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MAPPING GROUNDWATER AQUIFERS USING DOWSING, SLINGRAM ELECTROMAGNETIC SURVEY METHOD AND VERTICAL ELECTRICAL SOUNDING JOINTLY IN THE GRANITE ROCK FORMATION: A CASE OF MATSHETSHE RURAL AREA IN ZIMBABWE

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ABSTRACT

A survey was conducted in Matshetshe area, under the Filabusi district of Zimbabwe, to find groundwater by jointly using the Slingram electromagnetic survey method and dowsing method in traversing. The two methods independently managed to locate the same positions of high groundwater potential. The vertical electrical sounding was then done in the anomalous positions. This was to provide the depth of the weathered layers above the bedrock. Traversing results show that dowsing, an ancient traditional method of exploration, can be used jointly with the modern traversing geophysical methods in finding groundwater. The study revealed, for more accurate results, that the three methods must be analyzed jointly to overcome the vulnerability of errors linked to a single method. The information from the three methods was used to pinpoint prospective drilling sites for groundwater with a high degree of accuracy.

Key Words: Apparent resistivity, Dowsing, Profiling.

INTRODUCTION

Globally, water is one of the most important natural resource, which is obtainable as either ground water (GW) or surface water. GW environment is largely hidden from view, except from subsurface openings, like caves and mines. This gives people misleading impressions that the earth is solid and that GW occurs only in underground rivers and caves, whereas, in reality, most of the subsurface environment is not solid at all. It includes countless tiny pore spaces between grains of soil and sediment, plus narrow joints and fractures in the bedrock. Together, these spaces add up to an immense volume. It is in these small openings that GW collects and moves (Fredrick & Edward, 2003). Water extracted from the ground has three main uses: agriculture, industry, and urban consumption (Elizondo & Lofthouse, 2010). It is also, generally, free from bacteriological pollution and, therefore, safe for human consumption.

In Zimbabwe, an increased demand for GW has resulted from population increase, socio-economic development activities (Ranganai & Ebinger, 2003), and a degenerating economy characterized by the cholera outbreak in the period 2008 to 2009. This was due to the lack of access to safe water in the country. The principal cause was the collapse of the urban water supply, sanitation, and garbage collection system, along with the onset of the rainy season leading to faeces with cholera bacteria being washed into water sources. Due to shortage of water purification chemicals, such as chlorine, the capital city of Harare stopped receiving piped water as of December 2008 (WHO, 2008). Thus, drilling boreholes of sustainable yields in Zimbabwe became paramount to save life.

The search for GW in Zimbabwe has been in existence for several years. Traditionally, the dowsing exploration technique was used to detect groundwater. Dowser use forked sticks, pendulums, or wire rods to detect groundwater. A recent scientific appraisal suggests that dowsing might be based on a human response to changes in the earth's magnetic field, similar to the principles of navigation applied by whales and homing pigeons (Williamson, 1987). To try and justify the use of dowsing as a reliable and cheap technique of GW exploration, a German Association for Technical Cooperation conducted a project for third world countries. Two thousand sites in arid regions of Sri Lanka, Zaire, Kenya, Namibia, and Yemen were used over a period of 10 years (Hans-Dieter, 1995). Findings indicate a success rate of 96%. In Sri Lanka, a 96% success rate was obtained out of the 691 holes drilled. Furthermore, in hundreds of cases, the dowsers were able to predict the depth of the water source and the yield of the well to within 10% or 20%. It is important to note that no theoretical explanation was available of how dowsers really detected the presence of GW. However (Hans-Dieter, 1995) recommended the use of dowsing in conjunction with modern geophysical techniques to enhance the reliability of detecting sustainable ground water at a significantly lower cost.

The use of multiple methods to explore for GW triangulates data and overcomes the vulnerability to errors linked to a single method (Patton, 1990). In choosing the combining of surveying methods, we also took into account that it has been used, cost effectively, in a number of countries yielding successful results. Findings show that in Kenya, the Lake basin development authority in the initiation of the rural domestic water supply and sanitation program in Nyanza province (van Lissa, van Maanen, & van Odera, 1987) combined electromagnetic and Wenner profiling methods, in conjunction with the Schlumberger depth finding method, in exploring for GW. A success rate of around 80% of the boreholes drilled was obtained. Additionally, the average depth is only half that of existing boreholes, with a yield about 140% or higher.

GEOLOGY OF THE AREA

The Matshetshe area lies in the central region of the Matabeleland South province in Zimbabwe, which generally receives an average, annual rainfall of 538 mm (Baglow, 1998). The area is prone to seasonal droughts. The geology of the area is dominated by the Archaean granitic and gneisse rocks. These comprise of proterozoic intrusive granites, porphyritic granite, and tonalite of the younger granitoids (Baglow, 1998). The area consists of a shallow depth of weathering, of approximately 20 m - 40 m (Martinelli & Hubert, 1985). In most Impala farm areas, granite rock outcrops are extensively on the surface. In such areas, GW development potential is marginal to nil, but aquifers in these granite and gneissose rocks are controlled by secondary porosity and permeability. Therefore, GW in this area is confined to areas of weathering and fracturing. With all geomorphological factors being equal, the highest GW development potential is found in those areas possessing the deepest and most spatially extensive weathering (Astier, 1971).

METHODOLOGY

A desk study was the first step in this research, where the aerial photographs of the area was analyzed using a desk stereoscope. Features showing signs of high potential of GW were identified during this first step. These include fault systems and accompanying valleys, which appeared as dark lineation. This is due to increased soil moisture and vegetation density. Then a hydrogeological fieldwork reconnaissance of the area understudy was carried out. As a result, the area was divided into two GW potential availability zones. The southern part of the area was rated as having high GW availability, whilst the rest had medium to low availability.

The main fieldwork, involving geophysical measurements and dowsing, was then done, where the Geonics EM34-3, operating at a frequency of 1.6 Hz, was used in traversing, using the Slingram system. A low frequency signal was used to maintain a low induction number (McNeill, 1980). A point spacing of 40m was used for all profiles. This allowed us to explore a depth of up to 30 m deep. The profiles were 1,000 m long. These we designed so that they cut perpendicular across the fault systems that were observed from aerial photographs. At each station, measuring the measurements was performed with the instrument placed directly on the ground surface. Measurements points were selected carefully to avoid cultural magnetic sources. In cases impossible to eliminate the influence of cultural magnetic sources, data was eliminated during the preprocessing.

Then, dowsing was done using a “Y” shaped forked stick. This was done by a local experienced dowser, who went along the surveyed electromagnetic profile lines. The dowser held one fork in each hand with the palms upwards. The bottom of the stick pointed upward at an angle of approximately 45 degrees. The dowser moved back and forth along the profile lines. To achieve high concentration, the dowser ensured the area was clear from any onlookers’ interference. The bottom end of the forked stick was attracted downwards when the dowser passed over a possible water vein.

In the third and final step, direct current electrical resistivity equipment, comprising of an Abem terrameter SAS 300C transmitter/ receiver system, was used to perform VES. The choice of this equipment was made in view of its reliability, in all logical conditions so far encountered within Zimbabwe (Hallet, 1999). Stainless steel electrodes were used, since they are strong and are resistant to corrosion (Telford, 1990). Five soundings were done on the anomalous points observed by the dowser and slingram-system during the survey along the profile lines. The Schlumberger VES method involved moving electrodes progressively and symmetrically apart. This was followed by taking and recording of the resistivity data at certain electrodes spacing. Two distinct advantages of taking readings by moving the current electrodes were considered in preference to other methods. These are: (1) there are fewer electrodes to move and (2) the readings are less affected by any lateral variations that may exist (Mussett & Khan, 2000). At some points, the expansions of the current electrodes resulted in a too small of potential difference values, which became difficult to precisely measure. We overcame this problem by moving potential electrodes further apart, while keeping the current electrodes fixed. Further readings were, then, taken by expanding the current electrodes, using the new potential electrode positions. This also allowed an increase in the depth of the investigation.

RESULTS AND DISCUSSIONS

GW was expected to be found in the weathered zone or the fractured bedrock in this area of study. Thus, traversing allowed us to locate zones of fracturation or contact zones, which are potential areas for the storage of large quantities of GW. The EM34-3 data measured from all the profiles were plotted against distance into graphs and then interpreted per profile. Results of the three profile lines are shown on figure 01, 02 and 03.

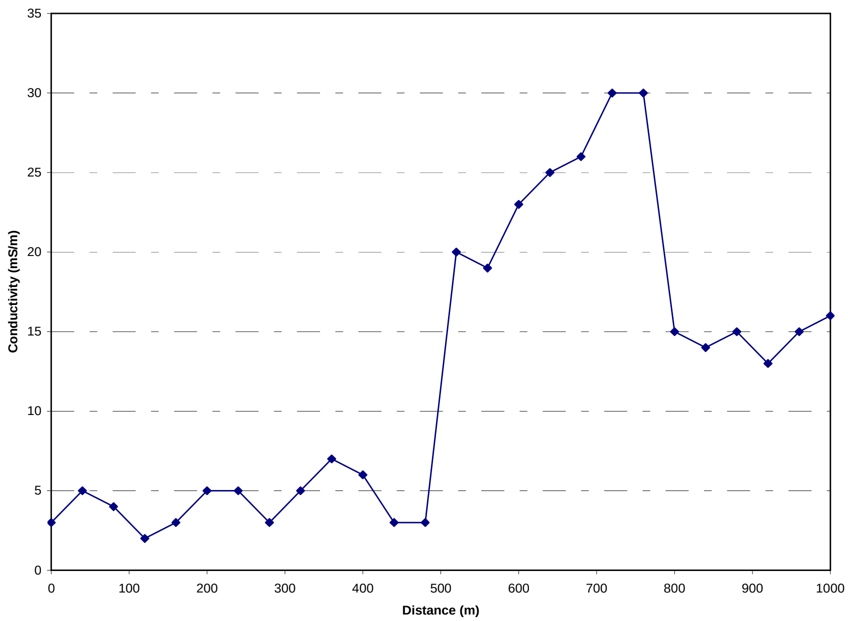

Figure 01: Plot of EM34-3 data from profile line 01 in the study area.

Profile 1 show that there is an area of high conductivity between the 350 m to 850 m that was marked from the origin. The position exactly laid on a fault system that was observed from aerial photographs of the study area. The dowser also clearly located the sites, stating that the turning effect was so strong that the bark peeled off the handles as the forked stick rotated in his hands. This, according to the dowser, indicated a huge water vein at a depth of approximately 40 m.

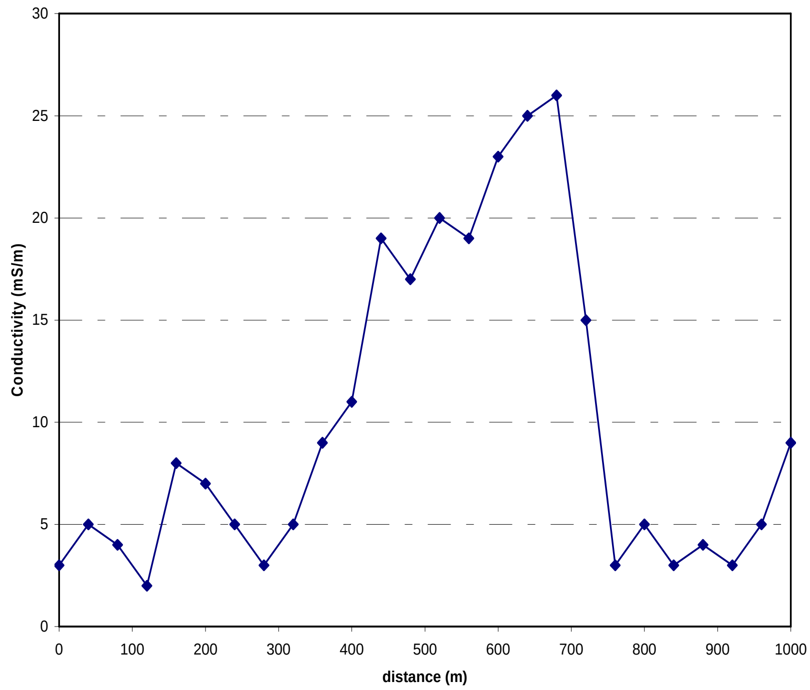

Figure 2: Plot of EM34-3 data from profile line 02 in the study area.

Profile 2 shows that the conductivity of the area is on average low between the origin and 300 m, then rises sharply to values above 25 mS/m, between 500 m and 850 m, and, thereafter, falls to around 13mS/m, between 850 m and 1000 m. This is presumed to be a contact zone, which may act as suitable aquifer. The contrast indicated the existence of a narrow dolerite dyke in this granite dominated area. The dowsing results were also located in this anomalous area. The dowser claimed a strong turning effect on the forked stick at 500 m from the profile origin.

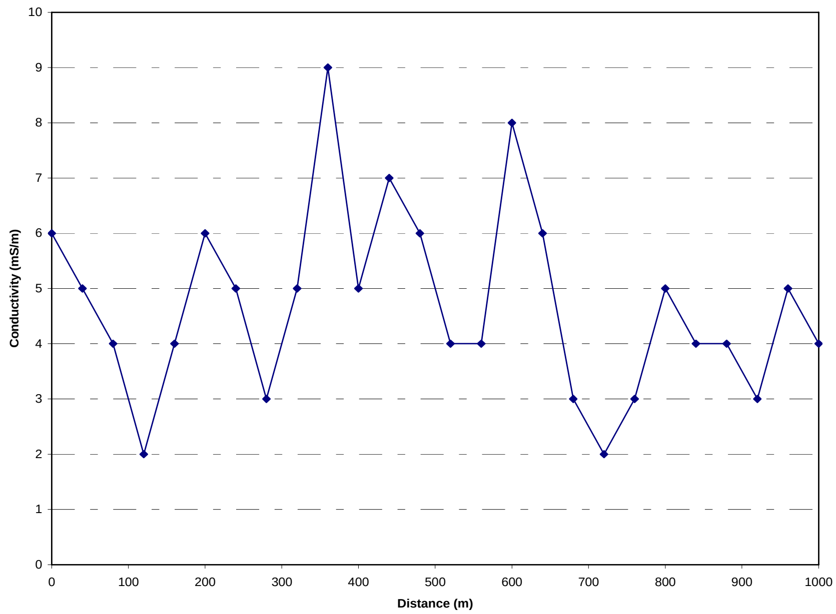

Figure 03: Plot of EM34-3 data from three profile line 03 in the study area.

The results of Profile 03 show that the conductivity of this area is a continuous variable along the traverse line. The area with lower conductivity of the range, 3mS/m, is clearly noted between 300 m - 400 m and 600 m - 1000 m. This may be interpreted as the granite rock basement reaching closer to the surface. This is evidenced by granite outcrops rocks in the surrounding areas. The results of dowsing coincided with EM34-3 results at the 450 m mark from the origin. But differences occurred at 600 m with the dowser claiming a weak turn, indicative of a small water vein.

The Schlumberger depths sounding were performed to simulate the thickness of the different underlying layers and their corresponding resistivities. The apparent resistivity data obtained from selected VES sites were plotted against half the current electrode spacing. The method of interpreting sounding curves uses curve matching techniques. This involves matching small segments of a field curve with an approximate theoretical curve, which enables one to determine both the thickness and apparent resistivity of particular layers in a half space (Cooper, 2000). From the interpretation of the resistivity curves, three layers of the subsurface are shown. These layers consist of the topsoil, regolith, and bedrock. The depth and thickness of subsurface layers were identified at the same time, giving the dimension of the aquifer. Simulated geophysical models, together with resistivity curves are shown on figure 04, 05, and 06. The sounding curves, generally, showed higher resistivities for the top layers of varying thickness. The second layer has resistivity values ranging between $50\,\Omega m$ and $150\,\Omega m$, which are the optimum groundwater target areas. The third layer consisted of the bedrock, with high values of resistivities.

The first VES was conducted 640 m from the beginning of profile line 01.

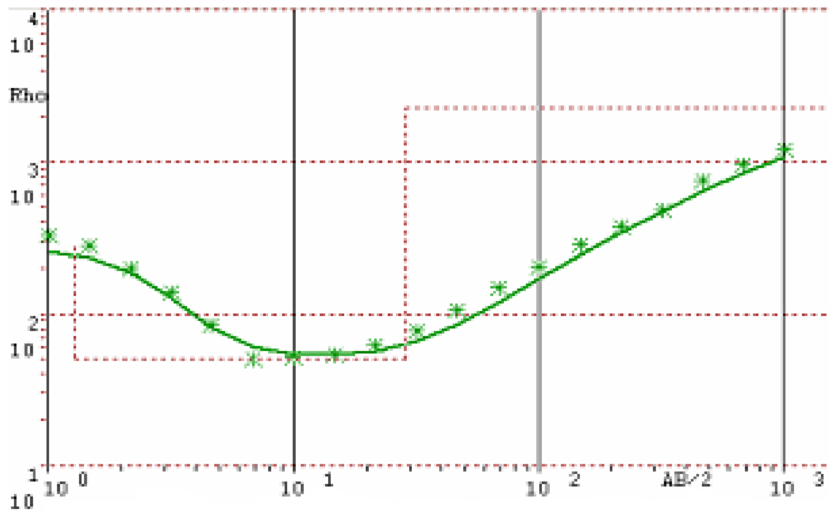

Figure 04: Interpreted model of Observed and computed resistivity Schlumberger depth sounding data from the VES 130 forward modeling program, at the 600m mark point along profile 1.

The resistivity values, as indicated by the VES curve, shown on figure 04, dropped from high resistivity values of 274 Ωm in the overburden, to a minimum value of about 53 Ωm . This showed that the weathered zone is highly saturated with GW. Its vertical thickness was about 31 m, which is enough to store a large quantity of GW. The depth to bedrock is about 35m, which is deep enough for areas where water is expected to come from the weathered zone. The bed rock has a higher resistivity value of about 1020 Ωm . It is probably fractured, hence saturated with water. Since the site was accessible with heavy drilling machinery, it was selected as a possible drilling site. Later, a borehole was drilled at this site to a depth of 70m. It struck water at various levels, with a static water level at 20m below ground level. A third VES was conducted 500 m from the beginning of the profile line 3. The geophysical resistivity curves, as shown on figure 4, dropped below 150 Ωm to a minimum value of about 103 Ωm , which is indicative of water bearing a geological structure underneath. The resistivity values, as indicated by the VES curve on figure 05,

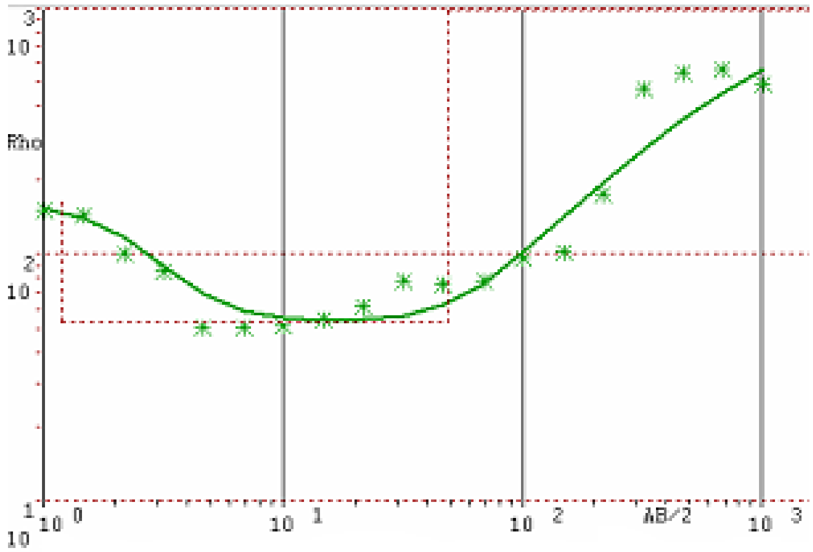

Figure 05: Interpreted model of Observed and computed resistivity Schlumberger depth sounding data from the VES 130 forward modeling program, at the 750m mark point along profile 2.

Shows that the weathered zone is highly saturated with GW. Its vertical thickness is about 40 m, which correlates mostly linearly with the quantity of the GW. The site is located at a well pronounced fault system. The depth to bedrock is about 48 m, which is quite deep and suitable for large quantities of GW in this area. GW is mostly expected to come from the weathered zone. The bedrock has a higher resistivity value than the weathered of about 1200 Ωm. The third VES results are shown on figure 06.

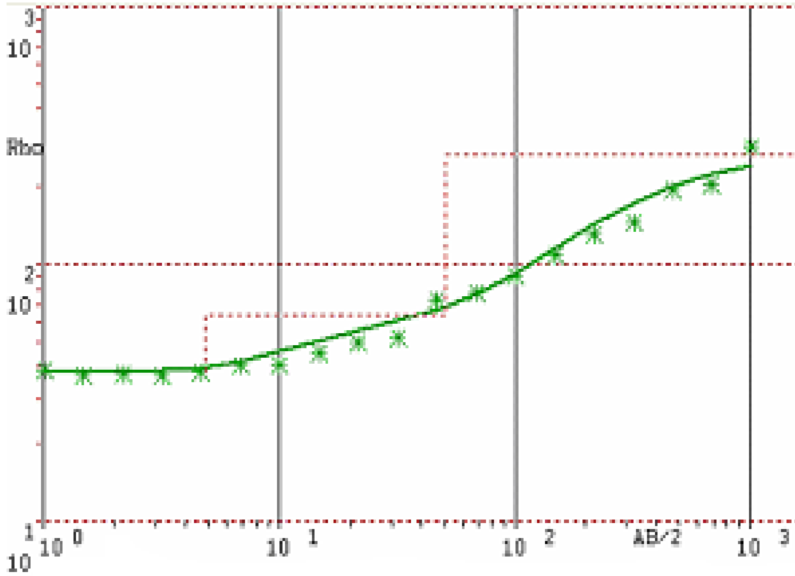

Figure 06: Interpreted model of Observed and computed resistivity Schlumberger depth sounding data from the VES 130 forward modeling program, at the 500m mark point along profile 3.

The resistivity data, shown on a graph of a resistivity curve, dropped from high values of 274 Ωm in the overburden, to a minimum value of about 50 Ωm in the weathered layer. This indicates that the weathered zone is highly saturated with GW. Its vertical thickness is about 28m, which is adequate to store a large quantity of GW. The bedrock has a higher resistivity value of about 1032 Ωm. The depth to bedrock is about 30 m. However, the lateral thickness of this site was too thin to allow the drilling of a high yielding borehole. The dowsing results also indicated a small water vein, due to a weak turning effect on the forked stick. As a result, this site, at 400 m on profile, was not recommended for drilling.

CONCLUSION

The slingram electromagnetic method and dowsing profiling gave the same results in the majority of cases. They jointly allowed the accurate identification of faults, intrusive dykes, or lithological boundaries. In this study dowsing proved to be an alternative, local available and a cheaper method of profiling when finding GW. Its usefulness becomes more reliable, when used in together with other modern geophysical methods. The VES method provided thickness of the aquifer. The triangulation of the three methods allowed the siting of boreholes with high yields of water. These could be used for small scale irrigation and provide water for livestock in this rural impoverished area. The proposed formula can only give successfully results if all data acquired is thoroughly analysed and jointly interpreted.

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