Journal of Applied Sciences

ISSN 1812-5654

Journal of Applied Sciences 5 (6): 973-977, 2005
ISSN 1812-5654

Vertical Electrical Soundings for Groundwater Assessment in Southeastern Iran: A Case Study

[1]G.R. Lashkaripour, [2]H. Sadeghi and [1]M. Qushaeei
[1]Department of Geology, University of Sistan and Baluchestan, Zahedan, Iran
[2]Department of Geology, University of Ferdowsi, Mashhad, Iran

Abstract: Vertical Electrical Soundings (VES) were carried out in the Chah-Hashem plain in southeast Iran for evaluating hydro-geological and structural conditions of subsurface sequences to a depth of around 250 m below ground surface. Utilizing the Schlumberger configuration, 400 vertical electrical soundings in 7 profiles were conducted in this area. The lengths of current electrode spacing (AB) ranging from 600 to 1000 m. Interpretation of these soundings indicates the presence of an unconfined aquifer that consists mainly of an alluvial aquifer. Zones with high yield potential have been determined as best locations for drilling for exploitations wells based on the resistivity data. On the whole, Chah-Hashem aquifer is an unconfined aquifer with average thickness of 65 m, noticeable extent and suitable quality.

Key words: Resistivity, sounding, aquifer, groundwater, Iran

INTRODUCTION

The Chah-Hashem plain lies in the southeast of Iran (Fig. 1). The plain is located in an arid area in Sistan and Baluchestan Province. The average elevation of the plain is about 550 m from the mean sea level. The study area lies in the north of Jazmurian depression about 60 km in west of Iranshar city (26°45′N-27°15′N and 58°30′E-60°30′) and covers about 4000 km^2. It is characterized by a nearly flat plain, as a part of Jazmurian basin.

The purpose of this study was to use the resistivity data and interpreting geoelectrical soundings to study the aquifer conditions. The use of geophysics for both groundwater resource mapping and for water quality evaluations has increased dramatically in the recent decades due to the rapid advances in microprocessors and associated numerical modeling solutions. The VES has also proved very popular with groundwater studies due to simplicity of the technique.

During recent years, increasing population and high demand for water during the growing season and low renewal rate of groundwater resources have resulted in the depletion of water resources in the study area. The need for this research is studying groundwater conditions and to protect groundwater supplies as a unique source of water for the region.

Geology of study area: Chah-Hashem plain is situated in the Flysch zone of eastern Iran. The major portions of the Flysch zone consist of shale, sandstone and limestone. In the Flysch zone, sediments of older than Cretaceous age are absent[1,2].

The bedrock of the aquifer consists of clay and hard rocks (shale, sandstone, etc.) in the age of Upper Cretaceous and partly Eocene. Quaternary sediments cover the study area. The Quaternary deposits which cover the plain area were composed mainly of fine grain alluvium of rivers, gravel to pebble of alluvial fan, sand to gravel and rock debris of the near mountains[3].

Hydro-geological conditions: The region is characterized by an arid climate and extremely low amount of precipitation. The average annual precipitation is 86.5 mm and the potential evaporation is 3790 mm per annum[4]. The scanty rainfall is confined to the winter season and rain usually occurs as thunderstorms and showers. The fresh groundwater in the region is originated from infiltration of rainwater, which has created unconfined Chah-Hashem aquifer.

The Chah-Hashem aquifer is the major aquifer in this region. The aquifer is an alluvial aquifer, which is mainly recharched from the annual rainfall. It is discharged artificially through a few hundred of dug wells and the galleries that know locally as qanat. The newly drilled wells in different parts of the aquifer are now used to

Table 1: Hydraulic parameters of the aquifer

Parameters	Amount
Average aquifer thickness (m)	65.0
Maximum aquifer thickness (m)	180.0
Range of groundwater depth (m)	2-24.0
Range of aquifer resistivity (Ωm)	10-40.0
EC range (μs cm^{-1})	728-2756.0
Average storage coefficient (%)	11.5

Corresponding Author: Dr. G.R. Lashkaripour, Associate Professor, Department of Geology, University of Sistan and Baluchestan, Zahedan, Iran Fax: 0098 541 2446771 E-mail: Lashkarg@hamoon.usb.ac.ir

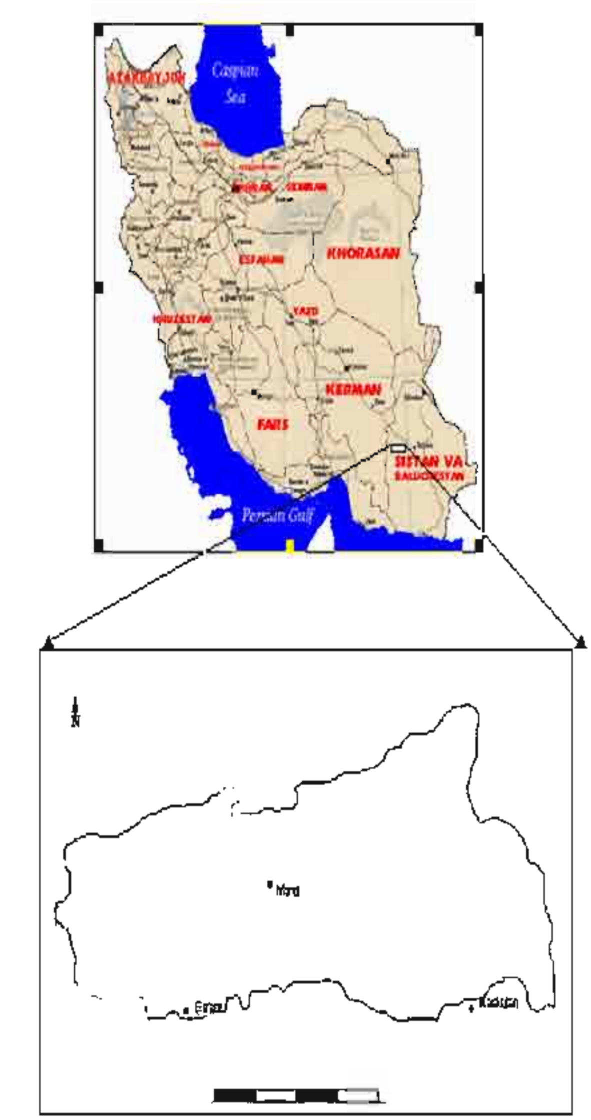

Fig. 1: Map showing the geographic location of study area

supply water for agricultural purposes and drinking water to the villages. Rapid agricultural development in the area has caused increase on demand for water supply. The monitoring of the groundwater level exhibits a decline of water level. The main reason responsible for this lowering of the groundwater table is that abstraction from groundwater resources has exceeded natural recharge in the recent years.

The present study was based on data from 400 vertical electrical soundings that carried out during in winter 2003, lithological and hydro-geological information from 9 wells and chemical analyses of groundwater samples from the 17 available wells have been used as check points. These data are used to evaluate the subsurface hydro-geological and structural conditions, to depth of about 250 m. In additions, estimation of the groundwater quality and recommendation for possible site-selections for drilling productive wells will be made. The aquifer hydraulic parameters are shown in Table 1.

Geoelectrical resistivity survey: The electrical resistivity of material depends on many factors such as groundwater salinity, saturation, aquifer lithology and porosity[5]. The resistivity techniques are popular and successful geophysical exploration for study groundwater conditions in the world. As mentioned above, the resistivity of material depends on many factors. For example, the resistivity of an aquifer is related to Electrical Conductivity (EC) of its water. When the groundwater EC is high, the resistivity of the aquifer could reach the same range a clayey medium and resistivity parameter is no more useful to determinate aquifer[6]. However, this method has been carried out successfully for exploration of groundwater. This technique is also widely used to determine depth and nature of an alluvium, boundaries and location of an aquifer.

The resistivity method has been used to solve more problems of groundwater in the type alluvium, karstic and another hard formation aquifer as an inexpensive and useful method. Some uses of this method in groundwater are: determination of depth, thickness and boundary of an aquifer[7], determination of interface saline water and fresh water[8-10], porosity of aquifer[11], water content in aquifer[12], hydraulic conductivity of aquifer[13,14], transmissivity of aquifer[15], specific yield of aquifer[16], contamination of groundwater[17,18]. Contamination usually reduces the electrical resistivity of pore water due to increase of the ion concentration[19]. However, when resistivity methods are used, limitation can be expected if ground inhomogeneities and an isotropy are presented[20].

Field survey and data processing: This research project deals with the detecting of the aquifer conditions and groundwater quality in the study area. The resistivity survey was completed with 400 Vertical Electrical Soundings (VES) by the Schlumberger array in 7 profiles, with a maximum current electrode spacing (AB) ranging from 600 to 1000 m. The sounding spacing was about 1 km and nine of these VES's have been conducted adjacent to the dug wells for subsequent calibration process. Position and extension of all the VES's are indicated in Fig. 2. Seven geoelectrical sections were drown along the profiles. The apparent resistivity measurements were made with a KD Sound 7800B Terrameter Unit. This equipment is light and powerful for deep penetration.

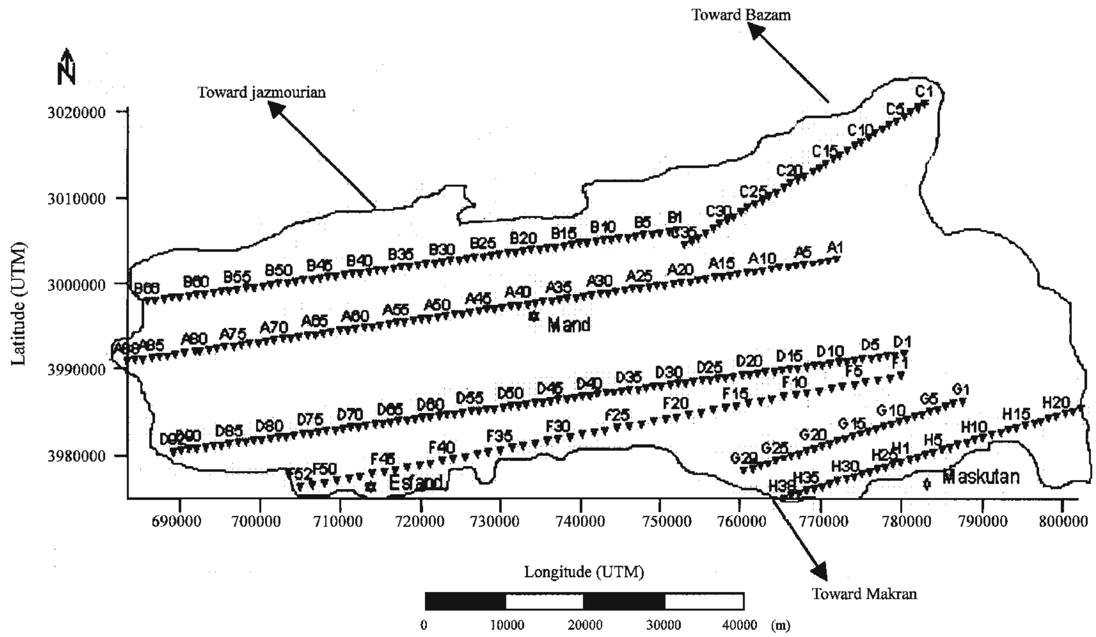

Fig. 2: The location of electrical profiles and soundings

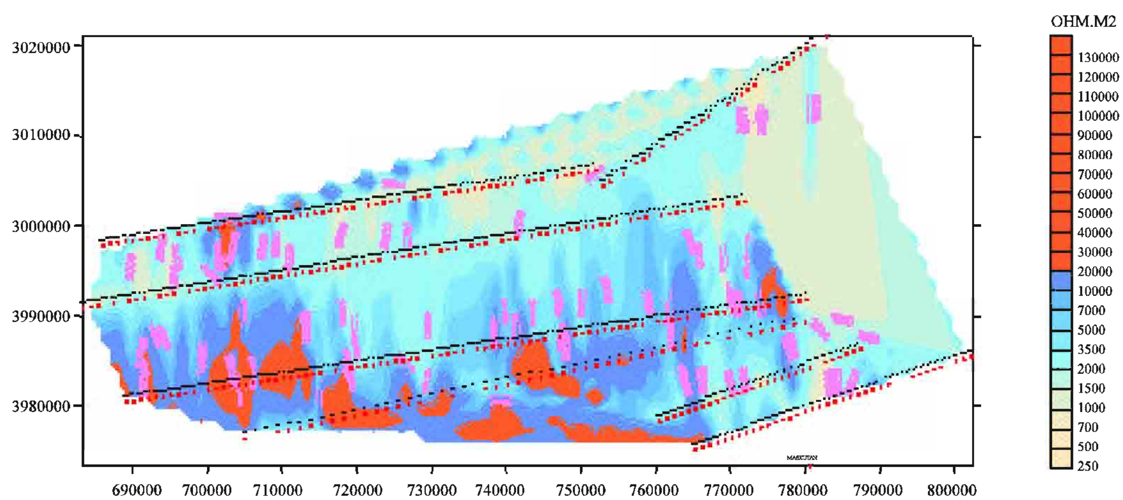

Fig. 3: RT map of the aquifer

The processing of field data were done after correcting and modifying the apparent resistivity curves according to the well-logs data and interpreted using VES and Zohdy[21] inversion software. However, thickness and characteristics of the aquifer are fairly well known due to the number of dug wells in the aquifer. The key to success of any geophysical survey is the calibration of the geophysical data with hydro-geological and geological ground truth information.

VES success must rely on the careful interpretation and integration of the results with the other geologic and hydro-geologic data for the site. Therefore, litologic information obtained from log could be used to calibrate the VES field curves. Where test hole-log information was available, the solution to automatic interpretation procedure was constrained by keeping know layer thicknesses constant during the program computations. In final, the results of the Schlumberger electrical soundings have been compared with the geological sections have been obtained from 9 drilled wells. These results are in a good agreement with the geological sections. Regarding to data of drilling wells and geoelectrical data the current penetration depth has been estimated about AB/4.

Thickness of the aquifer and resistivity of subsurface layers also was determined by the results of the electrical survey. From the interpretation of the resistivity curves a four-layer resistivities and thicknesses indicated four subsurface layers. These layers consisting of surface layer, alluvium, saturated layer and bedrock. In some causes more than one layer was evident in the saturated zone but these causes were also treated in this analysis as single layers. Depth and thickness of subsurface layers were identified and dimension of the aquifer and type of bedrock were also indicated. The aquifer thickness increases towards the south, the regional direction of increasing deposition in the plain. The maximum thickness of the saturated alluvial aquifer in the southern part has been estimated about 180 m. Average thickness of the aquifer is measured about 65 m. Bedrock of the aquifer is generally clay but in some parts has appeared as hard rock.

Yield potential in the southern part of the aquifer is more than the northern part. RT map that shows the potential of the aquifer in the whole study area is shown in Fig. 3. The best part of the aquifer for future development is south portion of the aquifer. In this part, the best water quality and quantity of groundwater sources are found with respect to high thickness and resistivity.

CONCLUSIONS

Four hundred VES's have been carried out to assessment the subsurface hydro-geological conditions to a depth of about 250 m. Based on the interpretation of geoelectrical data, the following conclusions are drawn:

- The alluvial aquifer mainly consists of gravel and sand in the southern part and sand and silt mixed with clay materials in the northern part. The resistivity of the aquifer increases towards the south and east due to decreasing salinity of water and/or clay content.
- VES tests revealed four subsurface geoelectric layers; thin top layer, the alluvium, the aquifer and the bedrock, respectively.
- The aquifer thickness increases towards the south, the regional direction of increasing deposition in the plain. The maximum thickness of the saturated alluvial aquifer in south has been estimated about 180 m. Average thickness of the aquifer is measured about 65 m.
- The bedrock of the aquifer shows different resistivity values due to type of bedrock from clay to hard rock.
- The zones with high yield potential have been determined for future development in the plain and for choosing the drilling sites.

ACKNOWLEDGEMENT

The present research has been supported by a grant from the Sistan Baluchestan Province Water Organization of the Ministry of Power, for which we express our sincere thanks.

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