Journal of Applied Geophysics 89 (2013) 116–124

Contents lists available at SciVerse ScienceDirect

Journal of Applied Geophysics

journal homepage: www.elsevier.com/locate/jappgeo

2D and 3D resistivity inversion of Schlumberger vertical electrical soundings in Wadi El Natrun, Egypt: A case study

Mohamed A. Khalil [a,b,*], Fernando A. Monteiro Santos [a]

[a] Universidade de Lisboa-IDL, Campo Grande, Ed. C8, 1749-016 Lisboa, Portugal
[b] National Research Institute of Astronomy and Geophysics (NRIAG), Helwan, Cairo, Egypt

ARTICLE INFO

Article history:
Received 19 July 2012
Accepted 29 November 2012
Available online 8 December 2012

Keywords:
2D
3D
Resistivity inversion
Hydrogeology
VES

ABSTRACT

The Wadi El Natrun area is characterized by a very complicated geological and hydrogeological system. 45 vertical electrical soundings (Schlumberger array) were measured in the study area to elucidate the peculiarity of this unique regime, specifically the nature of waterless area. 2D and 3D resistivity inversion based on the finite element technique and regularization method were applied on the data set. 2D and 3D model resolution was investigated through the use of the Depth and Volume of Investigation Indexes. A very good matching was found between the zones of high resistivity, the waterless area, and the non-productive wells. The low resistivity zones (corresponding to Lower Pliocene clay) were also identified. The middle resistivity fresh water aquifer zones were recognized. Available results can assist in the aquifer management by selecting the most productive zone of groundwater.

1. Introduction

Wadi El Natrun is an elongated depression attaining a length of about 50 km and a width ranging from 5 to 10 km. It is located between latitudes 30° 15′ and 30° 30′N, and longitudes 30° 00′ and 30° 30′. It covers an area of about 500 km^2, at a distance of 90 km northwest of Cairo, and 40 km from the Rosetta branch (Fig. 1). The lowest point of the depression is about 23 m below sea level, whereas the general lowland area of the depression is about 50 m below the level of its borders. A series of ten large, elongated salt water lakes occupy the central low part of the depression. They extend from the southeast to the northwest direction. The area of Wadi El Natrun is dominated by semi-arid to arid climatic conditions. The average annual rainfall is 39.3 mm/year (Atwa, 1968).

The main aim of the present study is to test the capability of 2D and 3D resistivity inversion of individual vertical electrical soundings (VES) to investigate the groundwater occurrence in the study area. Special attention is paid to explain the reasons behind the so-called waterless area.

Resistivity data are measured with the conventional Schlumberger array and processed and interpreted in both 2D and 3D manners. VES is based mainly on injecting electric current to the earth via two electrodes (current electrodes) and measuring the potential difference via two other electrodes (potential electrodes). This four electrode system has many types of arrays such as Schlumberger, Wenner and, Dipole–Dipole. The vertical resistivity sounding is based on the concept of a homogeneous, isotropic, layered horizontal earth model. VES is effective in ground water exploration, particularly for water table detection. For the 1-D case, where the subsurface is restricted to a number of horizontal layers, the linear filter method (Koefoed, 1976, 1979) is commonly used to calculate the true resistivity from the measured apparent resistivity.

The greatest limitation of the conventional or traditional VES method is that it does not take into account lateral changes in the layer resistivity. Such changes are probably the rule rather than the exception. A more accurate model of the subsurface is a two-dimensional (2-D) model where the resistivity changes in the vertical direction, as well as in the horizontal direction along the survey line, assuming that resistivity does not change perpendicularly to the survey line. If this is not the case, theoretically, a 3-D resistivity survey and inversion should be much more accurate.

The increase in computing power led to developing new 2D and 3D inversion codes (Günther, 2004; Loke and Barker, 1996; Marescot, et al., 2005; Santos and Sultan, 2008). However, there are a few references specifically devoted to 2D and 3D inversion of 1D Schlumberger soundings (Santos and Sultan, 2008; Uchida, 1991). Several authors have noticed the effect of non-layered structures located in the vicinity of vertical electrical soundings (e.g. Queralt et al., 1991). Therefore, it is possible to use the sensitivity of the Schlumberger array for 2D and 3D modeling and inversion (Santos and Sultan, 2008), particularly when the data are densely collected.

2. Geological and hydrogeological setting

The Wadi El Natrun depression is excavated in Pliocene sediments. It is dominated by shallow marine, brackish water deposits, clayey

* Corresponding author at: Universidade de Lisboa-IDL, Campo Grande, Ed. C8, 1749-016 Lisboa, Portugal. Tel.: +351 919954186.
E-mail address: khalil250@hotmail.com (M.A. Khalil).

0926-9851/$ – see front matter
http://dx.doi.org/10.1016/j.jappgeo.2012.11.014

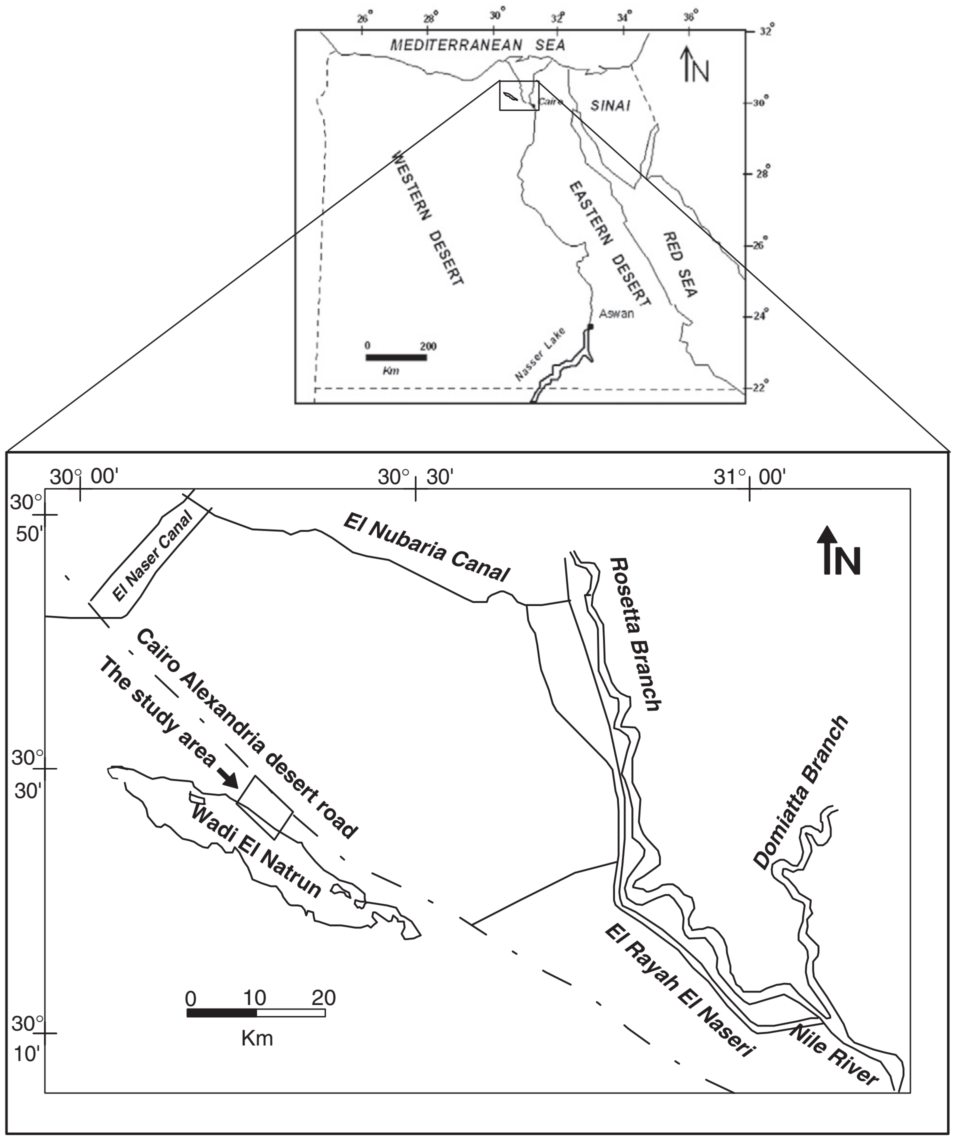

Fig. 1. Location map of Wadi El Natrun, and the study area.

facies at the base and fluviomarine and shallow marine deposits at the top. The geological and hydrogeological successions in the area are classified from top to bottom as follows.

2.1. Recent deposits

Recent deposits occupy the low land area in the main depression. They are composed of wind blown sand mixed with downwash gravel and sand of relatively high porosity. Water of this aquifer is of low salinity, and recharged essentially from the main Neogene aquifer to the east of Wadi El Natrun. The seepage from the aquifer infiltrates directly into the salt lakes in the main depression.

2.2. Pleistocene sand and gravel

These units occupy the area to the east and north of the Cairo–Alexandria desert road. They are characterized by gravels and coarse sands intercalated with thin streaks of impervious clays. This aquifer merges with the Pleistocene aquifer under the Nile delta and terminates towards Wadi El Natrun, where the Pliocene aquifer becomes adjacent to the Pleistocene aquifer. Groundwater of this aquifer has low salinity. The Pleistocene aquifer occupies only a small part of the study area, represented by a thin sheet parallel to the Cairo–Alexandria desert road. It has a thickness of 40 m, and is recharged from the intake area at the Nile delta basin. It receives infiltration from the Nubaria canal and the retained recharge is from irrigation water. Pleistocene deposits in Wadi El Natrun contain also the sub-recent lacustrine deposits, alluvial calcareous loam, and lagoonal clay and sand (Sanad, 1973).

2.3. Pliocene deposits

Pliocene deposits are dominated by loose quartz sands and sandstone separated by impervious clay layers. The Pliocene deposits have two water-bearing horizons. The upper horizon (Upper–Middle Pliocene) consists mainly of loose quartz sand and calcareous sandstone. This geological unit is mainly developed in the eastern portion of Wadi El Natrun. The groundwater of this horizon is under semi-confined conditions due to the existence of clay facies, which are interbedded with the sand layers. The lower horizon (Lower Pliocene) is mainly clay beds with sand intercalations. It is restricted to the Wadi El Natrun main depression. The groundwater of this horizon is found under confined conditions.

Generally, the main regional structural feature of the great desert west of the Nile Delta is a monocline (beds having an irregular