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-RESEARCH ARTICLE-

Correlation of Self Potential and Ground Magnetic Survey Techniques to Investigate Fluid Seepage in Archaeological site, Sungai Batu, Lembah Bujang, Kedah, Malaysia.

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Abstract

One of the substantial of geophysics is to investigate the subsurface condition of the earth (groundwater) using appropriate geophysical techniques. In this research the correlation of self potential (SP) and ground magnetic methods was used to investigate fluid seepage in Archaeological site, Sungai Batu, Lembah Bujang, Kedah, Malaysia. Self-potential method was used to determine flow of water, and Ground magnetic method was used to find object that can influence the result of self potential measurement and the aquifer depth, the lines were spread 0m $\leq$ x $\leq$ 9m, 0m $\leq$ y $\leq$ 30m with a trace intervals of 1.5m and 0.75m per electrode spacing respectively. The result display by Self Potential signals gives a clear understand that water flow from higher value (central) towards the lower value which is mostly at the southwest part than other areas and distinct level of feasible flow at different part ranges from -30mV to +35mV,which are very related to seepage flow patterns, negative SP anomalies were related with subsurface seepage flow paths (recharge zone) and positive SP anomalies were related with areas of seepage outflow (discharge zone); and Ground Magnetic signals shows good details of the buried materials with high magnetic values which was interpreted as baked clay bricks and low magnetic values indicate groundwater seepage with depth of 5m. Therefore, the two results have correlation significant at 0.8 which show good correlation in groundwater investigation in this study, which validates the results.

Keywords:

Correlation, Groundwater, Magnetic, Seepage, Self-Potential

Article history:

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Introduction

Water flows through the voids in a soil which are interconnected; since the velocities are very small. Water flows from a higher energy to a lower energy and behaves according to the principles of fluid mechanics. A flow line is the path a water particle would follow in moving from upstream to downstream. Ground water commonly is an important source of surface water, the contribution of ground water to total stream flow varies widely among streams, but hydrologists estimate the average contribution is somewhere between 40 and 50 percent in small and medium-sized streams Mizunaga et al. (2006), Wightman et al. (2003), USGeological Survey (2017). This paper aimed to used self potential and ground magnetic survey techniques to investigate fluid seepage in the study area and then correlate the two results. Electrokinesis is a process in which flow of fluids through a porous soil on rock generates electrical voltages (potentials), these potentials are called streaming or self potentials (SP) Revil et al. (2017), Zhang et al. (2017). The magnitude of the SP depends on the dielectric constant, electrical resistivity and viscosity of the fluid, on a coupling constant between the fluid and the soil/rock, and on the pressure drop along the flow path DesRoches et al. (2018), Leonard et al. (2011), Bogoslovsky & Ogilvy (1972). The SP anomaly caused by the flow can be measured on the surface above the flow path; this is the basis of the SP method for seepage detection and mapping.

Basic Concept of Self-Potential Method

Self-potential (SP) method is a passive geophysical technique, which measures extremely small, naturally occurring voltage variations in the earth, the technique is based on the observation that when certain materials are in contact with either a different material e.g. buried iron next to buried copper or a localized change in the condition of the same material e.g. interface of saturated and unsaturated condition, an electrical current is created Mizunaga et al. (2006), Bogoslovsky & Ogilvy (1972). This current is readily detectable with inexpensive, portable voltage measuring instrumentation, the technique is simple to operate, consisting of a series of measurements of electric potential (voltage) across two electrodes which are in contact with the ground and spaced at varying distances. The most relevant application of this method to environmental investigations is the tracing of shallow locate seepage zones when such zones are known to exist Ogilvy et al. (1969), Telford et al. (1976). The SP method is extremely sensitive to man-made electrical interferences, SP data is generated from measurements of naturally occurring electric potentials across two electrodes placed on the earth's surface and the potentials measured during these surveys are small, generally less than 100 millivolts, and may be positive or negative to locate anomalies of interest as stated by EPA (2016), Grant & West (1965), Giampaolo et al. (2017). Sources of SP effects are varied and include oxidation of sulfide mineral deposits, bioelectric activity in vegetation, varying electrolytic concentration in water, fluid motion through a porous medium called streaming potentials, and a variety of other meteorological e.g., thunder storms and geochemical sources Dobrin (1976), Zohdy et al. (1974), Roubinet et al. (2016).

Basic Concept of Ground Magnetic Method

Magnetic method is a passive geophysical technique which measures the strength of the total magnetic field at any given point on the earth; magnetic survey is used in environmental investigations to detect magnetic anomalies variations in the expected field which can be attributed to the presence of buried steel or iron objects as stated by Teh-Saufia et al. (2013), Rao & Murthy (1978), Nordiana et al. (2014). Magnetic surveys are always used to detect induced magnetism in iron and steel objects such as underground storage tanks (USTs), buried drums, and ferrous landfill refuse, performed as part of environmental investigations; these materials are unique for their ferromagnetic ability to be magnetized said by Nettleton (1973), Nordiana et al. (2013). The results of magnetic surveying can be used to direct excavation activities of buried drums and USTs, to direct the placement of both up-gradient and down-gradient monitoring wells in conjunction with data regarding the known or inferred direction of groundwater flow to facilitate the assessment of potential releases of contaminants from these objects on water quality. Magnetic methods were successfully used to delineate bedrock fracture zones as a result of the weathering of hematite to limonite in certain fracture zones as in Nettleton (1973), Nordiana et al. (2013). Differences in temperature, pressure and composition within the outer core cause convection currents in the molten metal as cool, dense matter sinks whilst warm, less dense matter rises. The Coriolis force, resulting from the Earth's spin, also causes swirling whirlpools Zohdy et al. (1974). A resultant magnetic field is created which encompasses the earth and can be represented as a vector quantity having a unique magnitude and direction at every point on the earth's surface. The earth's magnetic field is not completely stable says by Teh-Saufia et al. (2013). Both naturally-occurring and man-made magnetic materials can locally modify the earth's magnetic field as reported by EPA (2016). Therefore, the use of a base station is usually a prerequisite for reliable survey data. Remnant or residual magnetism is observed in many igneous and metamorphic rocks. The remnant magnetic orientation is usually stable and remains as a characteristic of the material, this remnant magnetic orientation is probably different from that of the earth's current magnetic field, given the propensity of the earth's magnetic field to wander magnetic north is constantly moving, although it appears to be relatively fixed with respect to human reference periods and even reverse several times over the course of geologic history reported by Ogilvy et al. (1969), Telford et al. (1976), Rao & Murthy (1978), Nordiana et al. (2014). Various forms of magnetometers are used in land, airborne and marine type operations such as (a) the total field proton precession magnetometer,(b) the vertical magnetic gradiometer, and (c) the fluxgate magnetometer, Telford et al. (1976), Nettleton (1976) discuss in detail the operation and construction of these and other magnetometers.

Study Area

Archaeological evidence suggests that Kedah is the oldest civilization site of Peninsular Malaysia. Before the sea route around the peninsula was firmly established, trade between India and China was conducted across the peninsular isthmus. Kedah sits in the northwest corner of Peninsular Malaysia. The state is fairly small, covering an area of 9,425 sq km that consists mostly of expansive padi fields and gently rolling hills. Off its coast are the isles of Langkawi, and rising to meet the western shoreline is the mountain of GunungJerai 1,200meters above sea level by Blogger (2013).

Methodology

The study was done in Archaeological site, Sungai Batu, Lembah Bujang, Kedah, Malaysia, the area is an open field void of grasses, has nearly flat topography and surrounded by palm trees in all sides, there are four (4) lines for both SP and Magnetic survey each as shows in figure 1.The lines were spaced every $0m \leq x \leq 9m$, $0m \leq y \leq 30m$ with a trace interval of 0.75m for electrode spacing and 3m per line with 39 stations for each line using pole-dipole (PDP) array for magnetic survey. SP survey, the base porous pot was buried below water level in a shaded area devoid of grass cover, and a moving porous pot to measure potential differences on a gridded survey, lines were spaced every 0m ≤ x ≤ 9m, 0m ≤ y ≤ 30m with a trace interval of 3m for electrode spacing, 3m per line with 21 stations for each line, between latitude 5.69400N–5.694265N and longitude 100.454582E–100.4547866E. According to Ogilvy et al. (1969) present the geophysical methods; magnetic survey and 2-D resistivity survey at Lembah Bujang, Kedah with purpose to study the archeological prospection with the objective to locate the buried structure remain in the area for shallow investigations. The results of high magnetic values (30-180nT) indicated a distribution of the anomaly features within the study area, these anomaly features are find according to the magnetic contrast (baked clay bricks) and the surrounding, mainly sandy clay. The 2-D resistivity profiles obtained some high anomalies (up to 3500ohm-m), the inversion results reveals that a rectangular gridding pattern and a dense anomaly existed in depth range 0-1m. Based upon on-site calibration at partly exhumed sites, such anomalies are interpreted as baked clay bricks. The results shows the presented of anomaly with magnetic values vary from -50nT to 180nT. This indicate the existed of buried structure at the area prove with the magnetic contrast (baked clay bricks) and the surrounding mainly sandy clay.

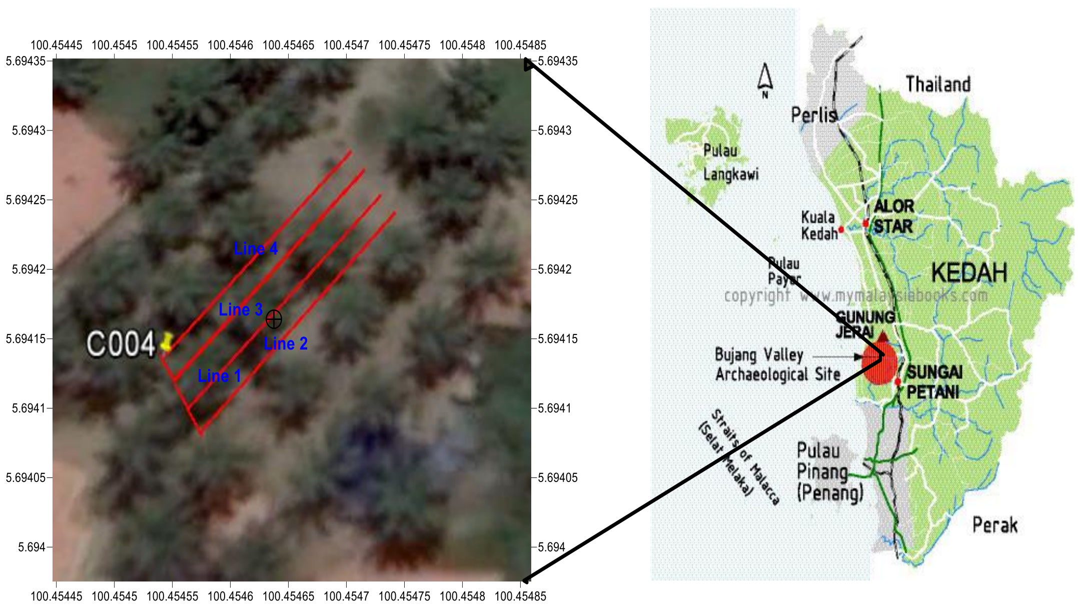

Figure 1: Map of Kedah and Study Area

Field Procedures and Data Acquisition (SP)

Non-polarizing electrodes are used because a standard metal electrode will, when placed in the earth, create spurious self-potential of its own, and are commonly of the porous-pot type, consisting of an unglazed ceramic pot containing a metal electrode and a saturated electrolytic solution, the solution contain a salt of the same metal as the central electrode a solution of copper sulfate was used with a copper electrode to prevent the creation of unwanted SP effects. The porous pot is placed on the ground surface, and electrical contact with the earth is achieved by seepage of the electrolytic solution through the porous ceramic. The electrode is connected to the ABEM SAS 300C Terrameter by insulated wire, a base station (reference point) was buried 20cm in a shaded area devoid of grass cover outside the grid, above the water level and not in a reduced environment such as a swamp, while the other electrode was moved to various measurement locations the voltage potential between the reference electrode and the measurement electrode is then measured for each survey point to produce data for contouring or profiling this type of method is known as fixed-base or total field which was used in this survey and the data obtained from the field were then input into Microsoft excel and then model using computer iteration software Surfer 8.

Field Procedures and Data Acquisition (Magnetic)

An instrument called a magnetometer was used in carryout magnetic surveys; the land instruments are light weight and portable, and measurements are taken by three people, however, are susceptible to interferences from man-made structures such as utilities, buildings, and fences. The total field proton precession magnetometer was used in this survey and is the most commonly used magnetometer because it is easy to operate, has no instrumental drift, and can acquire data rapidly. This instrument utilizes the precession of spinning protons of hydrogen atoms in a sample fluid (kerosene, alcohol or water) to measure the total magnetic field intensity, the sensor is oriented with one side facing approximately north and the sensor held stationary during the cycling period; have digital readouts and internal temporary storage of data. When conducting the survey we noted all visible sources of magnetic anomalies and alternating currents, such as buildings, power lines, and any large iron or steel objects and we make sure that all of us is free of magnetic materials such as, watches, phone, glasses and the magnetometer sensor is kept clean to avoid possible magnetic-bearing dirt throughout the survey and the data obtained from the field were then input into Microsoft excel and then model using computer iteration software Surfer 8.

Results and Discussion

Approximations of depth of burial were made using graphical methods of interpretation half-width rules as described in Nettleton (1976); for Self Potential and Magnetic data the depth was obtained from this Equation.

$Z = \frac{M}{2}$, where Z is the depth and M is the half width at the negative maximum

Table 1: Aquifer depth determined from SP data compared with corresponding magnetic survey data

Line No	SP Curve Depth (m)	Magnetic Curve Depth (m)
1	4.5	4.13
2	3.0	4.13
3	6.0	1.5
4	6.75	9.38

$$r = \frac{n\sum xy - (\sum x)(\sum y)}{\sqrt{n(\sum x^2) - (\sum x)^2}\sqrt{n(\sum y^2) - (\sum y)^2}} \quad (1)$$

For both SP and Magnetic surveys were interpreted, the half width rules was used with the distance along the x-axis and SP data and magnetic residual data on the y-axis using excel graph to determined the aquifer depth as shown in Figure 2-5 and the result of half width rules which was obtained from the graph was also shown in Table 1; the mean value, standard deviation, Pearson's correlation coefficient, Testing the significance of r (2-tailed) and Correlation significant at 0.8 which is a strong correlation is shown in Table 2 obtained from Equation (1 & 2).

$$\text{Test significane of 2} - \text{tailed (t)} = \sqrt[r]{\frac{n-2}{1-r^2}} \qquad (2)$$

Table 2: Statistical correlation of aquifer depth acquired from SP and Magnetic data for the four lines

	N	Mean value	Variance	Standard Deviation	Pearson's Correlation Coefficient	Sig. (2-tailed)
SP	4	5.063	2.766	1.663	0.757	1.638
Magnetic	4	4.785	10.921	3.305	0.513	0.845

Correlation is significant at the 0.8 level (2-tailed)

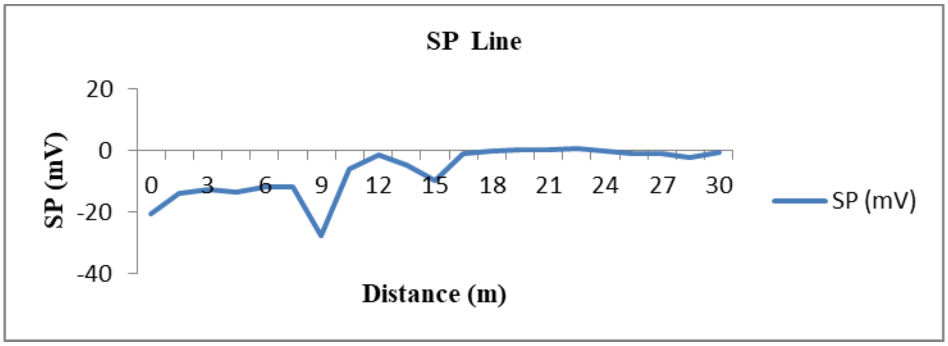

Figure 2. Graph of Investigation

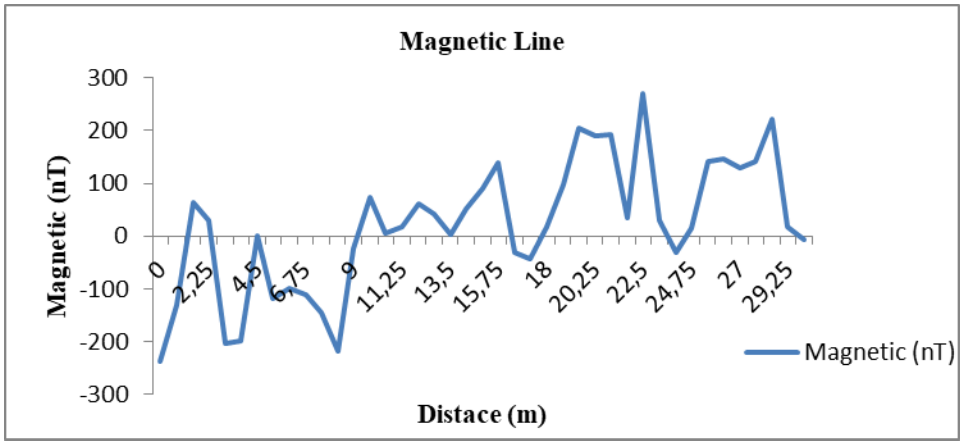

Figure 3. Graph of Investigation

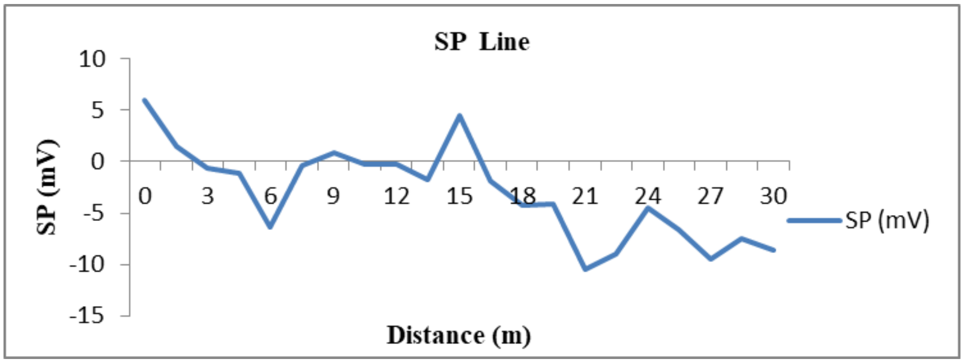

Figure 4. Graph of Investigation

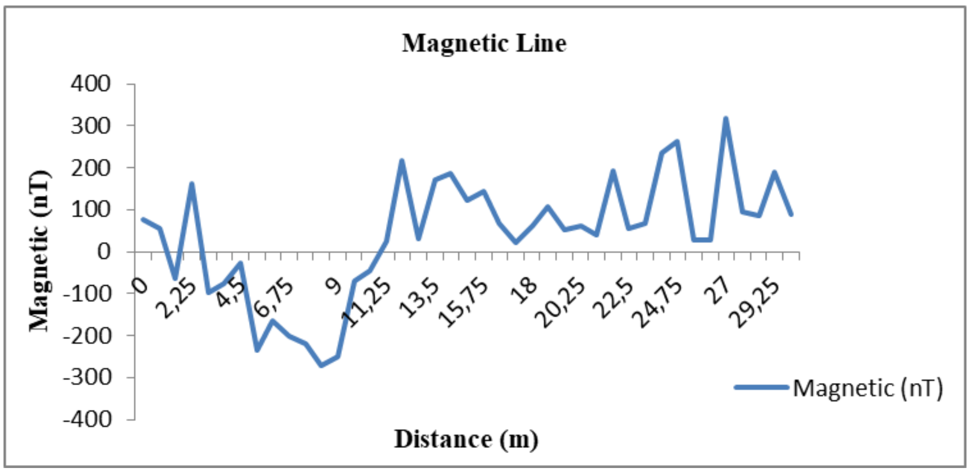

Figure 5. Graph of Investigation

Self-Potential: A total of 84 points were carried out, the field data obtained was interpreted using surfer 8 software, the survey coordinates and SP measurement were input into the software and the results were displayed in contoured map which obtained from non-polarizing copper-copper sulfate electrodes are very related to seepage flow patterns and the anomalies were positive and negative in this study which ranges from -30mV to +35mV as shown in Figure 6, inflow fluid produces negative potentials, the fluid outflow results produces positive potentials, which is in agreement with Mizunaga et al. (2006), Leonard et al. (2011), Teh-Saufia et al. (2013).

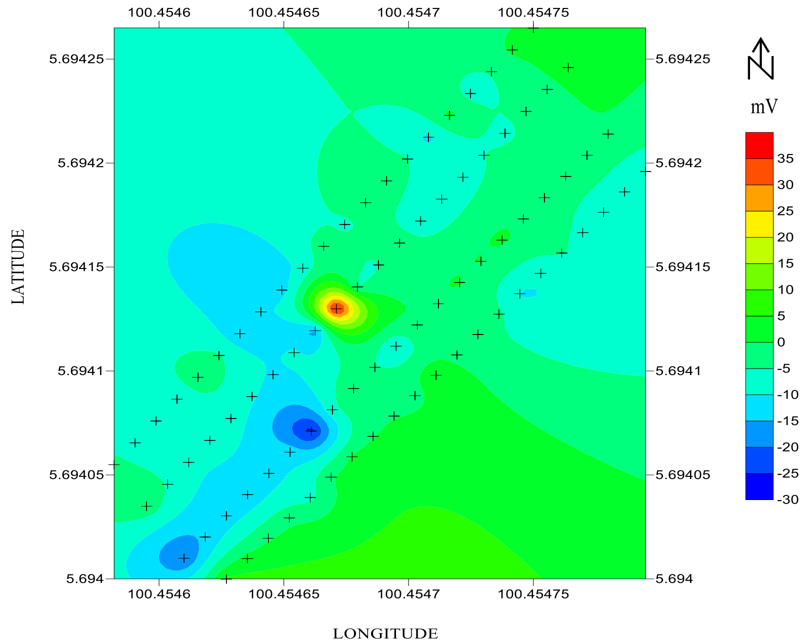

Figure 6. Self-Potential Flow Map

Magnetic: A total of 156 points were carried out, the field data obtained was interpreted using surfer 8 software, the survey coordinates and magnetic residual data were input into the software and the results are displayed in form of contoured map ranges from -40 to 300 nT as shown in Figure 7 and the low magnetic values was interpreted as the underground water and the high magnetic values was interpreted as baked clay bricks.

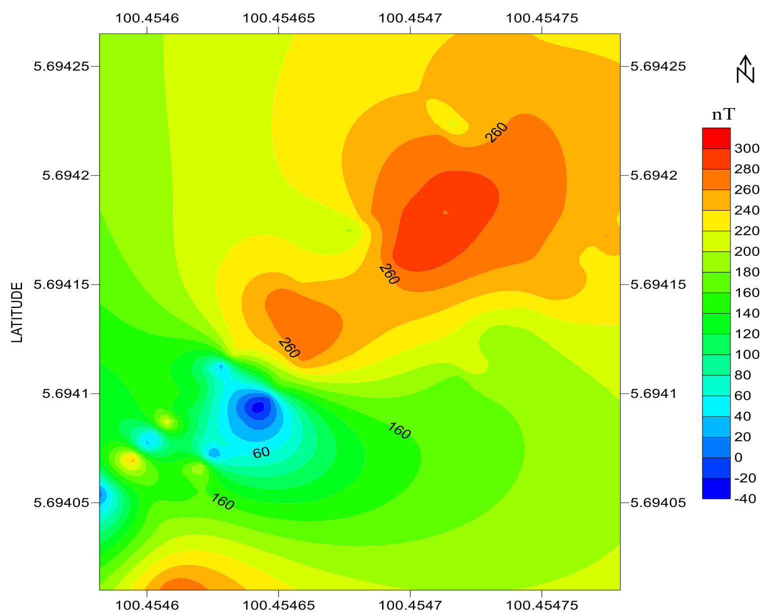

Figure 7. Magnetic Residual Contour Map

In this research the correlation of self-potential (SP) and ground magnetic methods was used to investigate fluid seepage in Archaeological site, Sungai Batu, Lembah Bujang, Kedah, Malaysia. In the Self-Potential surveys, a total of 84 points and in the magnetic search a total of 156 points were carried out, the field data obtained was interpreted using surfer 8 software. These two results have correlation significant at 0.8 which show good correlation in groundwater investigation in this study, which validates the results. It is reported after this research that, self-potential surveys offer an inexpensive method of seepage detection, negative SP anomalies are related with subsurface seepage flow paths and positive SP anomalies are related with areas of seepage outflow and also the positive anomaly higher values with red color to negative anomaly lower values with blue color, it is interested that the negative anomalous area detected the lower values indicates recharge (infiltration) zone for the subsurface which is mostly at the southwest part than other areas while the positive anomalous indicates discharge zone, and when correlated with magnetic surveys or others geophysical techniques. And from magnetic result, the low magnetic values were indicated as the underground water and the high magnetic values were indicated as baked clay bricks in the study area. It also shows that groundwater can be detected by magnetic analysis. The two techniques can also detect aquifer at the depth of 5m which is shallow and we suggested that the resistive layer in the study area is interpreted as unconsolidated and unsaturated. However, the two methods provided useful information about fluid seepage within the study area.

Conclusion

The results revealed the important of self-potential and ground magnetic techniques in delineating fluid flow and the depth in the study area; the data's were analyzed both qualitatively and quantitatively, Self potential surveys have been successfully used to map water seepage paths and the magnitude and sign (±) of self potentials will be affected by seepage flow (streaming potentials), positive anomalies represent subsurface water flow which is discharge area while negative anomalies represent areas of water infiltration (recharge) which is mostly find in the southwest part, which shown that groundwater seepage was the anomalies observed with depth of 5m. Physical aspects still not well understood and quantitative aspects still need to be developed. Software that can be use to interpret and also use to determine the depth to bedrock using Self Potential data effectively should be develop by programmers, because the depth calculated does not give better information that may lead to optimum well sites. The availability of borehole data, hydro-geological information and other geophysical techniques should be use to enhance Self Potential data interpretation.

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