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Vertical Electrical Sounding (VES) Resistivity Survey Technique to Explore Groundwater in an Arid Region, Southeast Iran

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Abstract: A geoelectrical survey using the electrical resistivity method was carried out in the Curin basin, Iran to investigate the sub-surface layering and evaluation of the aquifer characteristics. Applying the Schlumberger array, a total of 596 vertical electrical soundings were conducted along 26 profiles. Quantitative and qualitative Interpretations of data were carried out. Overall, isoapparent resistivity maps, the geoelectrical pseudosections analysis and the established geoelectric sections reveal the presence of the following geoelectric layers: (a) A superficial layer characterized by electric resistivity values ranging from 3 to 800 Ωm with a thickness of less than 15 m. (b) A second layer (dry alluvium layer) is thicker than the surface layer with electric resistivity values less than 100 Ωm. (c) A third layer that corresponds to the aquifer is characterized by electric resistivity values of less than 10 Ωm and depth values of less than 30 m in most locations. The maximum depth of this layer is 60 m that lies in northwest and southeast of area. (d) A fourth layer (bedrock layer), characterized by two electric resistivity values ranges. In most parts of the area, it is more than 60 Ωm, corresponds probably to Slate. In other area, it is less than 60 ohm-m, corresponds probably to Shale. From the quantitative interpretation of VES curves, the boundary of aquifer was determined. Finally, zones with high yield potential in the aquifer were determined. Southeastern and northwestern parts of the aquifer were the best parts for choosing the drilling sites and future development.

Key words: Resistivity, quantitative and qualitative interpretations, groundwater, curin basin

INTRODUCTION

Direct current resistivity method is a common tool for surveying water in arid areas. It is well known that this method can be successfully employed for ground water investigations, where a good electrical resistivity contrast exists between the saturated and unsaturated layers. The vertical electrical sounding with Schlumberger array as a low-cost technique and veritable tool in groundwater exploration is more suitable for hydrogeological survey of sedimentary basin. This method is regularly used to solve a wide variety of groundwater problems. Some recent studies include: determination of zones with high yield potential in an aquifer (Ahilan and Kumar, 2011; George *et al*., 2011; Joshua *et al*., 2011; Nejad, 2009), determination of the boundary between saline and fresh water zones (Sikandar *et al*., 2010; Hodlur *et al*., 2010; Adeoti *et al*., 2010), delineation groundwater contamination (Abdullahi *et al*., 2011; Ugwu and Nwosu, 2009; Enikanselu, 2008), exploration of geothermal reservoirs (Cid-Fernandez and Araujo, 2007; El-Qady, 2006), groundwater exploration in hard rock (Nwankwo, 2011; K'Orowe *et al*., 2011; Armada *et al*., 2009), estimation of aquifer specific yield (Onu, 2003) and estimation of hydraulic conductivity and transmissivty of aquifer (Ekwe *et al*., 2010; Egbai, 2011; Majumdar and Das, 2011; Tizro *et al*., 2010).

MATERIALS AND METHODS

Study area: The study was conducted in an arid region in the Curin basin. It is located south of the Zahedan city in the southeastern part of Iran (Fig. 1). Specifically, it lies between the geographic latitude 28°42' up to 29°00' North and geographic longitude 60°10' up to 60°15' East. Figure 1 shows also the positions of VES measurements. The study area has a terrain elevation average 1500 m and its climate is tropical and arid with the annual temperature ranging between -8 and 42°C. The average annual rainfall is around 73 mm. It covers an area of about 800 km^2.

Method of investigation: Electrical resistivity techniques measure earth resistivity by passing an electrical current into the ground and measuring the resulting potentials created in the earth. This method involves the supply of direct current or low-frequency alternating current into the

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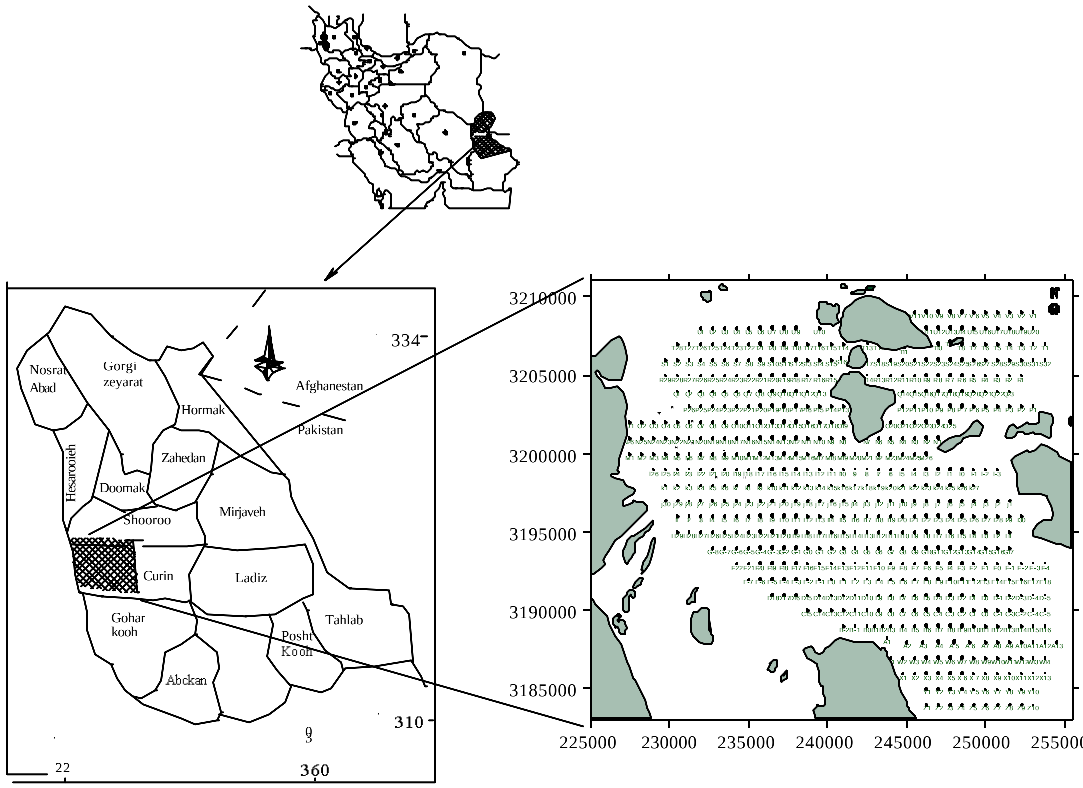

Fig. 1: Area of study

ground through a pair of current electrodes and the measurement of the resulting potential through another pair of electrode called potential electrodes. Since the current is known and the potential can be measured, an apparent resistivity can be calculated. For Schlumberger soundings, the apparent resistivity values (ρ_a) were plotted against half current electrode separation (AB/2) on a log-log graph and a smooth curve was drawn for each of the soundings. Then, the sounding curves were interpreted to determine the true resistivities and thicknesses of the subsurface layers. The resistivity of the subsurface material observed is a function of the magnitude of the current, the recorded potential difference and the geometry of the electrode array used. The depth of penetration is proportional to the Schlumberger array which uses closely spaced potential electrodes and widely spaced current electrodes. In general, the depth of infiltration is small in this method and only shallow subsurface layers have been surveyed (Danielsen *et al*., 2007).

A total number of 596 Vertical Electrical Soundings (VES) with a distance of 750 m were conducted along 26 geoelectric profiles, in order to evaluate the geoelectrical setting of the Curin basin, south of Zahedan city, Iran (Fig. 1). The soundings are arranged along profiles ranging approximately East-West. The profiles were spaced 1000 m each from the other. The Schlumberger electrode configuration having a maximum current electrode spread of 1000 m was used. The current electrode spacing begins with a distance equal to 2 m and extends up to 1000 m.

A KD Sound Terrameter instrument was utilized to acquire the VES data. The field curves were interpreted by the well-known method of curves matching with the aid of Russian software IPI7.63. The results of the interpretation are represented in the form of the resistivity values that can be used for preparing the isoapparent electric resistivity map and the geoelectric cross sections. These sections reflect both lateral and vertical variations in resistivity.

RESULTS AND DISCUSSION

The field results of the study are presented in both qualitative and quantitative interpretations. In the qualitative interpretation the shape of the field curve is observed to get an idea qualitatively about the number of layers and the resistivity of layers. The results of this method of interpretation involved isoapparent electrical resistivity maps and geoelectrical pseudosections.

In the quantitative method geoelectrical parameter i.e., true resistivity and layer thickness are obtained. The main objective of the quantitative interpretation of VES curve is to obtain the geoelectrical parameters and geoelectric section. A geoelectric layer is called by its fundamental characters, resistivity 'ρ' and thickness 'h'. It is hoped that the results of this study could also be used to determine the groundwater potentials of the study area.

Isoapparent electric resistivity maps: The isoapparent resistivity maps reflect the lateral variation of apparent resistivity over a horizontal plane at a certain depth. In other words, these maps indicate distribution of apparent resistivity in the area against distance of current electrodes.

The maximum depth penetration of the AMNB method is 1/3 to 1/4 of the maximum distance of current electrodes (Frohlich *et al*., 1996).

In the case study isoapparent electric resistivity maps were constructed at AB = 100, 200, 300 and 400 m. The choice of such spacing depends on the variability between them. These maps reflected the lateral variations of the electric resistivity at a depth of about 25, 50, 75 and 100 m, respectively.

Isoapparent electric resistivity map for AB = 100 m: This map (Fig. 2) reflects the lateral variation over a horizontal plane at a depth of about 25 m. It showed the apparent resistivity values in center, North and northeast parts of area were lower than others.

Since current is conducted electrolytically by the groundwater (in the saturated layers) and surfacely by effective surface of minerals (in the dry layers) (Zohdy *et al*., 1974), so the low values of apparent resistivity in center, north and northeast parts of area are attributed to the presence of saturated layer and the high values of apparent resistivity in other areas to the presence of unconsolidated and dry layer.

Isoapparent electric resistivity map for AB = 200 m: Figure 3 reflects the lateral variation over a horizontal plane at a depth of about 50 m. It indicates the presence of bed rock in northeast part of area and the adjacent of mountains and the presence of aquifer in others. It showed the apparent resistivity values in west of area were lower than east and also in the center were lowest, because sediments grain size will be decreased towards the center.

Isoapparent electric resistivity map for AB = 300 m: Figure 4 reflects the lateral variation over a horizontal plane at a depth of about 75 m. It indicates the presence

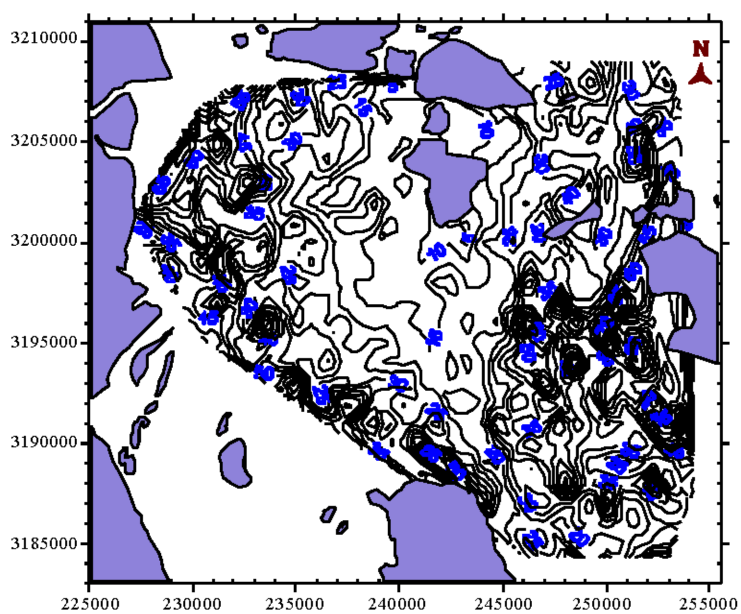

Fig. 2: Isoapparent resistivity map for AB =100

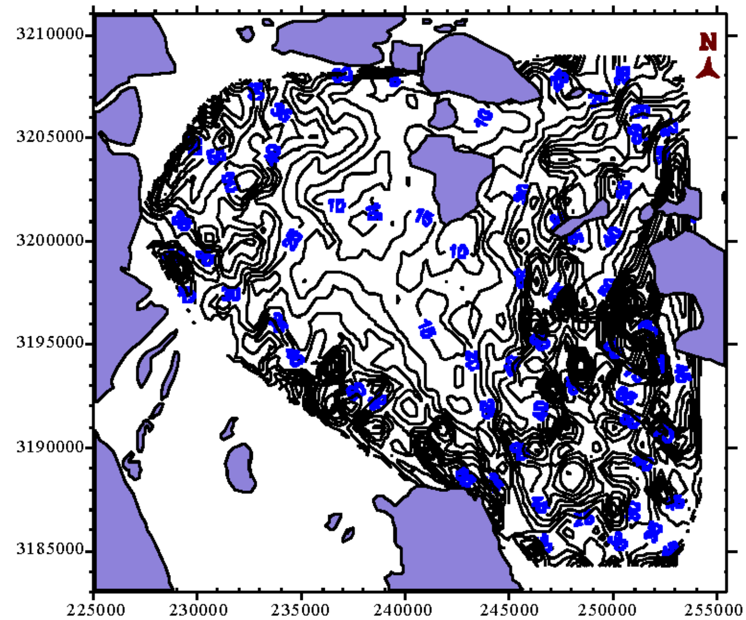

Fig. 3: Isoapparent resistivity map for AB = 200

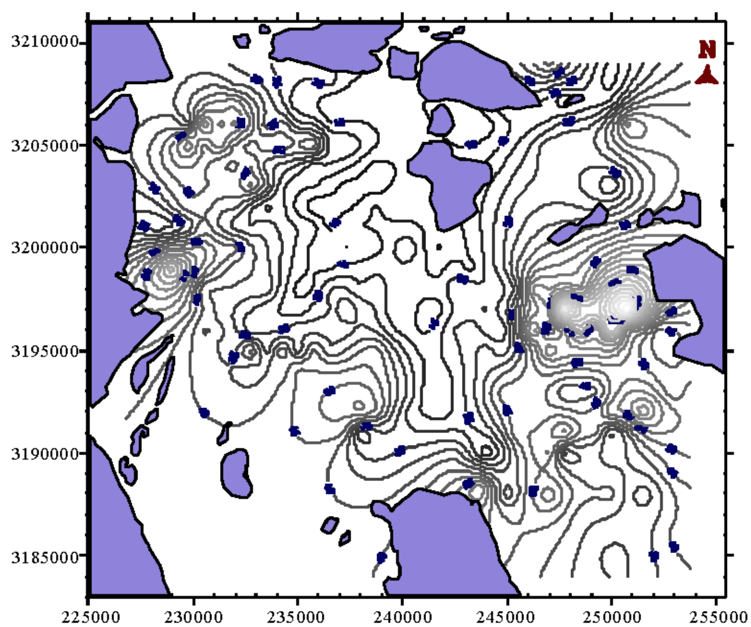

Fig. 4: Isoapparent resistivity map for AB = 300

of aquifer in northwest part of area and the presence of bed rock in others. High apparent resistivity in northwest part of area was due to high resistivity of aquifer because of course grain size.

Isoapparent electric resistivity map for AB = 400 m: This map (Fig. 5) reflects the lateral variation over a horizontal plane at a depth of about 100 m that indicated approximately the presence of bed rock in area. The

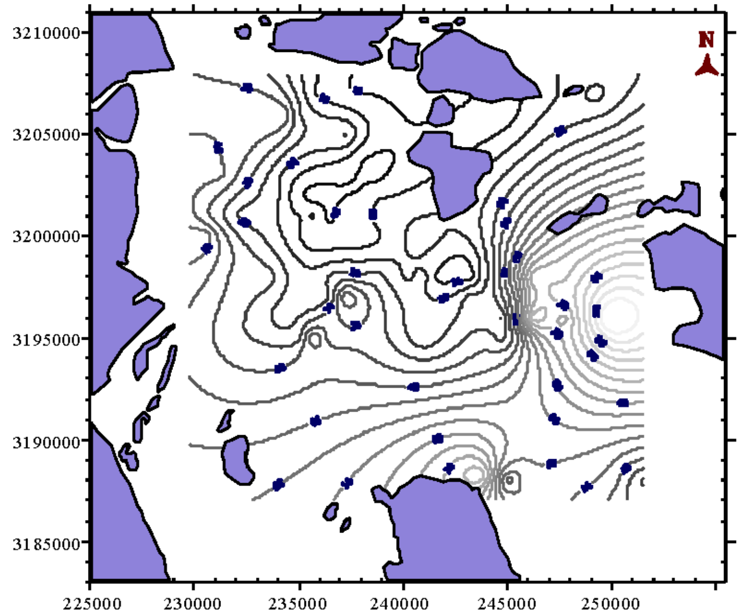

Fig. 5: Isoapparent resistivity map for AB = 400

apparent resistivity values of bed rock ranged from 10 to 100 Ωm. It was maximum in east of area. The bed rock was different with lower apparent resistivity in north part of area.

Geoelectrical pseudosections: The geoelectrical pseudosection reflects the apparent resistivity distribution versus electrode spacing values (AB/2).

Geoelectrical pseudosection of the profile B: The apparent resistivity values were different together in upper part of pseudosection of the profile B (Fig. 6). The apparent resistivity value reached more than 100 Ωm in soundings 0, 2, 6, 8, 9 and 10 because of coarse grain size of surface soil and also was lower than 40 Ωm in middle part because of influence of aquifer. It increased again in high depth because of influence of resistant bed rock. The lowest value of apparent resistivity was in soundings 3 and 4 because of the present of a fine grain lens.

Geoelectrical pseudosection of the profile G: The apparent resistivity values in this pseudosection were decreased toward middle parts and also increased toward high depth again because of present of resistant bed rock (Fig. 7).

Generally, the apparent resistivity values in central part of profile B was lower than side parts because of influence of aquifer in central part and coarse grain size alluvium in side parts.

Geoelectrical pseudosection of the profile L: Pseudosection of profile L included two parts, the first had high apparent resistivity values limited to soundings -1, -2, -3 and 15 to 26 and the second had low apparent resistivity values limited soundings 0 to 14 (Fig. 8). The more depth part of pseudosection that represented to bed rock had the apparent resistivity values of 30 to 60 Ωm in profile sides and about 10 to 20 Ωm in central of profile. The lowest value of apparent resistivity was in soundings 7 and 11 with the apparent resistivity value lower than 10 Ωm.

Geoelectric sections: In the case study, the results of quantitative interpretation of VES curves indicated that geoelectric section consisted of the following features (for example, the geoelectric section of profile B, G and L that has been showed in Fig. 9, 10 and 11):

- Near-surface layer that had highly variable resistivity ranging from about 3 to 800 Ωm. The difference in the resistivity values was due to the variation in the amount of grain size. Areas with high resistivity values indicated the presence of gravel and sand as top soil, while those with relatively low resistivity values indicated the presence of clay or intercalation of clay with sand. The thickness of top soil layer varied in different parts. However it often was estimated less than 15 m

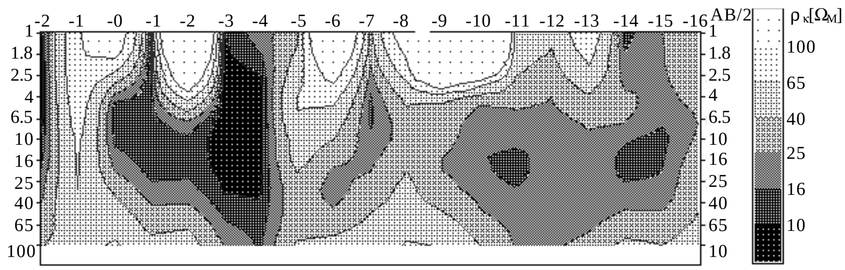

Fig. 6: Pseudosection of the profile B

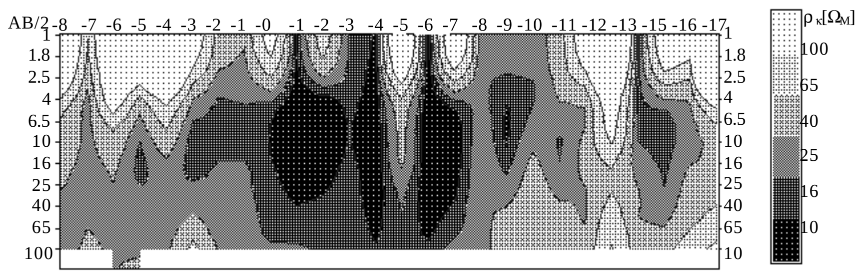

Fig. 7: Pseudosection of the profile G

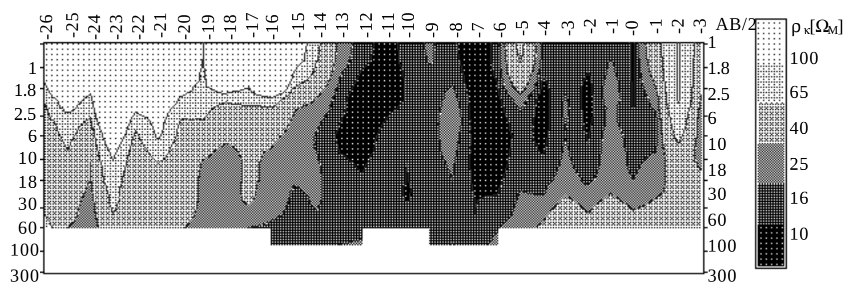

Fig. 8: Pseudosection of the profile L

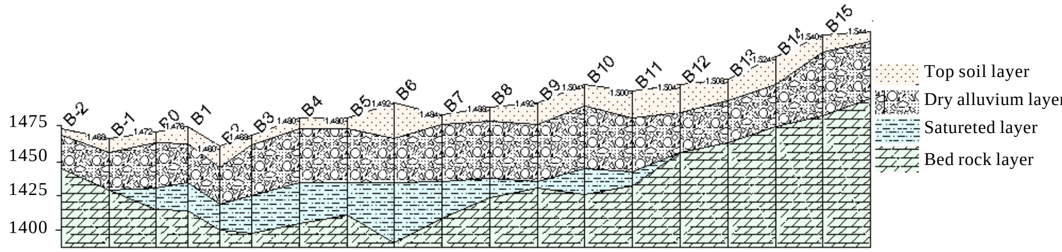

Fig. 9: Geoelectric section of profile B

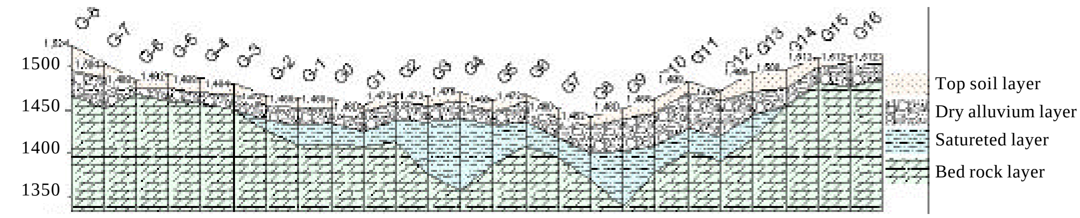

Fig. 10: Geoelectric section of profile G

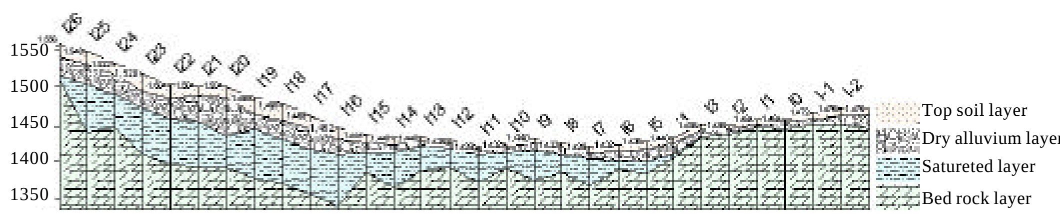

Fig. 11: Geoelectric section of profile L

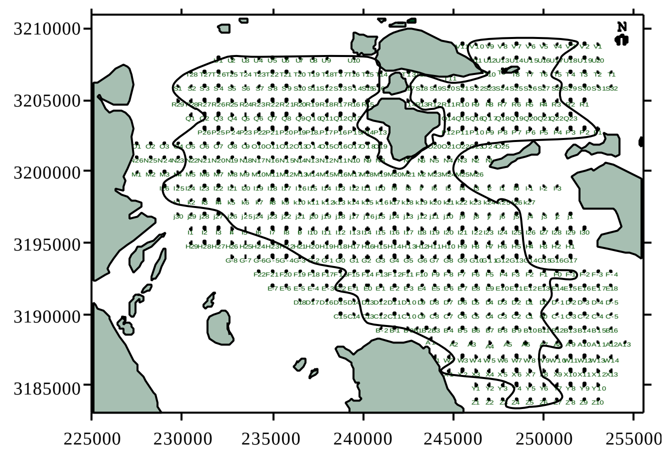

Fig. 12: Aquifer boundary map

- Dry alluvium layer was thicker than the surface layer and its electrical resistivity was measured to be less than 100 Ωm often
- The third geoelectric layer that corresponded to the saturated layer had resistivity values of less than 10 Ωm and depth values of less than 30 m. The depth of this layer was higher in both northwest and southeast and even reached 60 m with the electrical resistivity about 25 Ωm. This layer was more fine-grained toward the center of the study area. In center, it had the depth less than 25 m and the resistivity less than 10 Ωm
- The fourth layer was interpreted to be bedrock with tow resistivity ranges. In most parts of the area, the resistivity was more than 60 Ωm corresponded probably to a Slate bedrock layer. Where the resistivity value was less than 60 Ωm corresponded to a Shale bedrock layer

Rock resistivity depended on a number of factors such as the amount of water present in fractures, weathering, porosity, fracturing and the degree of saturation (Yusuf *et al*., 2011).

The depth of bedrock layer increased toward the center of area. The maximum depth was located in the northwest of region. That was over 100 m.

Also, the boundary of aquifer and the best locations for drilling well is determined from quantitative interpretation of VES curves. The aquifer boundary map is shown in Fig. 12.

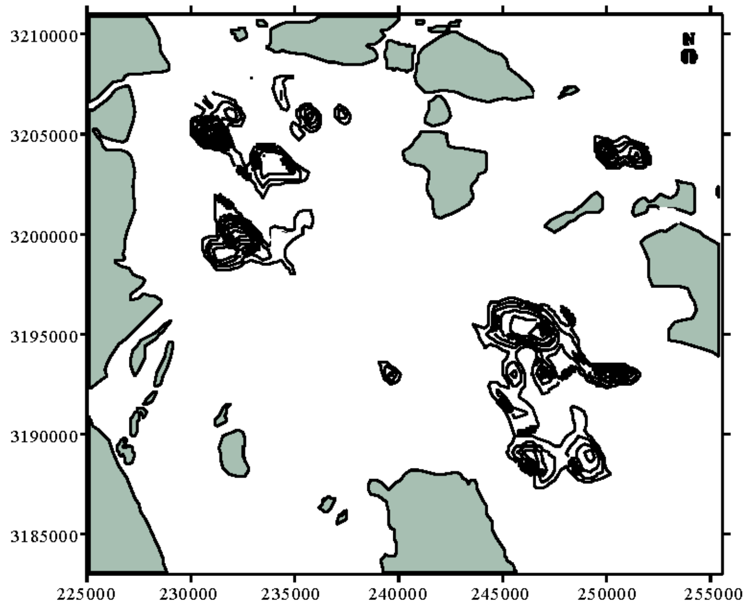

Fig. 13: Map showing the best locations for drilling well

On a purely empirical basis, it can be stated that the potential of an aquifer is directly proportional to its transverse resistance (RT). In the case study, the area with transverse resistance more than 1000 ohm m^2 were represented zones with high groundwater potential and suitable for drilling wells. Accordingly, southeastern and northwestern parts of the aquifer are the best part for choosing the drilling sites (Fig. 13).

CONCLUSION

According to the results of the resistivity survey carried out in the Curin basin, it is now possible to reach the following conditions:

- The study of isoapparent resistivity maps showed that generally, the direction of resistivity contours was North-southeast approximately. This direction corresponded to the direction of a temporary river which acts as drainage of area. The distribution of apparent resistivity values in all maps showed that high values dominated the western and eastern part of the region due to course grain talus. Also, in center, the apparent resistivity values were lowest due to fine grain alluvial
- Overall, the geoelectrical pseudosections analysis in case study showed that:
  - A-The resistivity values were decreased towards the center of area due to decreasing grain size
  - The eastern and western parts of area (side parts of profiles) had high resistivity that indicated poor weathering
  - The maximum resistivity values were observed in surface. The low resistivity anomalies were extended in middle depth of profile due to influence of groundwater
  - The resistivity values were increased in more depth due to presence of bed rock with high resistivity
  - The lowest of resistivity values were observed in saturated zones
- Four major geoelectric layers were identified from the results of qualitative and quantitative interpretation of 596 VES curves in Curin basin. The first layer was interpreted to be near-surface layer had highly variable resistivity ranging from about 3 to 800 Ωm and a thickness of less than 15 m. The second one was dry alluvium layer with a resistivity of less than 100 Ωm and a thickness of more than the surface layer. The third geoelectric layer that corresponded to the saturated layer had a resistivity of less than 10 Ωm and a depth of less than 30 m in most parts of the area. The fourth layer was interpreted to be bedrock. This layer in most parts of the area was probably Slate with a resistivity more than 60 Ωm and in others had a resistivity of less than 60 Ωm corresponded to Shale

- The boundary of aquifer was determined from quantitative interpretation of VES curves
- The best locations for drilling well and zones with high groundwater potential were determined. Southeastern and northwestern parts of the aquifer are the best parts for choosing the drilling sites and future development

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