.6	Groundwater
	12	68-80	15.3	Clay
VES 16	6	0-6	99.2	Alluvium
	15.4	6-21.4	77.4	Gravelly Sand
	2.6	21.4-24	89.4	Alluvium
	18	24-42	40.6	Clay
	28	42-70	21.5	Groundwater
	10	70-80	35.9	Clay
VES 17	2	0-2	111.8	Alluvium
	18.5	2-20.5	60	Gravelly Sand
	6.5	20.5-27	86.5	Alluvium
	10	27-37	40.1	Clay
	31	37-68	19.7	Groundwater
	12	68-80	34.4	Clay
VES 18	3	0-3	80.9	Alluvium
	14.5	3-17.5	66.3	Gravelly Sand
	7.5	17.5-25	86.2	Alluvium
	7	25-32	37.6	Clay
	42	32-74	18	Groundwater
	6	74-80	28.6	Clay
VES 19	2	0-2	57.1	Gravelly Sand
	16.1	2-18.1	187.3	Sandy Gravel
	5.9	18.1-24	64.8	Gravelly Sand
	7	24-31	78.5	Alluvium

VES Site	Thickness (m)	Depth (m)	Resistivity (Ωm)	Interpreted Lithology
	12	31-43	29	Clay
	37	43-80	13	Groundwater
VES 20	2.4	0-2.4	77.5	Gravelly Sand
	29.4	2.4-31.8	170	Sandy Gravel
	5.2	31.8-37	70.8	Gravelly Sand
	5	37-42	89.4	Alluvium
	13	42-55	40.7	Clay
	25	55-80	16.7	Groundwater

FIGURE 4 shows the results of using Surfer to model the geo-electric layers. The model that was derived from the resistivity software (progres) showed that the layers are significantly distinct from one another in terms of their resistance to the flow of electric current (FIGURE 5). The variance that has been measured in the region spans from relatively low to relatively high, with corresponding resistivity values of 3.71 and 187.3 m respectively. The results of the sounding indicate that the region has anything from four (4) to five (5) geoelectric strata, which are comprised of gravelly sand, clay, alluvium, gravelly sand, and groundwater respectively. As shown in FIGURE 4, VES 10, VES 11, VES 12, and VES 14 each have a total of four geoelectric layers, whereas VES 1, 2, 3, 4, 5, 6, 7, 8, 9, 13, 15, 16, 17, 18, 19, and 20 each have a total of five geoelectric layers.

When you look at how the twenty VES points connect, as shown in FIGURE 5, you can see a clear drop in apparent resistivity values at about 20 m and 50 m. It is noteworthy to mention that this decline does not exhibit a consistent pattern across all VES stations. This observation is consistent with the data presented in FIGURE 5 and 6, which depict the graph, layer model, and geoelectric cross-section of the layer model, respectively. This means that the geological formations in the studied area are isotropic, as shown by the fact that the curves for apparent resistivity and depth (see TABLE 1) always point in the same direction and have the same size. The region is characterized by the presence of a physically regulated and depressed aquifer type. The regulation of shallow groundwater in the studied area is influenced by various factors, including fractures, geometry (dip), fracture diameter, interconnectivity, and the confined structure of the aquifer [24,25].

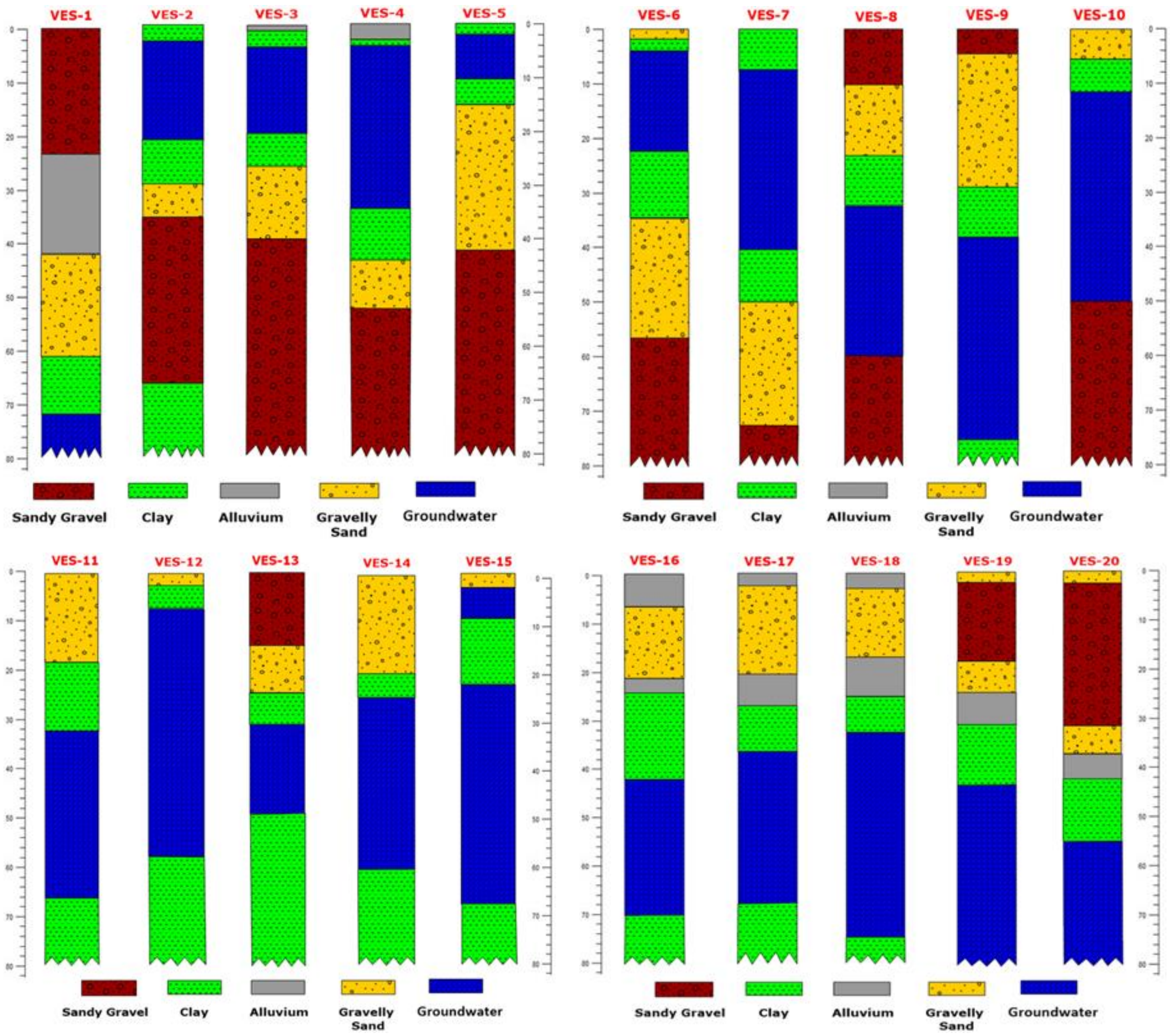

FIGURE 4. Model of the geological and geoelectrical sections at each of the twenty VES points.

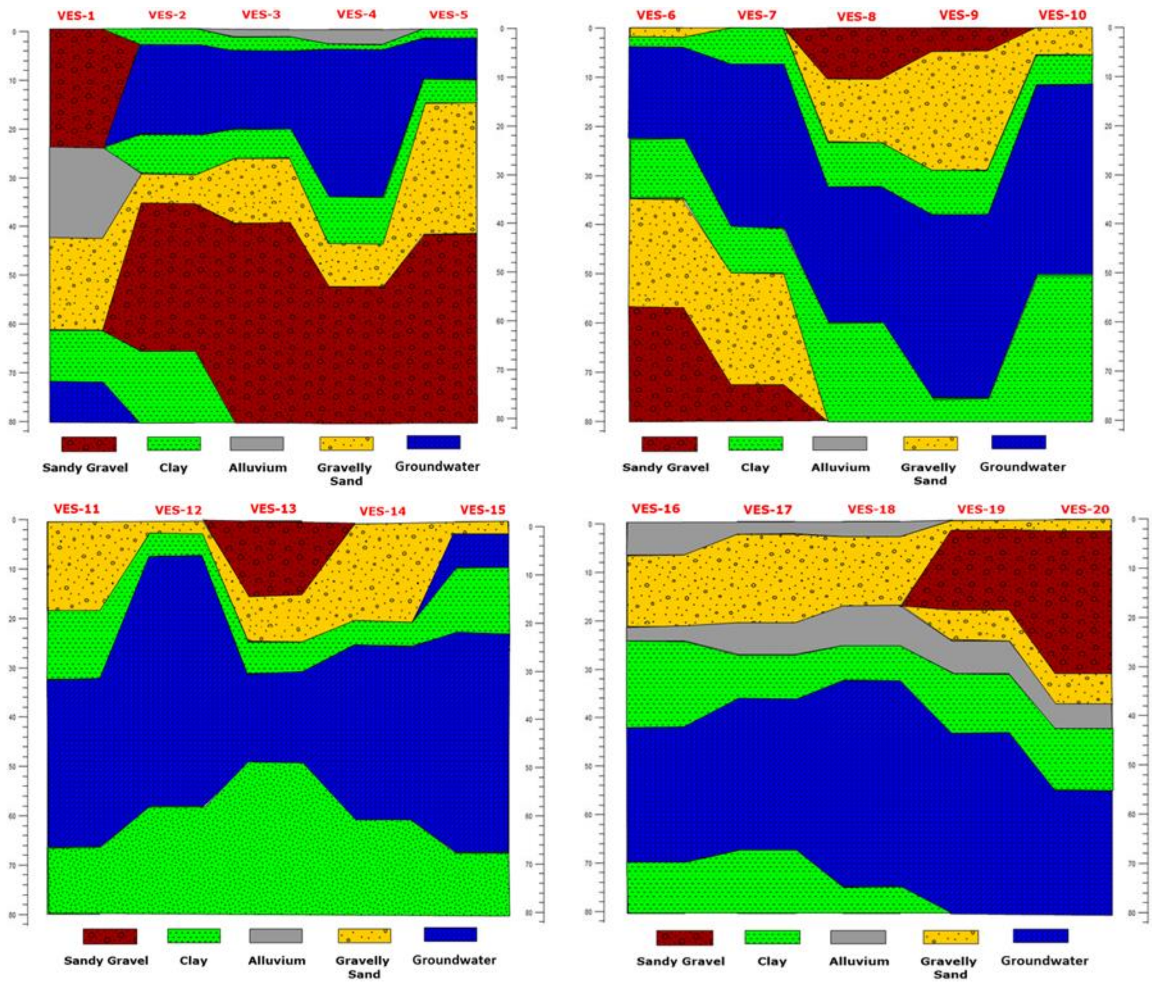

FIGURE 5. The twenty locations of the VES and their geoelectric correlation.

The results of the analysis of the data showed that there were impermeable layers in the area being studied. This gave information about the nature of secondary porosity and permeability as well as the presence of these two properties. The findings of the analysis of the data that was acquired indicated the presence of impermeable layers in the region that was being investigated. The major goal of groundwater prospecting in the region should therefore be to locate cracks, bedding planes, weathered zones, and lenses of sandstone or siltstone layers. At the regional scale, the concepts of groundwater table and groundwater flow are, for the most part, very imprecise. This is because the presence of groundwater in the region is largely controlled structurally, and the phenomena that guide its occurrence and flow direction are likely, discontinuous, and extremely non-uniform.

Due to the underlying geological formations and geodynamics, which have changed over the course of geological history, it has been determined that there is no unique depth in terms of groundwater development in the area. The findings of the investigation that had been carried out led to the discovery of this conclusion.As a result, using water tables to determine groundwater levels or when talking about the hydrogeological significance and potential of the research region could be rather misleading or wrong. Following the findings of this study, developing groundwater would involve making an excessive approximation of the data, as well as a generalization of the facts, which would be both deceptive and unscientific in terms of the empirical factuality involved.

The primary drawback of the VES technique for groundwater exploration in the region is that it cannot provide information on fracture geometry and that the subsurface geo-electric layers are presented as fat layers or homogeneous unit slabs based on resistivity variability, when in reality this is not the case due to the presence of caves, boulders, voids, textural diversity, and cuts that can disrupt homogeneity and pose problems to the resolution o. Understanding the local and regional geology will aid in the interpretation of VES data, which only shows a moderate apparent resistivity contrast of the subsurface. Combining VES with the Azimuthal resistivity survey (ARS) approach is recommended to further define the groundwater in the study area since ARS can accurately detect the fracture geometry, geological features of the conductors, and anisotropy. By defining flow and geometric attributes with suitable simulation models, decision-making based on risk for aquifer characterization structures can reduce uncertainties in the flow of water systems knowledge and the economical assessment of aquifer yields.

CONCLUSION

This research demonstrated the applicability of vertical electrical sounding (VES) in precisely detecting zones with shallow subterranean water, and it was conducted as part of a study with the intention of enhancing the water delivery system that is located around the Bengkulu city lake. On the basis of the findings derived from VES modeling, it has been established that the subsurface is composed of approximately four or five separate layers. The aquifer, in particular, can be found in the third layer that is buried beneath the surface. In addition, considerable groundwater-bearing zones were discovered in the area during the investigation. The resistivity of these zones increases from the overburden to the bedrock and ranges from 10 to 20 Ωm. The resistivity decreases as it moves from the overburden to the bedrock. The ability to collect clearer information about the subsurface shallow water zones in the area will be made possible as a result of this, which will increase the success rate of drilling in this environment.

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