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Groundwater Investigation Using Self-Potential (SP) Method in Part of Kirkuk City - Northern Iraq

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ABSTRACT

Self-Potential (SP) geophysical method is conducted in Seikanian suburban area which is situated at about (5 km) north of Kirkuk City. The study area suffers from deficiency of water supply. To acquire SP data, two survey lines of gradient layout are achieved, one in northern part near the foothill, another is perpendicular to the former, addition 22 grid points of SP measurements spreading over the whole studied area. Water pumping test is carried out in a well with SP reading monitoring the water table drawdown operation by sounder. The aim of study is to delineate underground water accumulation and sensitivity of SP signal to water hydraulic head in the well. The acquired data are interpreted qualitatively and quantitatively after profiling curves and drawing SP contour maps using Surfer 8 Software. The results showed that there is streaming electric potential condition in the subsurface of the studied area indicating groundwater existence and the pumping test procedures with accordance by monitoring SP device proved that SP reading is sensitive to hydraulic head which is a good tool to estimate some hydraulic properties namely water transmissivity and conductivity of the aquifer. The water table depth is about 7 m in the study area.

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التحري عن المياه الجوفية باستخدام طريقة الجهد الذاتي في جزء من مدينة كركوك – شمالي العراق

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الملخص

أجريت الدراسة باستخدام طريقة جيوفيزيائية الجهد الذاتي السطحي في ناحية سيكانيان التي تقع في شمال مدينة كركوك بحوالي 5 كم والتي تعاني من قلة تجهيز المياه للسكان. من اجل الحصول على بيانات أجري مسح بخطين نشر نوع الانحدار:- ,خط مسح في الجزء الشمالي القريب من اقدام التلال من منطقة الدراسة وأخر خط عمودي على الأول, إضافة الى اجراء قياسات 22 نقطة شبكية متوزعة على منطقة الدراسة. تم اختبار ضخ الماء لاحد الابار مع مراقبة مستمرة لنزول ماء الجوفي باستعمال مسبار الماء وتسجيل قراءات بواسطة جهاز الجهد الذاتي.الهدف من الدراسة هو الكشف عن وجود التجمع للمياه الجوفية ومدى حساسية هذه الطريقة لتغاير العمود الهيدروليكي للمياه .فسرت المعلومات على شكل منحنيات خطوط المسح وكذلك رسم خرائط الكنتورية باستخدام برنامج (Surfer8).اثبتت النتائج ان هنالك تدفقا كهربائيا من الجهد الذاتي والذي يؤشر الى وجود تجمع للمياه الجوفية في منطقة الدراسة وان نتائج الضخ في البئر الاختباري مع المراقبة المستمرة القراءات بجهاز الجهد الذاتي ذي حساسية مع تغاير العمود الهيدروليكي للماء في البئر ويمكن ان تعطي تخمينا لبعض الصفات الهيدروليكية للطبقة الحاملة للمياه مثل الناقلية و الايصالية المائية للخزان الجوفي. عمق الماء الجوفي في منطقة الدراسة هو 7امتار.

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Introduction

Geophysical applications are conducted for shallow and deep subsurface materials characterization through many methods. One of those is surface self-potential (SP) method, which measures the electric potential present naturally in the earth (Nyquist & Osiensky 2002). It is applied in many geological fields such as mineral exploration, geothermal, engineering and environmental studies. The self-Potential technique measures the electric potential occurs naturally in the ground surface, and it is employed to determine the groundwater flow path (Zakaria et al. 2020). The SP signals present in near surface of the earth is created by electro-kinetic or streaming potential due to fluid presence in the ground, diffusion potential in a boundary of different chemical substances and redox reaction of subsurface metal materials (Fritjof and Graham, 2003). The underground water flow yields electrical potential which is defined as streaming potential of the water path (Birch 1993) expressed as the following equation: -

$$E_{k=} \varepsilon\rho \; C_E \; \partial P/4\pi \; \eta$$

were

E_k = electrokinetic potential

ε = dielectric permittivity of pore fluid

ρ = electric resistivity of pore fluid

η = dynamic viscosity of pore fluid

∂P = the change of pressure

C_E = coupling coefficient of electrofiltration

The relationship between self-potential signal and groundwater has been studied by many researchers, Revil et al. (2003) investigated the coupling between hydraulic flow and electrical current density which is electrokinetic in nature. They proposed methods for estimating the shape and depth of the water table.

Revil et al. (2004) studied the SP field and the distribution of the piezometric head.Tthey described the phreatic surface and to reconstruct the electrical resistivity contrast relation through an integral equation.

Field test was performed (Rizzo et al., 2004) by set of self-potential electrodes measurements using the electrical response which is analyzed in piezometric head distribution, that the new methodology allows visualization of preferential fluid flow pathways and the distribution of heads during pumping test experiments.

Electrical self-potential signals and hydraulic heads associated with a pumping test in an unconfined aquifer were reproduced (Titov et al., 2005). The results show that SP signals allowed monitoring subsurface flow in the course of pumping experiments.

Self-potential signals explain the heterogeneous nature of an aquifer (Jardani et al., 2009), they showed the advantage in using self-potential signals to reconstruct the shape of the water table.

Nwosu et al. (2011) conducted self-potential measurements and apparent resistivity in Imo State Nigeria; who deduced the spread of high SP anomaly in areas related to aquifer which form discharge zones with strong lateral flow, and low SP anomaly in areas corresponding to the infiltration zone.

Susilo et al. (2017) performed self-potential method to map underground river flow in karst area in Druju Village, South Malang. They indicated to the produced anomaly related to a layer of carbonate rock and underground river flow.

The intensities and directions of the water are evaluated by self-potential method in addition to the direction of the water seepage integrated with 2-D resistivity. The results show the highly saturated zones location (Nordiana et al., 2018).

Self-potential investigation carried out in farming land nearby Quldara Village, Northeast Kirkuk town. The acquired data processed and presented as profiles and contour maps. The data interpretations indicated existing of ground water in the study area (Ali,2018).

Research carried out in Malang in the karst area, Druju Village, Sumbermanjing District, Indonesia by Hasan et al., (2019), they applied self- potential method by leap frog configuration. They assumed that the low potential value is an indication of groundwater distribution.

Self-potential and 2-D resistivity methods were used to determine the flow pathways of the ground water and potential groundwater zones in Johor, Malaysia. The recharge zone of the aquifer was recognized with negative potential values while positive values showed the discharges zones for this area (Zakaria et al., 2020).

Electrical resistivity and self-potential geophysical methods were employed in a study area for exploration of the shape of preferential flow paths (Kukemilks and Wagner, 2021). The possible signals associated with flowing groundwater in the subsurface were detected.

Sultan et al. (2022) aims to evaluate the hydraulic characteristics of the aquifer in Laylan area, Kirkuk, NE Iraq. The pumping test process carried out to monitoring the water level change and SP measurement. A mathematical relationship obtained to connect the two variables.

Study Area

Seikanian is suburban of Kirkuk City (35^{O} 55' 22"- 35^{O} 56' 49"N) (44º35'21"- 44^{O}36'25" E) (Fig.1). It is situated in the northeastern limb of Kirkuk anticline suffering from deficient water supply, despite many drilled water wells, but there is scarce information about an aquifer location and its boundary. The area is characterized by different topography features; where at north, there is high area of hill series; at south there is low topography area with narrow valley surrounded by higher elevation lands, its subsurface is underlain by lower Bakhtiari Formation which is composed of inclined beds of sandstone, mudstone and conglomerate (Al-Hayali et al.,2021; Jassim and Goff, 2006).

The aim of the present study is to use geophysical self-potential method to delineate groundwater occurrence and sensitivity of the method, s signals to water hydraulic head of the water during pumping test operation.

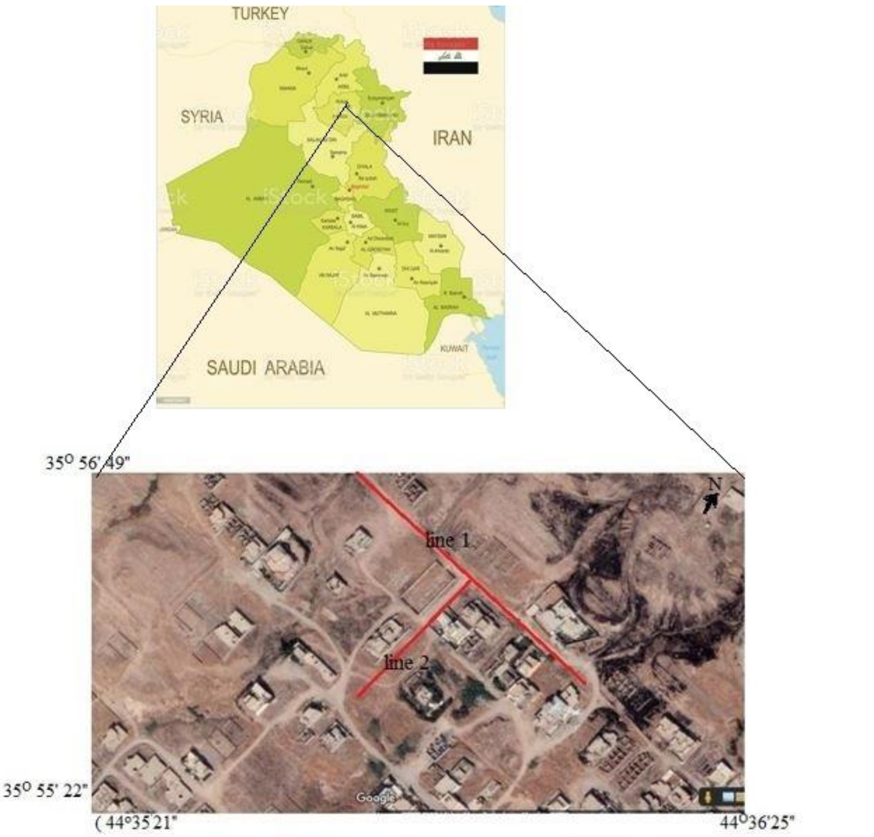

Fig. 1. Location of the study area

Materials and Methods

The SP signal (Potential difference in mV) on the ground surface is measured by two non-polarizable copper electrodes with two porous pots which are sunk in copper sulfide solution (Cu SO4) of SP instrument (WDJS-2 Digital DC IP Receiver). There are two SP survey methods applied for acquired data, gradient (frog leap) layout, in which the two electrodes moved at the same time in a constant distance from the beginning of the survey line up to the terminal. The second is total field (fixed base), in which one of the electrodes is fixed in a station outside the survey line as a reference base, while the other electrode is moving in certain distance successively along the line (Fig.2). To collect SP data in vicinity of Siekanian area, two survey line are carried out using gradient survey method (Fig.1); line1at north along the foothill of the high topography area of 120m length and 10m distance between the electrodes; and line2, which is normal to the former line form its center of 100m length. In order to gain more SP data to be processed and interpreted later, we achieved 22 grid points of SP measurements spreading over the whole study area using GIS with SP device available in the Applied Geology Department in Kirkuk University, to construct observe contour map of SP data by kriging interpolation method using surfer 8 software from Golden software company. The regional contour map is yielded by polynomial regression operation while the residual contour map is produced by separation technique.

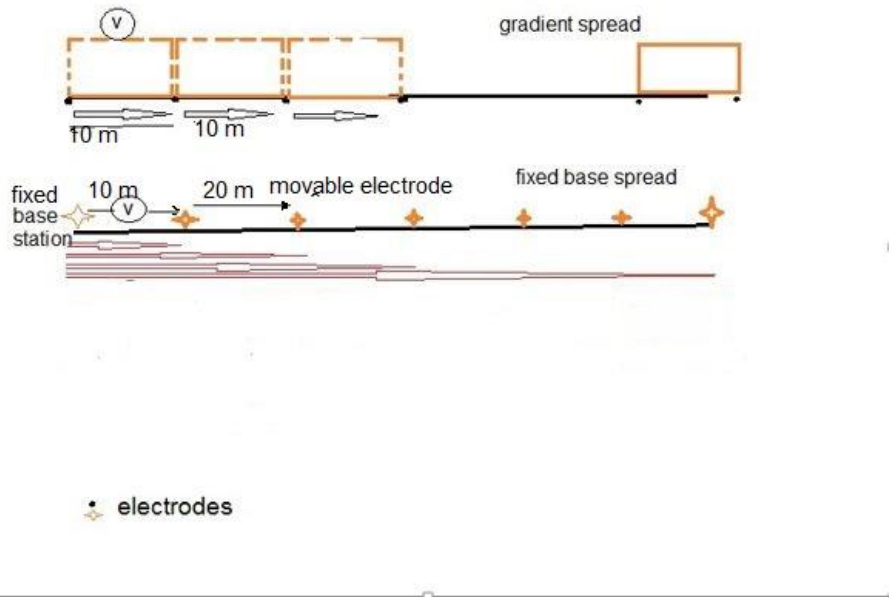

Fig.2. The SP electrodes layout schemes

Results and Discussion

Interpretations of the SP line profiles and contour maps

1- Line1

This SP line is taken along the high topography of the foothill area in the study area. It is negative curve line, along which the SP measurents range between (-18 and -64) mV (Fig.3). It shows a fluctuation nature with frequent minima and maxima indicating recharge area of ground water streaming; in120m, there is a trench extent from this line toward the downhill toward the valley giving the minimum negative SP value that may indicate less recharge water situation. Reynold (2011) realized that the positive or negative self-potential of one-hundred mV indicates the movement of ground water.

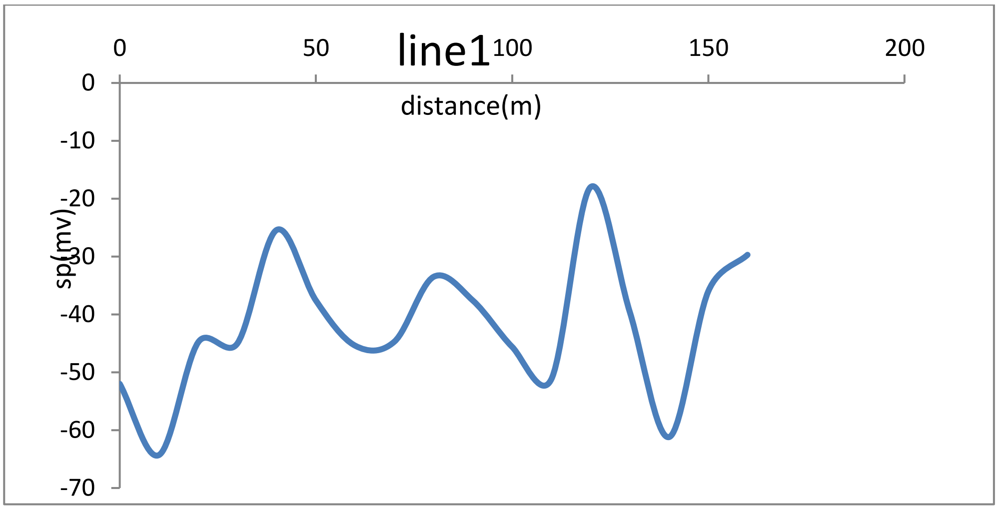

Fig. 3. SP line-1

2-Line2

This SP line is cross to the line1 from its center; it extends from high topography area toward low topography. It reveals lower negative SP amplitude than line, of (-1 to -25) mV range except at 40m there is unique positive value (19.8) mV plain anomaly because it situates within part of the main valley, where the groundwater accumulates (Fig.4). This survey line extends from the foothill area toward near underground water storage of the aquifer near the valley, which characterized by relative lower SP negative amplitudes.

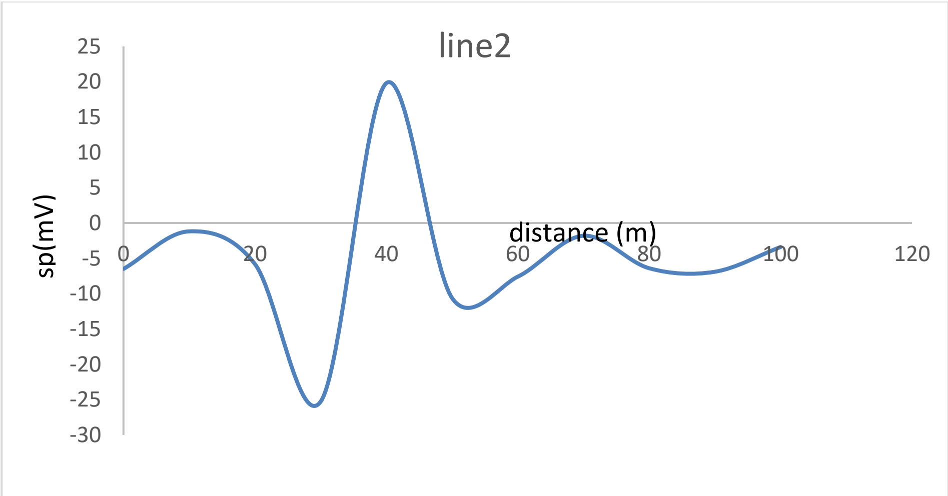

Fig. 4. SP line-2

3- Observed SP contour map

The observed SP contour map of Seikanian area comprises many positive and negative anomalies. There is a negative (-30 mV) elongate ellipse form in the east of the map (Fig.5) and a positive (60 mV) value at the ultimate eastern south. Other semicircles of (30,10,50,5) mV anomalies at the center and west of the map with positive anomaly in western north of (50 mV). These SP anomalies reflect the flow of ground water in the area. The negative and low positive SP amplitudes are at the eastern and northern parts of the map, where the foothill and higher area surround the valley at south and west of the map, and the higher positive SP values are at low level areas in the studied area.

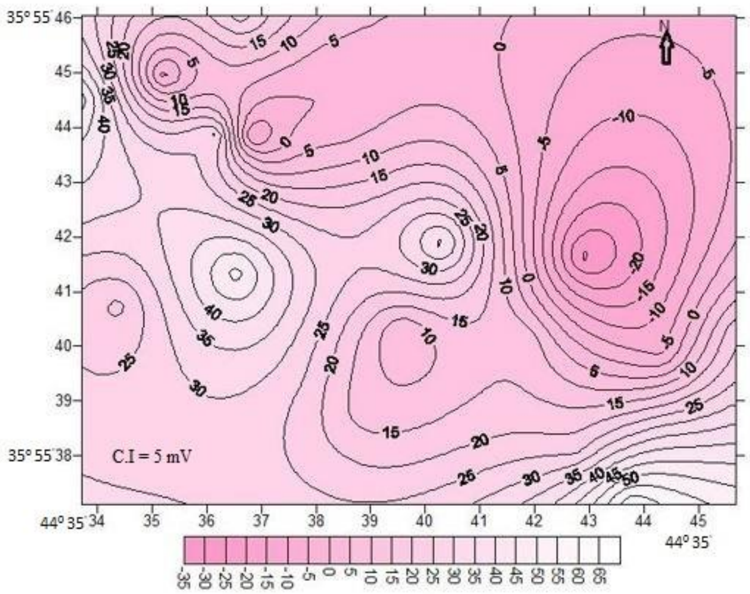

Fig. 5. Observe SP contour map

4- Regional SP contour map

The regional SP contour map (Fig.6) is composed of arrange of broad negative and positive SP parallel lines that varies from -5 to 50 Mv. A northeastern side, there is negative SP, then it changes to high positive at southwestern. The regional contour SP map reflects the regional effect of the groundwater subsurface flow in the aquifer.

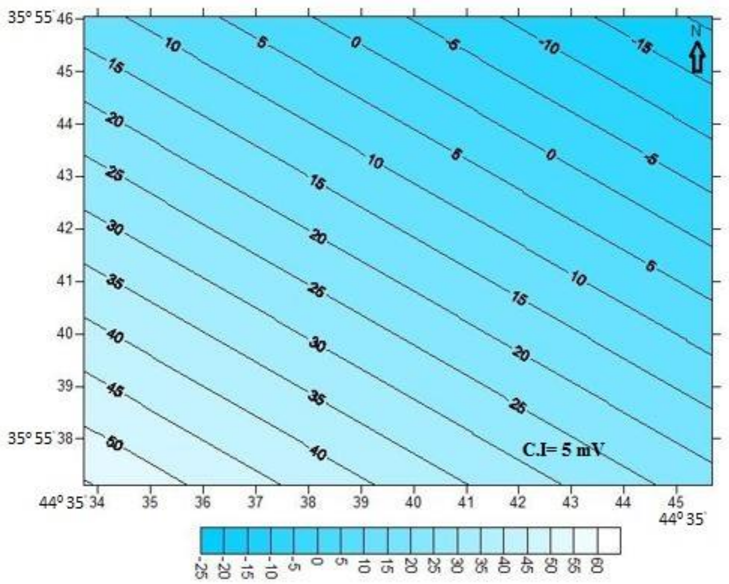

Fig. 6. Regional SP contour map

5- Residual SP contour map

This SP contour map (Fig.7) possesses many positive and negative semicircles of maxima and minima anomalies. There is a wide negative (-35) mV at the eastern side and positive (5) mV at the center. Another two negative values are at the western north (-20 to -15) mV and positive (20) mV in mid-west. There are two positive anomalies at the ultimate eastern south (35) mV with ultimate north western (30) mV. The near surface underground water streaming effect is revealed in the positive and negative anomalies in the SP amplitudes. The underground water path direction is from the negative recharge infiltration zone (Nwosu et al., 2011; Zakaria et al., 2020) which represent the foothill and high-level areas toward the positive SP that indicates the accumulation of water in the lower topography valley. The major positive anomalies extend along the main valley along northwestern to the southeastern trend. The residual contour map represents the shallow underground water situation.

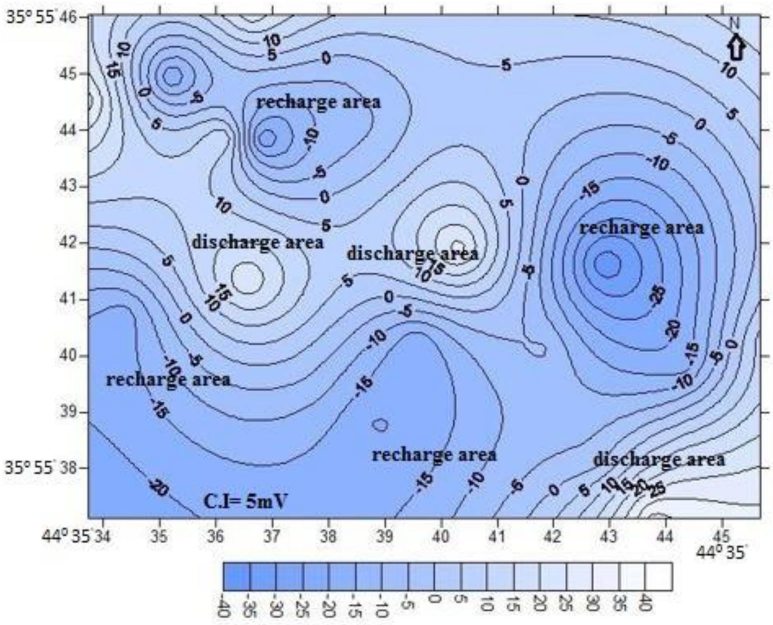

Fig. 7. Residual SP contour map

Figure (8) shows the correlation between the SP 3-D residual image (bottom) and the topography 3-D image (top) of Seikanian area. The most positive higher SP amplitudes spread at low topography within the main valley in accordance with the most negative SP values which expand in high topography ground at the rest of the area.

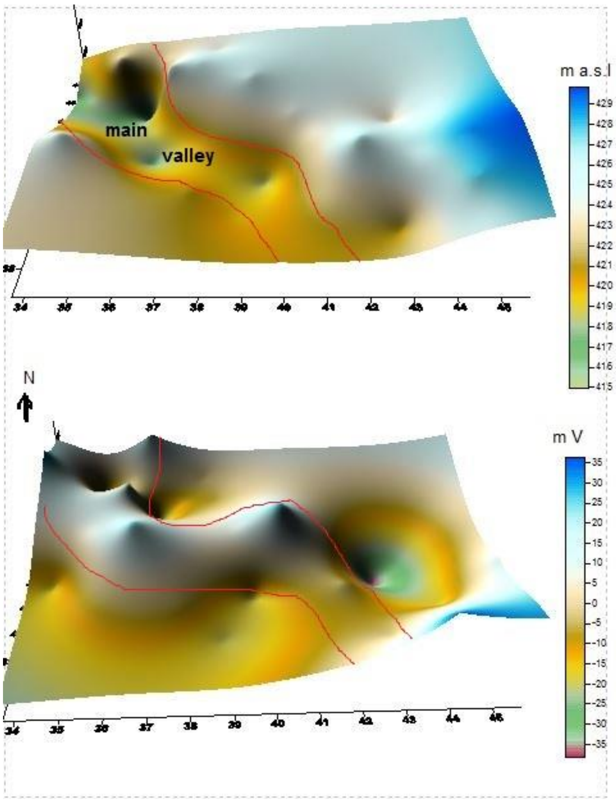

Fig. 8. Topography (top) &3-D SP residual (bottom) images

Pumping test and SP measurements

For data collection and later on analysis necessary for determining characteristics of some hydraulic properties in the study area, the SP readings are recorded for water table drawdown with the elapsed time during pumping test operation by SP device fixed near the borehole during the water withdraw (Fig.9). The groundwater flow in certain pumping test experiment is the source for a measurable electrical field at the ground surface which is outcome of the electrokinetic coupling between the water velocity and the electrical current density (Rizzo et al, 2004).

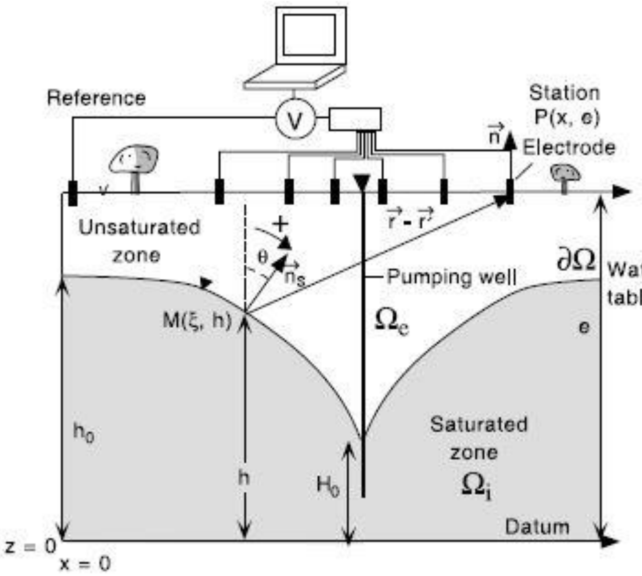

Fig. 9. Pumping test procedure and SP monitoring Scheme (after Rizoo et al ,2004)

Figures (10&11) indicates that the SP signal is sensitive to the water table fluctuation. The relationship between the SP values and each of water drawdown and its elapsed time reading is strongly linear (Titov et al.,2005; jardani et al., 2009). It tells that the SP measurements on the ground surface reflect the hydraulic head, so the results of this procedure enable a rapid estimation of some hydraulic properties such as hydraulic conductivity, transmissivity of the aquifer which requires the logging of drawdown and its elapsed times during the water withdraw. This outcome is feasible especially in the area having few wells in a basin and the water table monitoring by sounder not workable or there is missing in some hydrological data. At this time the SP measurements might be the alternative of those parameters (drawdown and elapsed time) by application of the empirical equation in Figures (9&10) for a certain aquifer and could be generalized at other locations within the study area.

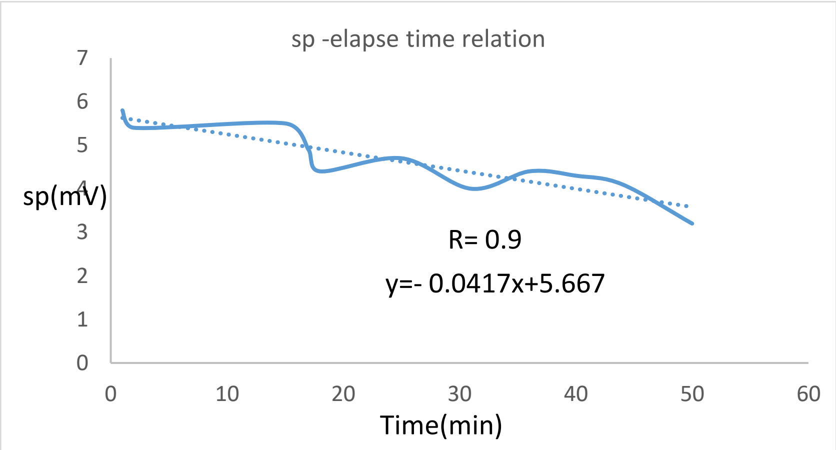

Fig. 10. Correlation between the elapse time with SP measurements in the pumping test

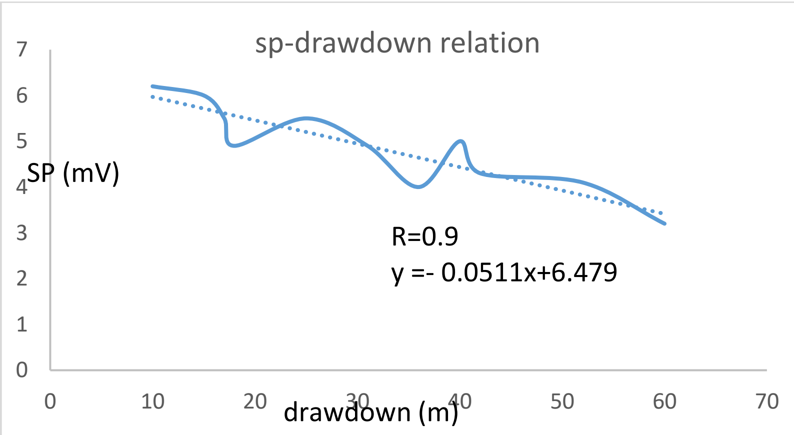

Fig. 11. Correlation between the drawdown with SP measurements in the pumping test

Quantitative interpretation

Formerly geophysical SP data have been applied for qualitative interpretation but recently it is used for quantitative interpretation of subsurface problems also. Geophysicists are applied different techniques in those trends, Nwosu et al. (2011) applied half-max width method in the graphical analysis for SP anomaly survey curve line to determine the depth of water table. The interpretation of line2 (Fig.12) shows the water table depth is at about 7 m in the study area.

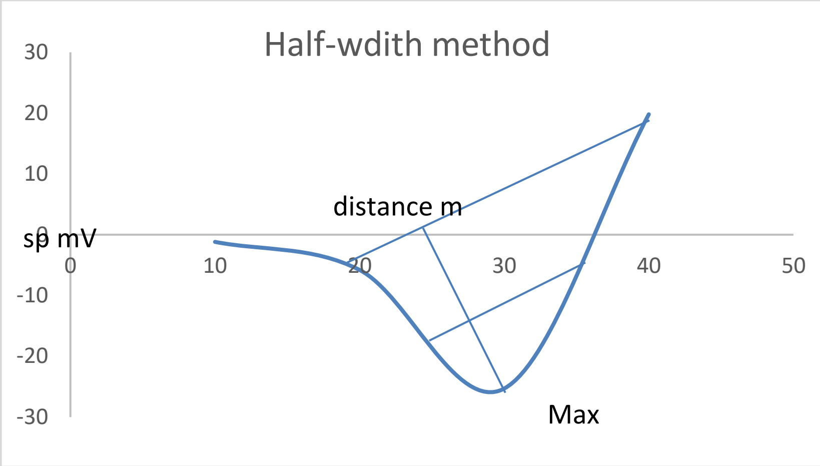

Fig. 12. Half-Max Depth interpretation method for SP gradient line2

The two surveyed gradient lines interpreted curve profiles reveal distinct positive and negative SP amplitudes that reflect the streaming potentials produced from underground water flow. The most SP negative values in the line-1 indicate recharge or infiltration zone in the area while line-2 shows less SP negative amplitudes with clear positive anomaly because it extends from recharge zone toward downhill of low topography lands of discharge underground water accumulation zone. The SP contour maps have given convinced image of the anomalies spread all over the investigated area indicating the underground streaming water. The high topography in Siekanian area is characterized by negative anomalies which represent the recharge zone, while the low topography area, more definitely the valley, has positive anomalies with most discrimination. It is revealed in the residual contour map, where the high the SP amplitudes spread over the valley indicating the groundwater accumulation in the area. The quantitative analysis of the SP curve anomaly yields the water table depth at about 7m, while the actual average depth is 9m.

The pumping test operation with SP monitoring the underground water depth during the water withdraw in the well shows that the SP measurements are sensitive to the water table and the elapsed time, and they are in a good linear relationship, it might help in a rapid estimation of some hydraulic properties such the hydraulic trasmissivity and conductivity of the aquifer.

Conclusion

Application of the geophysical surface self-potential method could delineate underground streaming water which produces electrical potential differences measured by two non-polarizable electrodes on the ground surface using two gradient survey lines and grid SP points measurement. The profiles and contour maps schemes analysis of the SP amplitudes and signs indicate groundwater accumulation in the low areas which is characterized by positive SP values while the recharge areas produce negative SP amplitudes spreading over the rest of the study area. The pumping test accompanied by the SP monitoring at a well prove that the SP measurement is sensitive to the water table changes and it is useful in provision of some hydrologic properties of the aquifer. The ground water depth is determined at 7m.

Conflict of interest

The author declares that there are no conflicts of interest regarding the publication of this manuscript.

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