GEOPHYSICAL EXPLORATION FOR GROUNDWATER RESOURCES POTENTIAL OVER BASEMENT FORMATIONS AT KWANDOLWA AND MWISHO WA SHAMBA VILLAGES, KOROGWE DISTRICT, TANZANIA

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ABSTRACT

In this paper results of geophysical exploration studies to identify potential areas with groundwater resources at Kwamndolwa and Mwisho wa Shamba Villages in Korogwe District have been presented. The resistivity curves of eight sites at the two study areas were obtained using field data measurements made based on the application of a vertical electrical sounding (VES) method. The resisivity values obtained for sites VES-K3 and VES-M2 were found to be 10.9 and 24.0 ohm-m respectively. The interpretation of the resisivity values made for the two sites gave also an indication of the presence of sedimentary rocks composed of sandstone materials at the basements, known to constitute a good water bearing potential. These results are to be used as a guideline for borehole siting, providing information on the depth to the groundwater relevant to the development of effective water supply schemes at the study areas. Verification of the exact quality of water will be obtained during drilling tests.

Keywords: Geophysical, Groundwater, Exploration, Interpretation, Methods

INTRODUCTION

Water is a basic need for supporting various domestic and industrial activities. It can be obtained as the surface water or groundwater. The development of water supply schemes in many developing countries has been focusing on surface water resources, giving more attention to the urban areas, than the rural areas because of the poor economic conditions that exist in the rural areas to pay back for the investment costs. In Tanzania, the challenges of providing clean and safe water to the rural areas can therefore be met most cost effectively from groundwater resources.

The development of groundwater schemes in the rural areas is more desirable than surface water, because it does not pose major constraints on water quality, since it is free from pathogenic organisms and need no purification for domestic use. The occurrence of groundwater is a result of the percolating water from the surface through the soil of the recharge areas, and hence, resulting in significant purification [Todd, 1995; Linsley et al., 1992]. The purification process depends on the depth of the water table below the surface, and the type of soil. The concentration of pollutants in percolating water, is generally less severe for rural areas if a better selection of borehole sites is made.

This paper describes the results of a study made on geophysical exploration for identification of the potential areas with groundwater resources located on the foothills of Usambara Mountains in the north-eastern part of Tanzania. This study has generated information to be used as a guideline to assist for borehole siting. The information was obtained by conducting electrical resistivity measurements of the subsurface that allow to locate the availability of groundwater and its quality [Mhilu, 1999].

FEATURES OF THE STUDY AREA

Location

Field data has been gathered from two study areas at Kwamndolwa and Mwisho wa Shamba Villages located on the East and West Usambara foothills about 9436538/0444883 and 9457217/0421405 northings and eastings respectively. The study areas have been selected within Korogwe District (see Figure 1), on the basis of their rural set up features, coupled with an inherent water scarcity problem.

- **Kwamndolwa Village:**
  This village is located east of Korogwe town, and has a population of about 2,829 inhabitants, [National Census Report, 2002]. The water demand in the study area is primarily for domestic purposes and small-scale livestock keeping. Current water supply needs are met from two shallow wells dug by hand to a depth generally ranging between 3.0 and 12.0 m, and several water holes less than 1.0 m deep that often run dry over the dry seasons .

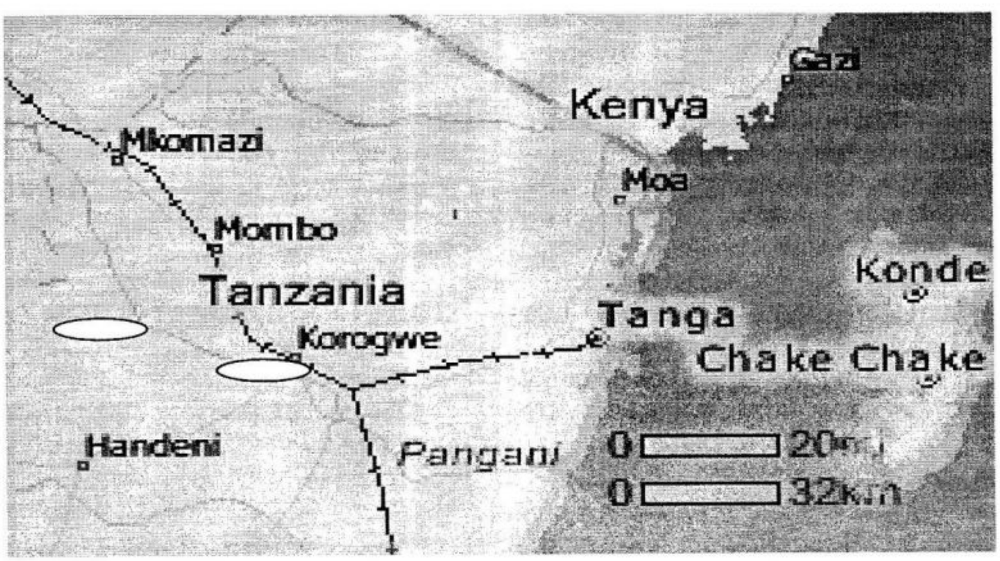
- **Mwisho wa Shamba Village:**
  This village is located near Mombo town, and has a population of 3,271 inhabitants based on 2002 census. Water demand in the study area is for domestic purposes and partly for livestock keeping. The villagers get water from a Zimui stream and shallow wells in the range specified above, and are mostly polluted.

Hydrogeology

The nature of the geology of the study areas is characterized by the metamorphic rocks of the Usagaran system. The rocks range from acid quartz – feldspathic granulites and gneises to ultra basic rocks such as the serpentines. These rocks are known to have low porosity and permeability, and hence large groundwater reserves can only be found at sites with fissures connected to the more important fault systems. Accordingly, water strikes are expected to be encountered from the alluvial and colluvial valley fill and from the weathered overburden.

Following the absence of sufficiently thick porous rocks in the basement areas, which could store recharged rainwater, groundwater recharge and movement, is very much restricted to the weathered overburden or to the alluvial valley sediments. Generally speaking, groundwater levels in the study areas are very variable, and water strikes have been observed at 1 to 40 m. The areas have also calculated groundwater recharge of water sheds of 1 to 20 mm. per annum [Tanga Water Master Plan, 1976].

Although the areas are within variable salinity conditions, the aquifers carry good quality groundwater with electrical conductivity not exceeding 2000micro-ohm/cm [Tanga Water Master Plan, 1976].



Key:
Surveyed area —

Figure 1: Map of Tanzania showing the study areas

GEOPHYSICAL INVESTIGATION

Approach

The purpose of conducting electrical surveys is to determine the subsurface resistivity distribution of the land formations to provide information concerning water occurrence and its quality in the study area. The resistivity measurements are normally obtained by a Vertical Electrical Sounding (VES) method [Mhilu,1999; Nur and Kujir, 2006]. In this method an electric current is injected into the ground through two current electrodes: A and B (see Figure: 2). Measuring of the resulting voltage difference at two potential electrodes: M and N placed between the current electrodes, allows to trace the existence of groundwater flow channels [Bhattacharya and Patra, 1968].

The technique was performed with the aid of a SAS 400B ABEM TERRAMETER adopting a Schlumberger electrode configuration shown in Figure 2.

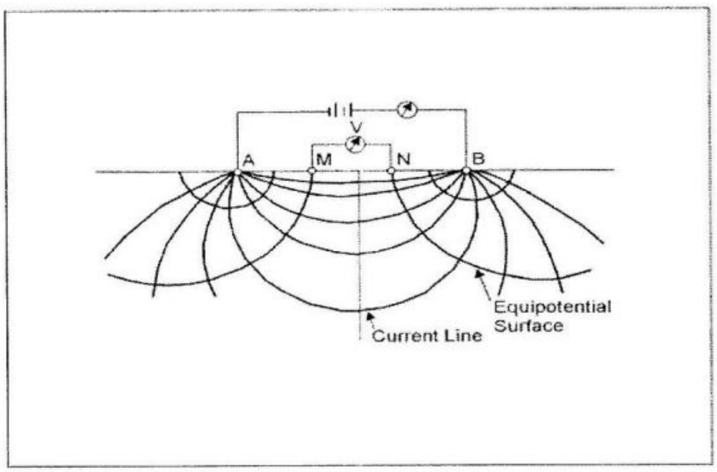


Figure: 2 A common four electrode array used to measure the subsurface resistivity (Schlumberger arrangement)

From the current I and voltage V values, apparent resistivity values are calculated using the equation

$$\rho_a = k\frac{V}{I} \qquad (1)$$

where, k is the geometric factor which depends on the arrangement of the four electrodes.

According to the Schlumberger arrangement used, a series of measurements of resistivity are made by increasing the electrode spacing in successive steps about a fixed point. The basis for making VES is that the further away the potential difference of the electric field is made, the deeper the probing will be achieved. In this investigation, a maximum of the current electrodes separation of 300 m. was adopted, to achieve a deeper penetration of the electric field. Measurements of the resistivity values are obtained by increasing electrode spacing at intervals of 0.5 m. to 125 m. at each of the four sounding points investigated at Kwamndolwa, and Mwisho wa Shamba study areas.

From field measurements, the apparent resistivity values are calculated using Equation 1 expressed in the corresponding Schlumberger arrangement put in the form [Todd, 1995]

$$\rho_a = \pi\left\{\frac{\left(\frac{AB}{2}\right)^2 - \left(\frac{MN}{2}\right)^2}{MN}\right\}\frac{V}{I} \qquad (2)$$

where, AB and MN are the current and potential electrode spacing, respectively.

The apparent resistivity values obtained from field measurements in accordance to the Schlumberger electrode spacing $\frac{AB}{2}$ [Shankar, 1994] were plotted against half the current electrode spacing $\frac{AB}{2}$ on a logarithmic graph paper. The resulting plots showing the resistivity sounding values at Kwamndolwa Village study area are presented in Figure 3 through Figure 6, while those for Mwisho wa Shamba Village study area are presented in Figure 7) through Figure 10.

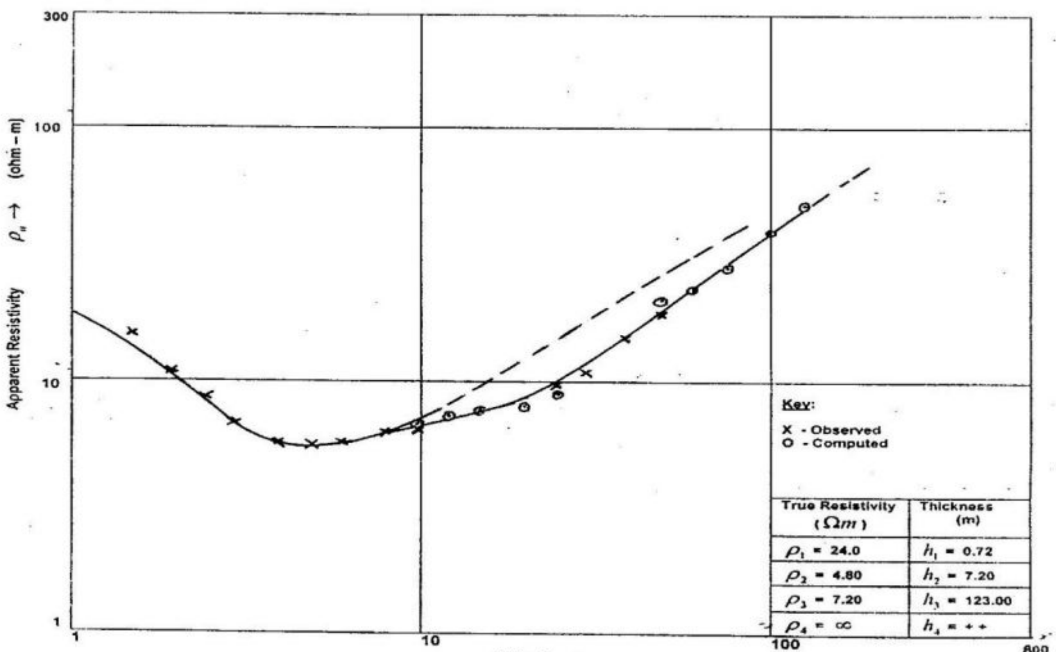


Figure 3 Observed and computed resistivity curves for VES: 1K

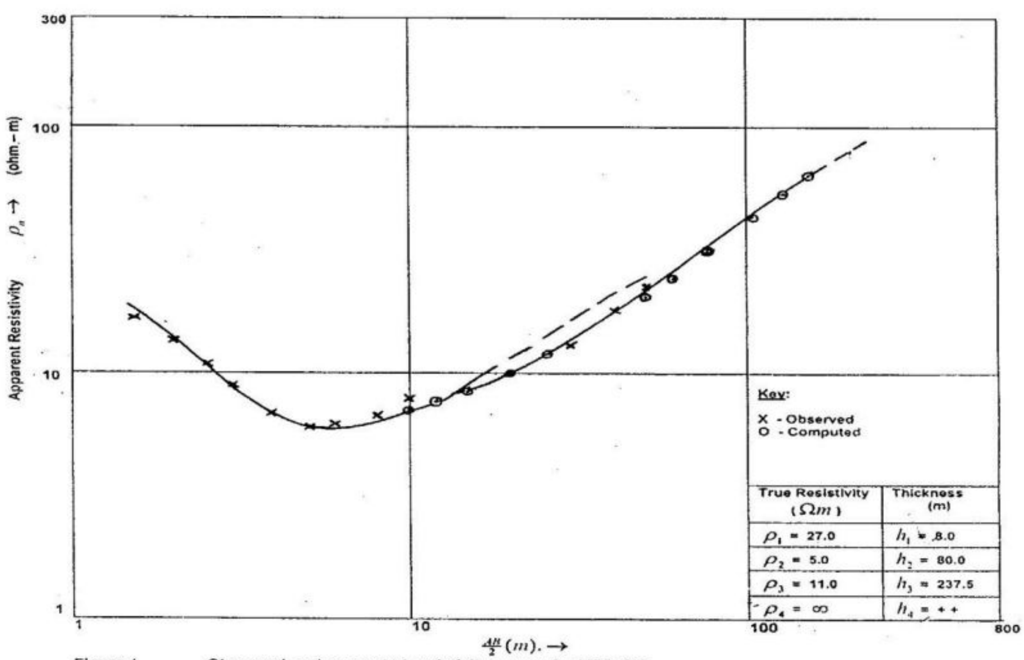


Figure 4 Observed and computed resistivity curves for VES: 2K

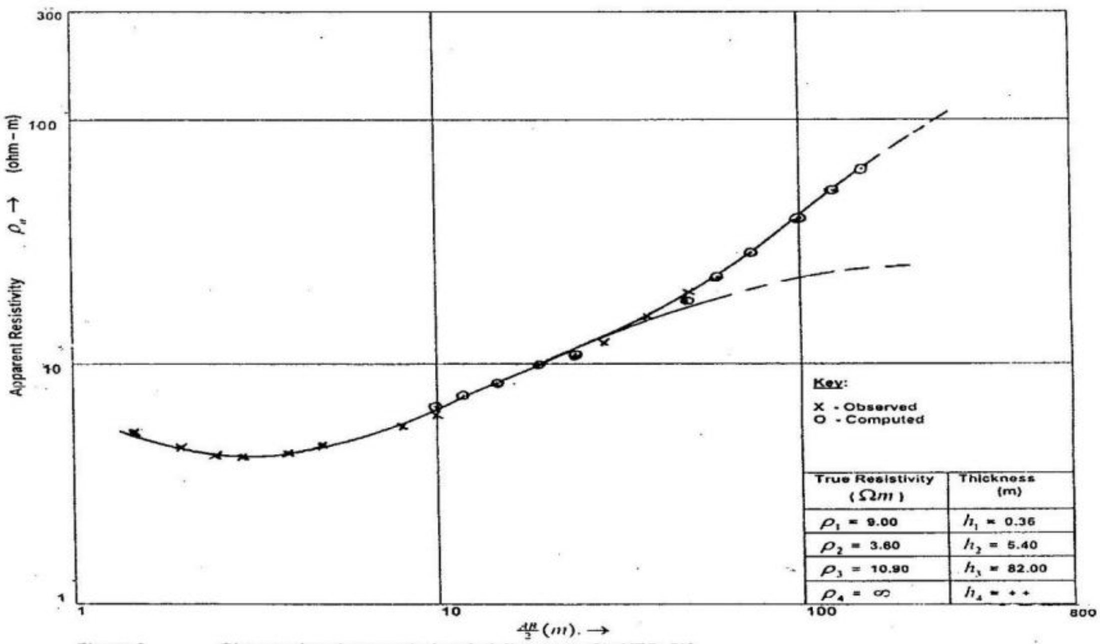


Figure 5 Observed and computed resistivity curves for VES: 3K

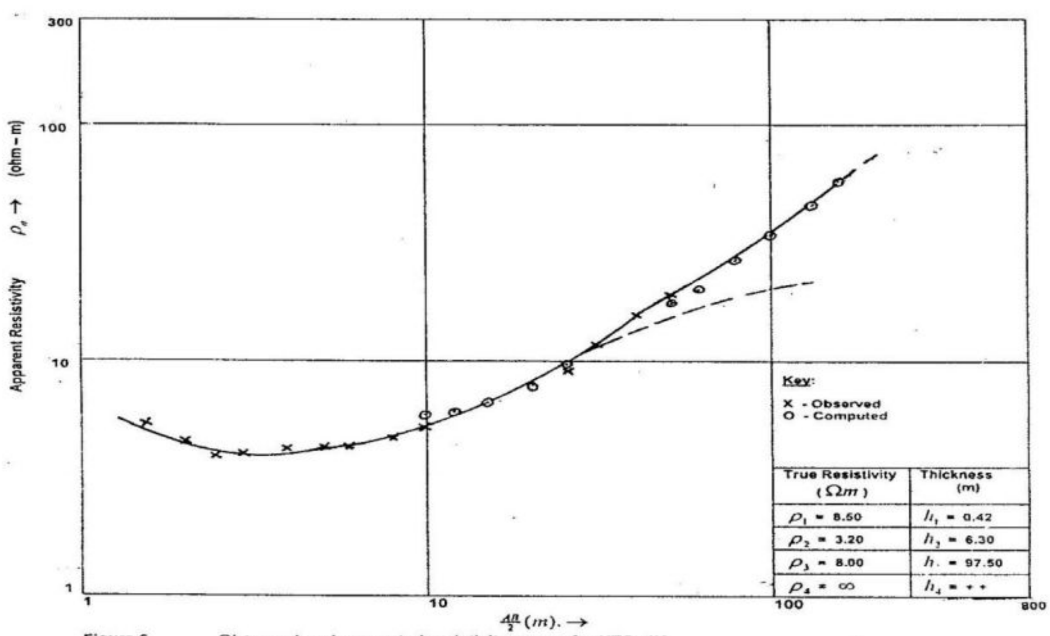


Figure 6 Observed and computed resistivity curves for VES: 4K

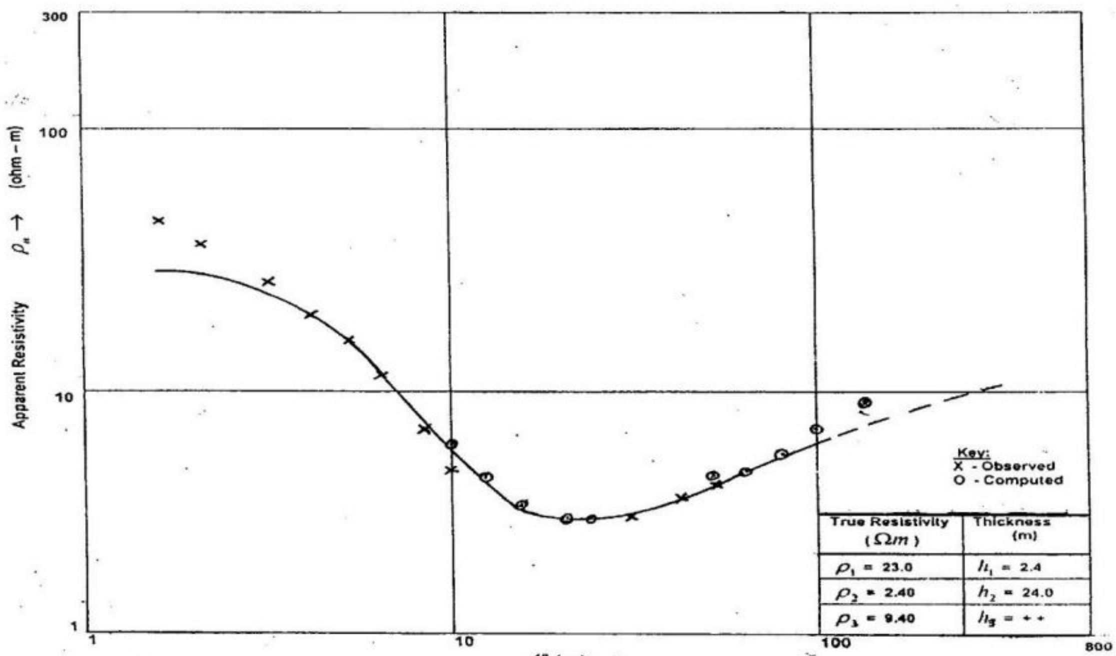


Figure 7 Observed and computed resistivity curves for VES: 1M

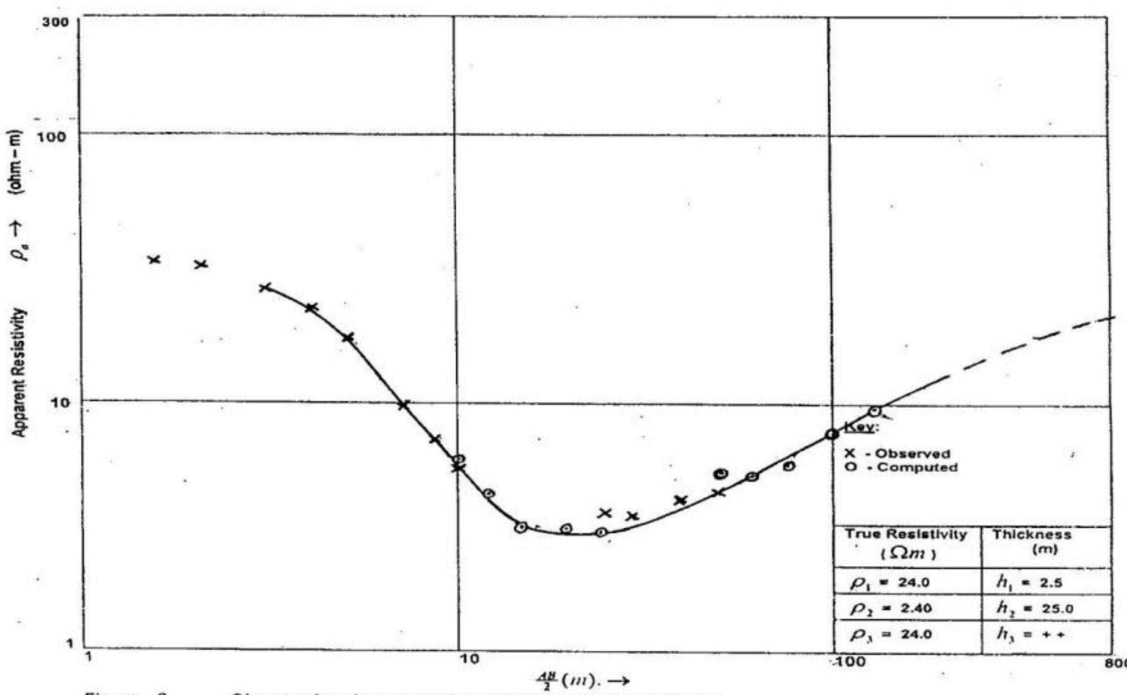


Figure 8 Observed and computed resistivity curves for VES: 2M

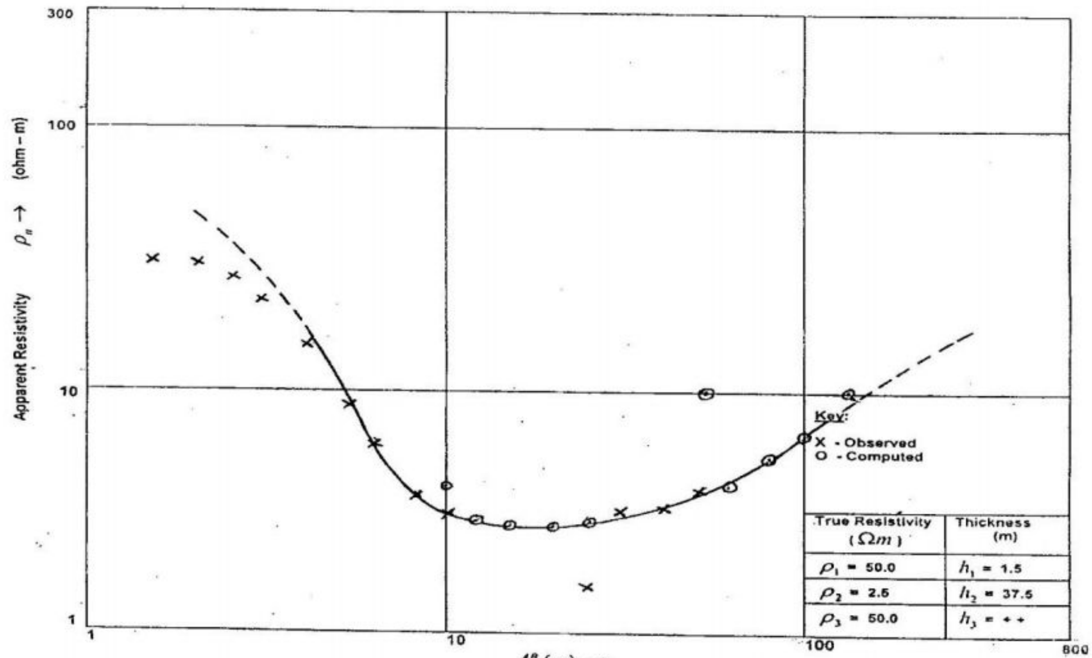


Figure 9 Observed and computed resistivity curves for VES: 3M

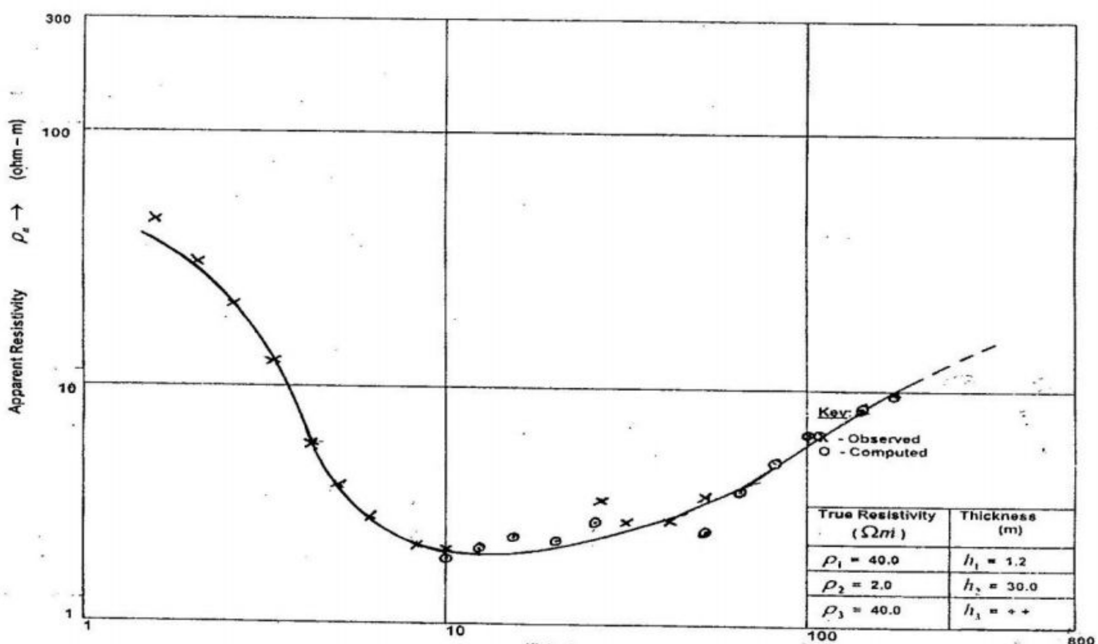


Figure 10 Observed and computed resistivity curves for VES: 4M

Interpretation of Resistivity Curves

The ability of a rock unit to conduct an electric current depends primarily on three factors. These are:

- The amount of open space between particles known as porosity.
- The degree of interconnection between the soil open spaces.

- The volume and conductivity of the water in the pores.

The presence of water and its chemical composition are the principal control factors on the flow of the electric current because most of the rock particles offer high resistance to electric flow. The resistivity decreases as porosity, water content, and water salinity increases. For groundwater the resistivity values vary mostly between 10 to 100 ohm-m.

The interpretation of the obtained VES curves is frequently accomplished by curve matching technique. The method generally involves matching small segments of field data with theoretically computed standard resistivity curves using a set of Orrellana Mooney Master Curves [Mooney and Wetzel, 1956] which enables one to determine both the thickness and apparent resistivity of a particular layer. This method is however, complex to handle and it requires an experienced personnel. Alternatively, a computer software [Mooney, 1974] is used to compute a layered earth model using least square technique to match the theoretical apparent resistivity curves as close as possible to the field curves. In these studies, the results of the interpreted VES resistivity values for the two study areas are presented in Table 1 and Table 2 for Kwamndolwa and Mwisho wa Shamba Villages respectively. Most of the VES carried out had a 3-layer geoelectric section, and normally the top layer consisting of alluvium soil mixed with sand. Its resistivity decreases with increasing clay content in the intermediate layers, while in the last layers is either sandstone, lime or shale formations. These are easily be distinguished from their resistivity values as can be seen in Table 1 and 2. The exact characteristics of each earth layer will however, be determined after borehole drilling test at the sites have been made.

Table 1: Apparent VES resistivity values over Kwamndolwa study area

VES No.	Apparent Resistivty Values (ohm-m)				Layer Thickness (m)			
	ρ_1	ρ_2	ρ_3	ρ_4	h_1	h_2	h_3	h_4
1K	24.0	4.8	7.2	Inf. high	0.72	7.20	123.00	++
2K	27.0	5.0	11.0	Inf. high	8.00	80.00	237.50	++
3K	9.0	3.6	10.9	Inf. high	0.36	5.40	82.00	++
4K	8.5	3.2	8.0	Inf. high	0.42	6.30	97.50	++

Table 2: Apparent VES resistivity values over Mwisho wa Shamba study area

VES No.	Apparent Resistivty Values (ohm-m)				Layer Thickness (m)		
	ρ_1	ρ_2	ρ_3	ρ_4	h_1	h_2	h_3
1M	23.0	2.4	9.4	Inf. high	2.40	24.00	++
2M	24.0	2.4	24.0	Inf. high	2.50	25.00	++
3M	50.0	2.5	50.0	Inf. high	1.50	37.50	++
4M	40.0	2.0	40.0	Inf. high	1.20	30.00	++

Key:

Inf. High – Infinity high value of resistivity that could not be determined.

++ - Increasing layer thickness that could not be determined.

DISCUSSION OF RESULTS

The results of apparent resistivity curves obtained for (VES 1K – 4K) for Kwamndolwa and (VES 1M – 4M) for Mwisho wa Shamba study areas shown in Figure 3 through 6 and in Figure 7 through 10 respectively, compare very well with the theoretical standard master curves.

After the obtained VES curves have been individually interpreted the layer thicknesses corresponding to the apparent resistivity values have been computed to obtain a consistent project wise picture of the subsurface geology of the study areas. In both study areas, all the VES carried out had a 3-layer geophysical section. The apparent resistivity values of the first-, second-, and third- layers at Kwamndolwa study area range from 8.5 to 27.0; 3.2 to 5.0 and 7.2 to 11.0 ohm-m respective, and for the case of Mwisho wa Shamba study area, they range from 23.0 to 50.0; 2.0 to 2.5 and 9.4 to 50 ohm-m. Beyond the third-layer resistivity values for both study areas are infinity high and could not be determined.

The low apparent resistivity values of the top layers for VES-1K, VES-2K and VES-4K sites at Kwamndolwa study area indicate the presence of alluvium soil with layer thicknesses of 0.72, 8.0 and 0.4 m respectively. The apparent resistivity for VES-2K was found to be 27.0 ohm-m indicating the presence of water with a top layer thickness of only 0.36 m. The intermediate layers (second-layers) obtained for all the four sites indicate the presence of clay with less water bearing significance. In the last layers, only site VES-3K with resistivity value of 10.9 ohm-m gave an indication of the presence of water in a sandstone formation extending to a depth of 82.0 m. Based on this data, water extraction can therefore be made at a depth of 60 m which is technically and economically feasible than at site VES-2K where a very deep drilling would be required.

A different trend of VES carried out at Mwisho wa Shamba study area, recorded the resistivity values of the top layers for VES-1M to VES-4M, to be in the range between 23.0 and 50 ohm-m, indicating the existence of water of varying quality in the alluvium soil mixed with sand with layer thicknesses ranging between 1.2 and 2.5 m only. The intermediate layers at these sites indicated the presence of clay with less water bearing significance. In the last layers, only site VES-2M with resistivity value of 24 ohm-m indicate the presence of water bearing sandstone formation, extending to a depth of 37.0 m. At this site water extraction at a depth of 60 m is also considered to be technically feasible than at VES-M3 and VES-M4 where the lower basements have either lime or shale formations with less water bearing significance. Apart from the investigation of the groundwater potential of the study areas, it is envisaged that the obtained results will provide vital information for those working in the field about the wells drilling locations, and probably the depth at which good quality water striking is expected. The exact rock profiles of the areas being studied will therefore be revealed by a geologic log plot to be obtained by examining well cuttings to be collected during drilling tests. Examination of water samples to be collected at the two sites shall also confirm the quality of water including its pH. As far as is also known, there are no published geophysical studies in the study areas.

CONCLUSIONS

This study has provided a useful information based on geophysical investigations in view of boreholes siting at the two study areas. The geophysical investigations were conducted by applying the well known VES technique that allow to trace the presence of groundwater resources bearing formations at the two study areas.

Data obtained from the field survey were computed to derive the apparent resistivity values for different electrode spacing that were recorded. The apparent resistivity values plotted against electrode spacing as double log-graph sheets having 62.5 modulus were interpreted by curve matching using standard master curves [Mooney and Wetzel, 1956] to check the validity of an interpretation of field data.

Following an individual interpretation of VES curves, the computation of the corresponding layer thicknesses for each resistivity value has been made and their results are presented in Table 1and 2 for the two study areas. Although the investigated areas fall within a zone with variable salinity conditions (resistivity values normally less than 1.0 ohm-m), two sites VES-3K and VES-2M were found to have apparent resistivity values greater than 10 ohm-m, indicating the presence of sandstone basement formations with water bearing significance. These results suggests that the aquifers could carry good quality groundwater resources depending on the concentration of salt that would be confirmed during drilling tests. The study has therefore yielded some useful results that are going to be applied for groundwater development schemes for Kwamndolwa and Mwisho wa Shamba Villages, through a carefully controlled pumping and well development surveillance programme.

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