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Geoelectric Measurements for Groundwater Assessment in Gedaref Area, Sudan

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ABSTRACT. Vertical electrical soundings (VES) and hydrogeological data from Gedaref area of Sudan were collected, analysed and interpreted to test the possibilities and limitations of VES in groundwater exploration and evaluation.

The results which were presented in the form of resistivity, salinity and transverse resistance (T) maps had shown a close agreement with the general hydrogeological condition of the region. Zones with maximum (T) are usually good targets for drilling fresh water wells. Correlations had also been made between aquifer resistivity and water salinity. The correlation procedure adopted in this study could be applied to evaluate water prospects of new target areas in the region or elsewhere.

Introduction

The Gedaref area lies in the eastern region of the Sudan Republic. It encompasses an area of about 22300 km^2 between Latitudes 13°00′N-14°30′N and longitudes 35°00′E-36°15′E. The climate of the area is characterized by large seasonal variations; during summer time (April-June) the average daily temperature is about 40°C, during winter the average temperature is between 18°C and 22°C. The rainy season usually extends from the end of June to September with an average annual precipitation of 500 to 800 mm. Potential evapotranspiration rates highly exceed the precipitation rates though short duration runoffs occur during the rainy season. More than 50% of millet in Sudan is produced in the Gedaref area and it is mainly watered from seasonal rains. Since the early sixties and with the increase in the demand of water-supply in the area, efforts have been focussed on groundwater exploitation.

Previous geological studies were carried out in the area by Wilcockson and Taylor (1933), Grabham (1934), Andrew (1948), Delany (1952), Ruxton (1956), Whiteman (1971) and Almond *et al.* (1984). Groundwater resources have been addressed by a number of researchers (Suleiman 1968, Kheir 1980, Imam 1983, Adam 1987).

This study is intended to apply resistivity measurements to assist in groundwater exploration and evaluation through well-defined objectives. These objectives are addressed through the following questions :

1. Can Vertical Electrical Sounding (VES) provide reliable results in relation to groundwater availability and water quality in a clastic sedimentary aquifer?
2. Can some empirical hydrogeophysical correlations be established using VES data?

General Geology and Hydrogeology

The stratigraphic sequence in the Gedaref area starts with the Precambrian-Cambrian crystalline basement complex rocks (Fig. 1). These basement rocks are unconformably overlain by the Mesozoic Gedaref Sandstone Formation which is followed by Tertiary-Quaternary basalt flows, sills and dykes. On top of the stratigraphic sequence rest the Quaternary-Recent surficial deposits. Figure 2 summarizes the stratigraphic sequence in the study area. Previous gravity survey in the area (Ibrahim *et al.* 1992) delineated major sedimentary basins in the region with maximum depth of the sedimentary cover reaching more than 2000 m. Groundwater occurs in the area mainly within saturated layers of the Gedaref Sandstone Formation. It occurs as well in fractured, fissured and highly jointed basalt and in weathered and fractured basement rocks.

The Main Aquifer

The Gedaref Sandstone Formation is the main aquifer in the study area. It is a multilayered system consisting of interbedded sandstones and mudstones. The water-bearing units occur as thin sandstone layers interbedded with relatively thick mudstone beds. Localized zones of highly silicified sandstone occur in some places. The average thickness of the water-bearing units of the aquifer system is about 40 m and water is struck at depths from 7 m to 125 m. The aquifer system is characterized by average transmissivity of $3.24 \times 10^{-4} m^2 s^{-1}$, average storativity of 4×10^{-3}, and groundwater velocity of 4.38×10^{-3} m day^{-1} (Adam 1987). The average hydraulic gradient prevailing in the area is in the order of 6×10^{-3}. Two major flow directions exist in the area (Fig. 3) due east and due west indicating a groundwater divide in between. There are other minor flow directions mainly to the north and southwest. Salinity varies within the main aquifer from 280 ppm to 1800 ppm with a gradual increase down gradient (Fig. 4) and with the penetration depth.

Electrical Resistivity Survey

The objectives of the electrical resistivity survey were to delineate water-bearing

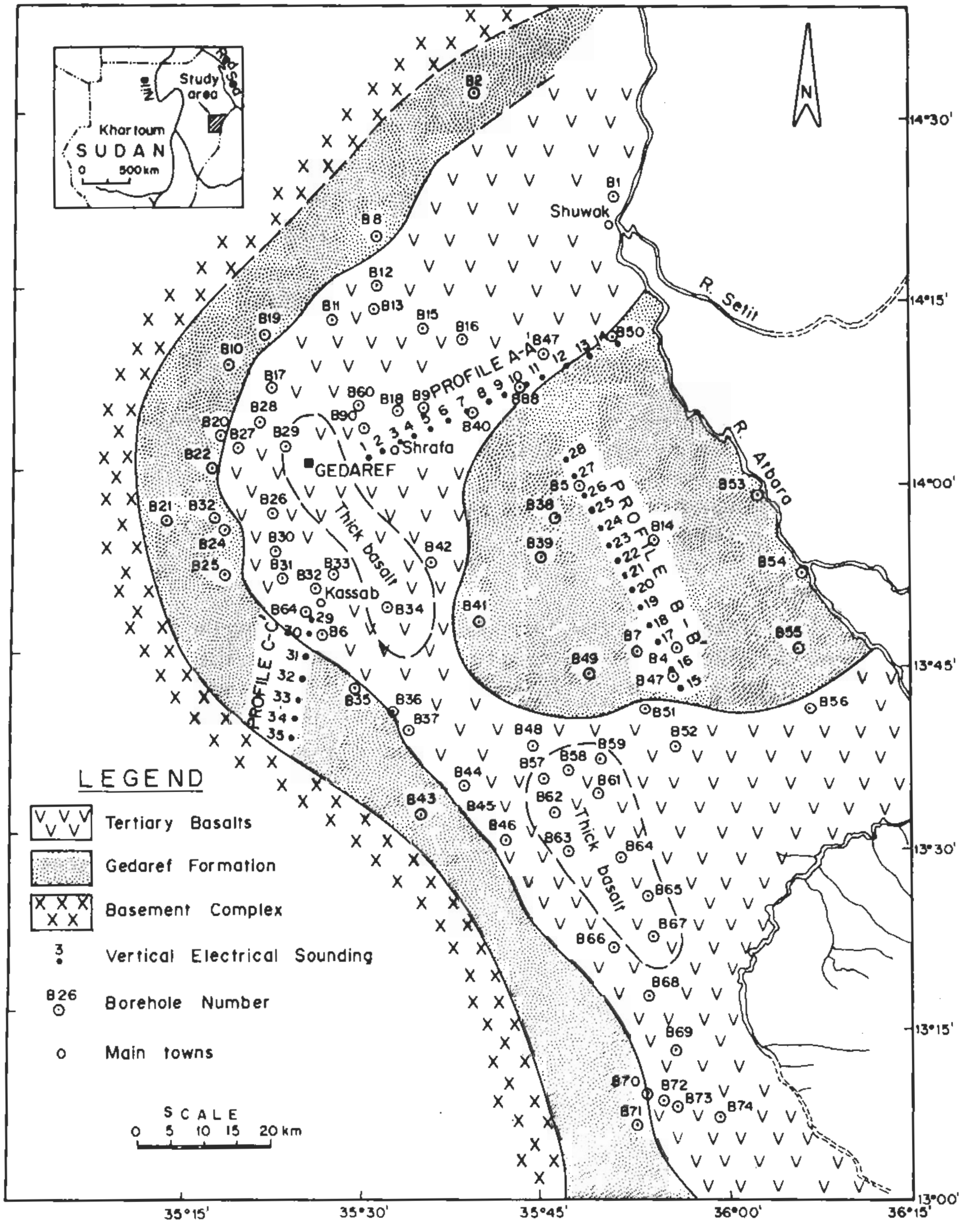

FIG. 1. General geology map of the study showing borehole and vertical electrical sounding locations.

Age	Formation	Lithology	Thickness (m)
Quaternary - Recent	Surficial deposits	Heterogeneous assemblage of gravel, sand, silt and clay	< 10
Tertiary - Quaternary	Cotton soil	Heavy gray to dark chocolate swelling / cracking clays	< 15
Tertiary	Basalt	Sills, flows land dykes of basaltic rocks	65
Jurassic - Cretaceous	Gedaref Sandstone Formation	Sandstone, mudstone and highly silicified sandstone	5→200
Precambrian - Cambrian	Basement complex	Metasediments, metavolcanics and igneous complexes	

FIG. 2. Stratigraphic sequence in the Gedaref area.

formation, to distinguish between different rock types, and establish the depth to the bed-rock where possible.

Measurements

A total of 36 vertical electrical soundings were performed during the course of this study, using the Schlumberger electrode configuration . To ensure a penetration of up to 300 m, a maximum current electrode separation of 2000 m was reached. The data were collected along three profiles, totaling 97 km in length and having different orientations (Fig. 1). A portable ABEM SAS 300 resistivity equipment was used for measurements at 6 samples per decade. Steel rods were used as current and potential electrodes and were continually watered to reduce the contact resistance between the top soil and the electrodes. The apparent resistivity values were then plotted as a function of half-current electrode separation on bi-logarithmic paper and thus sounding curves were produced. The dominant type curves in the areas were HA type (Fig. 5).

Interpretations

Equivalence is a well-known problem in the interpretation of vertical electrical sounding curves. A multilayer curve can generally correspond to a great number of different subsurface distributions of layer resistivities and thicknesses. The number of possible solution is reduced by mutual correlation of several sounding curves, by knowledge of the local geology and by drilling information. A reliable meaningful interpretations can be made when additional subsurface information, preferably lithological borehole data is available (Telford *et al.* 1976).

Borehole data from 14 sites occupied by VES had been collected and analysed. The results suggested that average depth to Gedaref sandstone aquifer is at least 80 m and that the lithologies include clays and basalts which both constitute the unsaturated strata. The aquifer is represented by sandstone which is underlain in some

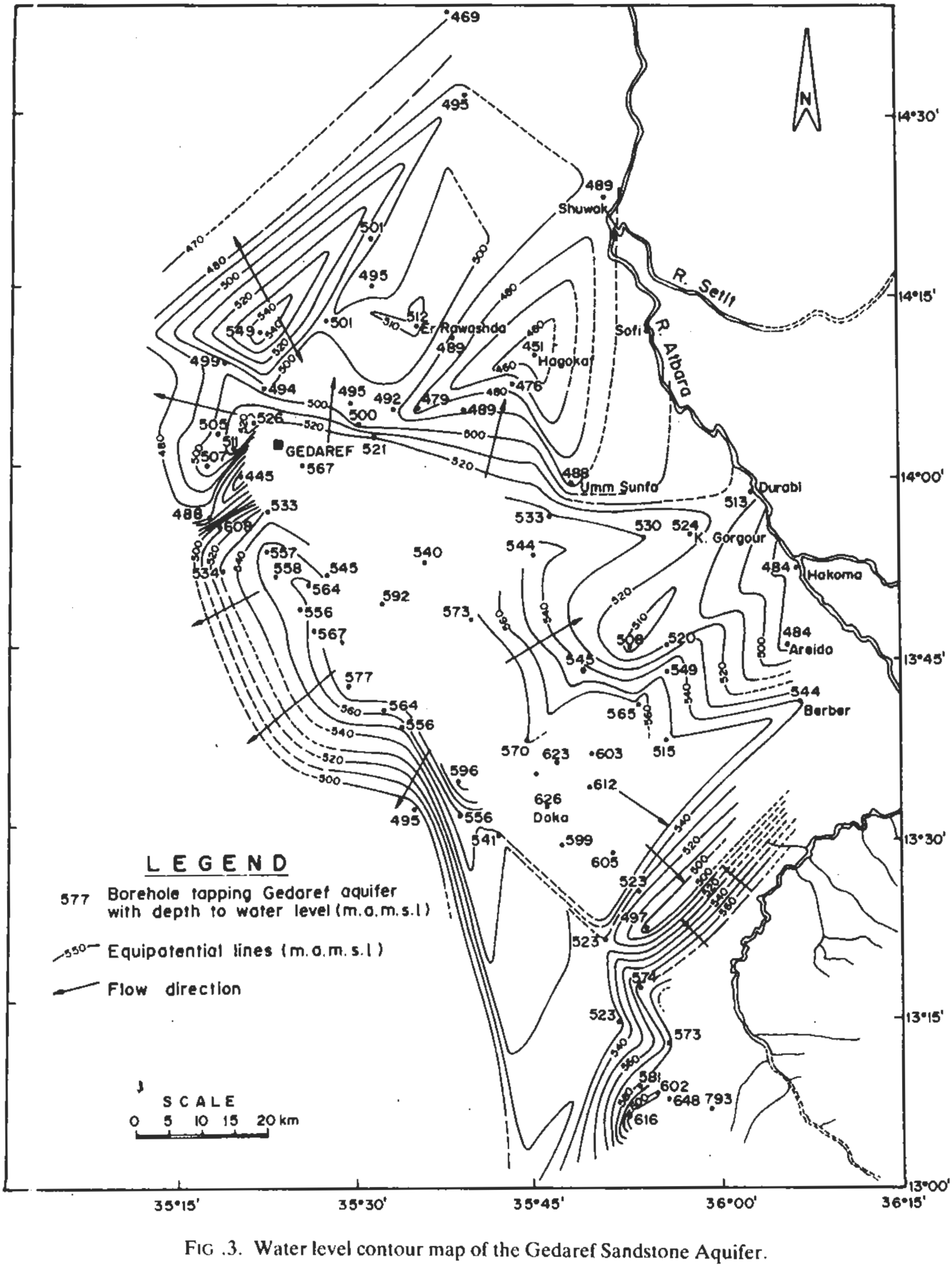

FIG .3. Water level contour map of the Gedaref Sandstone Aquifer.

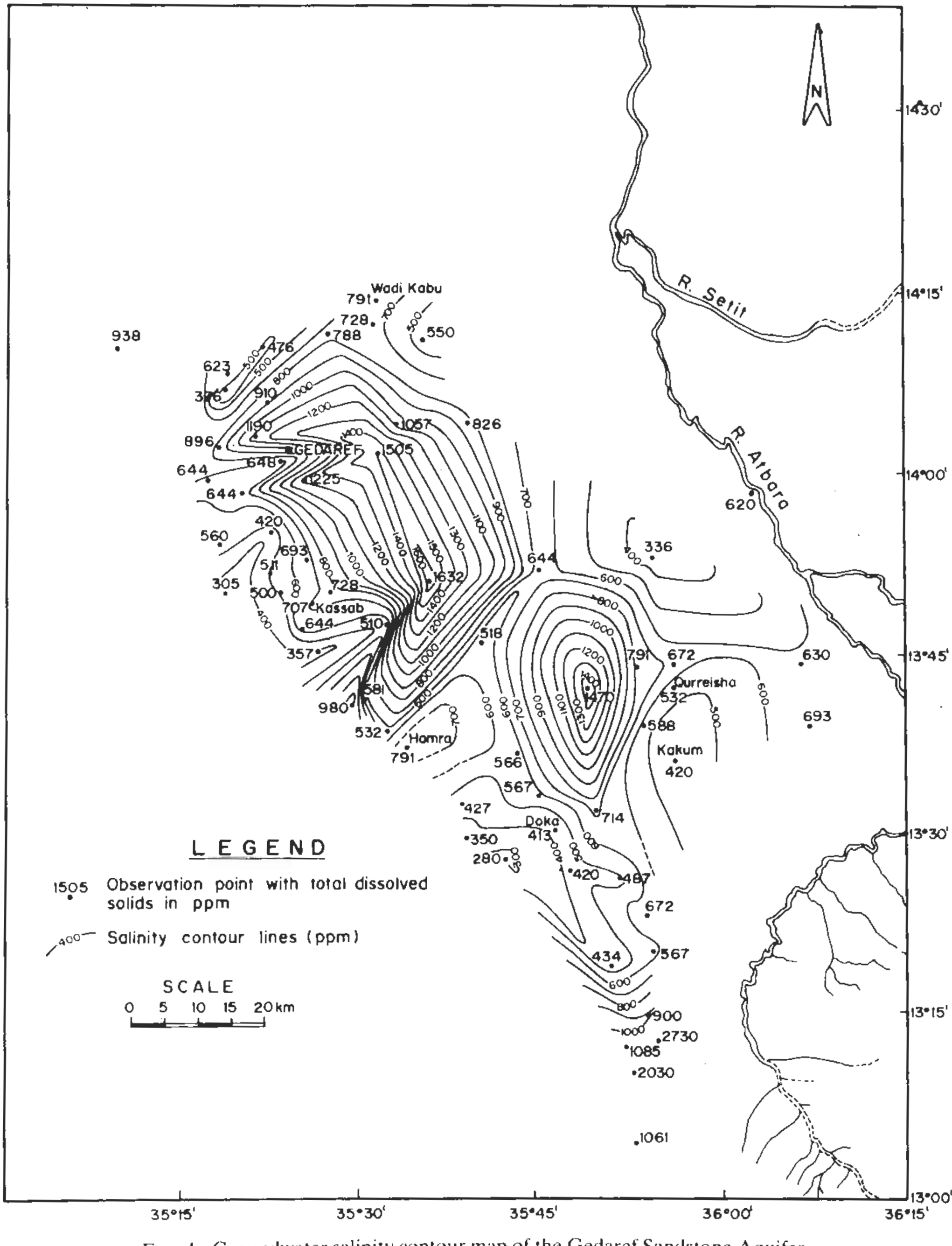

FIG. 4. Groundwater salinity contour map of the Gedaref Sandstone Aquifer.

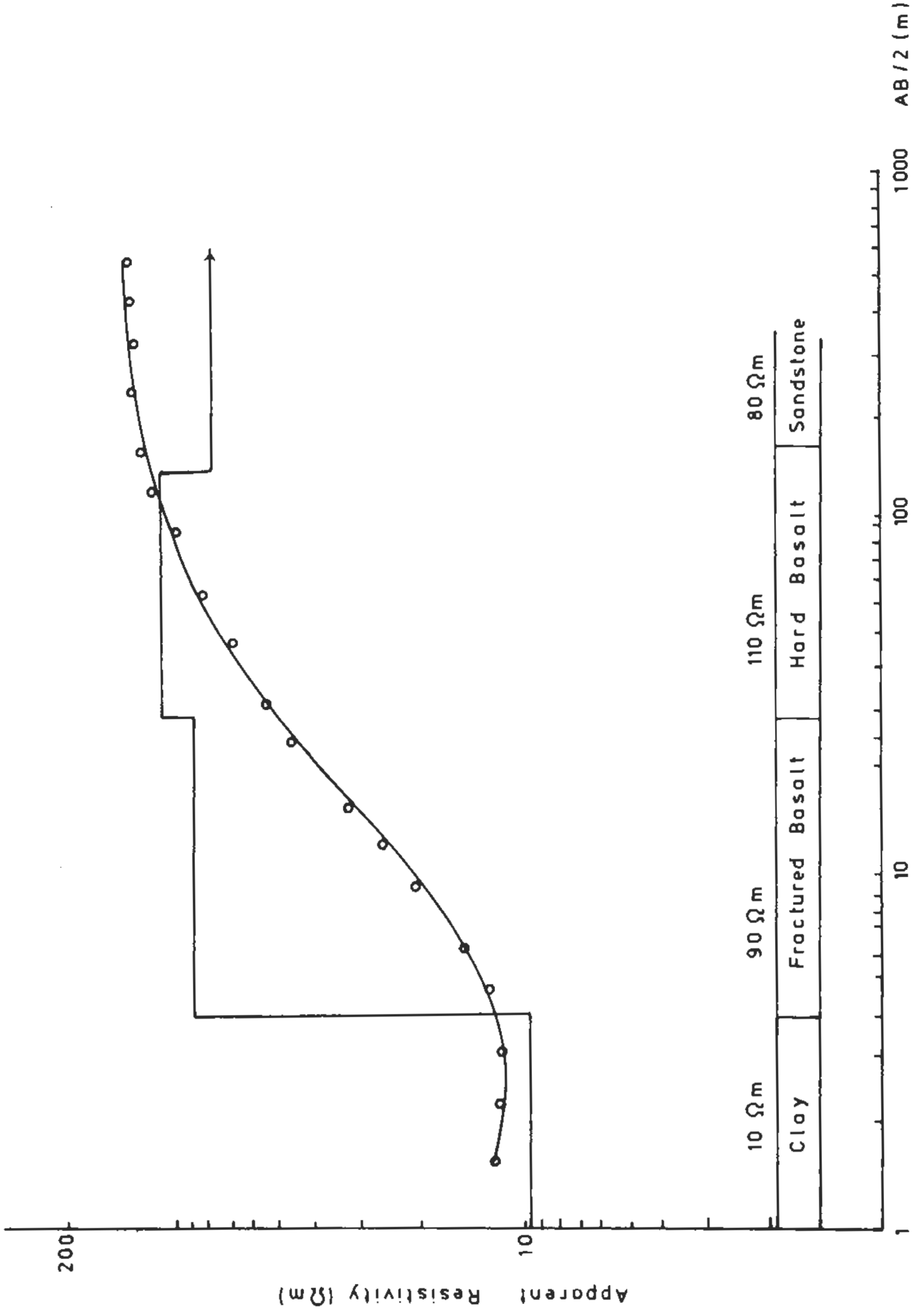

FIG. 5. VES 1 profile A-A′ and its geological interpretation.

places by highly silicified sandstone. Mudstone with variable thicknesses have also been reported in some localities.

Inversion of sounding data was achieved iteratively using inverse filters (O'Neil 1975). The match between the field data and the model was obtained with a root-mean-square (RMS) of less than 5% in most cases. Figure 5 shows an interpreted sounding curve and its possible geological interpretation near borehole B90. Correlation of resistivity values and the lithology is given in Table 1.

TABLE 1. Correlation of resistivity values and lithology.

Lithology	Average resistivity (Ohm m)
Clay	8
Fractured basalt	71
Hard basalt	178
Gedaref Sandstone	
Silicified sandstone	≥ 300

Results and Discussion

In Figure 6, a contour map of aquifer resistivities has been drawn, using SURFER contouring program. The variation in resistivity is generally between 60-120 m. The map shows two possible fresh water zones existing in the NE and the south. The wider spacing of the contours in the central part may indicate the stability in water quality. The map also shows two resistivity zones in the NE and south with close contour spacing which suggest rapid changes in water quality.

Comparison between the iso-resistivity contour map (Fig. 6) and iso-salinity map (Fig. 4) shows some similarities. Nevertheless, some of the differences between the two maps can be attributed to the time lag between chemical data sampling and VES measurements. Modification in water quality could have occurred over the last few years due to the increase in drilling and pumping activities in the area.

In the interpretation of the aquifer resistivity in terms of water quality the formation factor (Archie 1942) is assumed to be constant for the whole area. Thus, the variation in the resistivity reflect only the changes in water quality. This assumption, however, ignores the fact that, parameters such as porosity, cementation factor, and groundwater temperature are equally important factors.

Using simple regression analysis, Fig. 7 shows the correlation between aquifer resistivity and groundwater salinity (TDS). As evident the water quality data correlate well with aquifer resistivity (correlation factor – 0.91). In order to reduce uncertainty in our interpretations and determine the actual cause of the anomalies and whether they are due to chemical changes or thickness, transverse resistance (T) (resistivity × thickness) map of the aquifer is produced (Fig. 8). Such maps generally reflect the change in one or a combination of factors, such as thickness, clay content or salinity. The closely spaced contours reflect changes in water chemistry and aquifer thickness

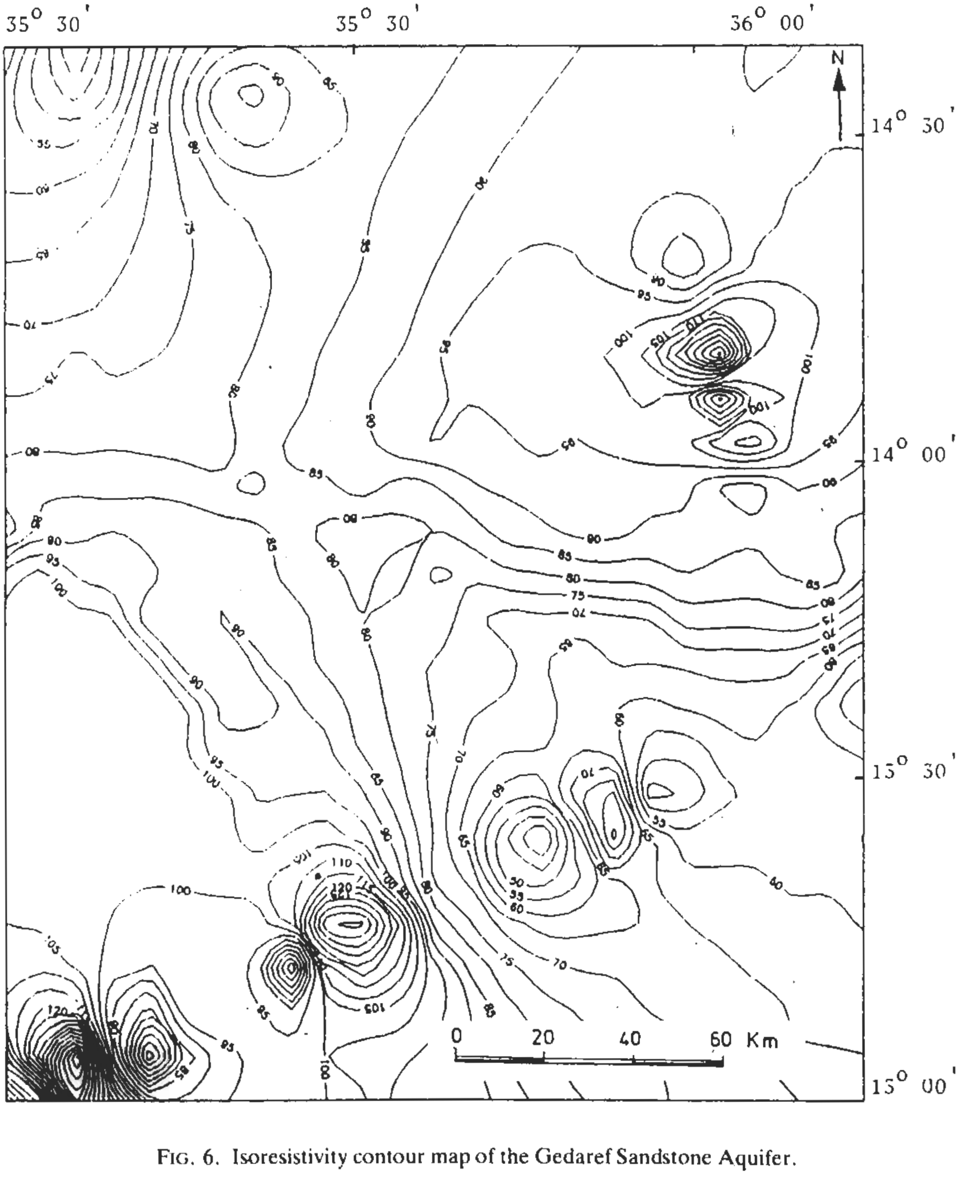

FIG. 6. Isoresistivity contour map of the Gedaref Sandstone Aquifer.

from previous geophysical and geological studies (Ibrahim *et al.* 1992), block faulting is evident. It should be noted that anomalous zones with maximum transverse resistance values (Fig. 8) are expected to be the best locations for drilling fresh water wells. Comparison of this map with iso-resistivity and iso-salinity map shows clearly that the change in samples water quality is likely caused by salinity changes rather than aquifer thickness variations.

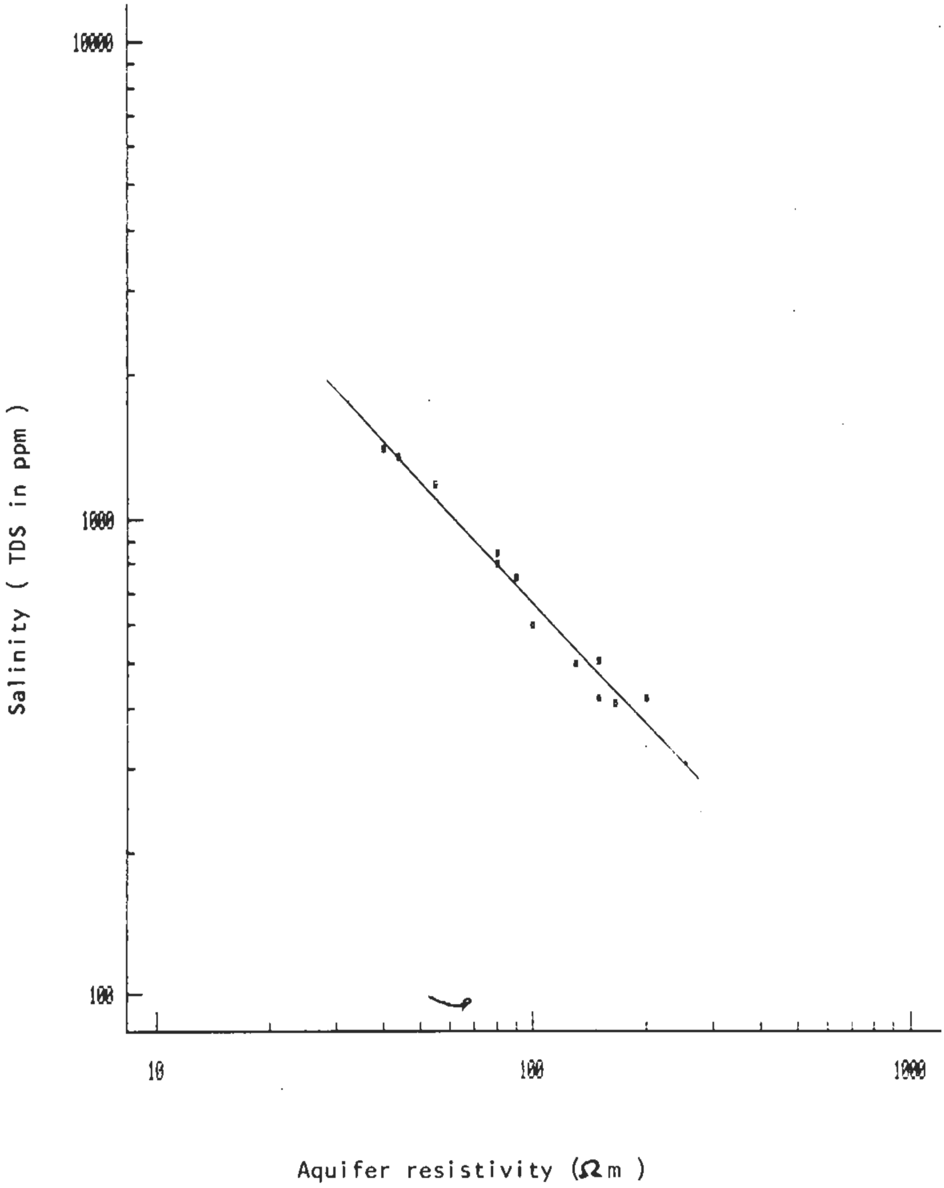

FIG. 7. Correlation between aquifer resistivity and groundwater salinity.

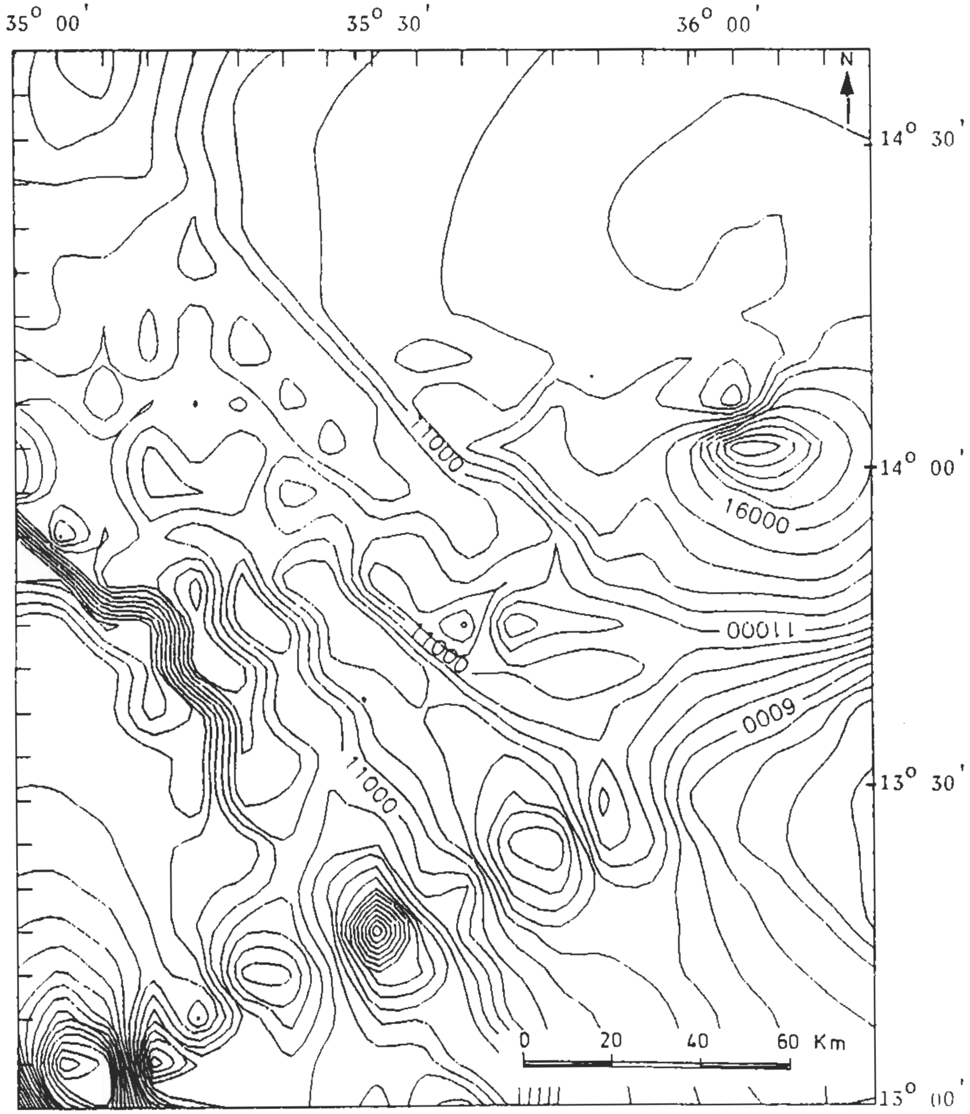

FIG. 8. Transverse resistance contour map of the Gedaref sandstone aquifer.

Conclusion

This study is intended to answer two questions concerning the application of vertical electrical sounding to solve groundwater problem and obtain some empirical graphical relationship between electrical and hydrogeological parameters. Results of geophysical and hydrogeological data have clearly shown a good agreement between the two approaches and the suitability of VES in the assessment of groundwater quality. The procedure adopted in this research can be extended for other areas in the region and elsewhere.

Acknowledgement

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References

Adam, E.G.E. (1987) *Water Resources Evaluation of Gedaref Basin,* Ph.D. thesis, Univ. of Khartoum, Sudan (unpublished).

Almond, D.C., Kheir, O.M. and Poole, S. (1984) Alkaline basalt volcanism in Northeastern Sudan: A comparison of the Bayoda and Gedaref areas, *JAES* **33**:(2): 233-245.

Andrew, G. (1948) *Geology of the Sudan. In:* **Tothill, J.D. (ed.)** *Agriculture in the Sudan,* Oxford Univ. Press, London, pp. 84-128.

Archie, G.E. (1942) The electrical resistivity as an aid in determining some reservoir characteristics. *Petroleum Technology, Technical Report* **1422.** Amer. Instit. Mining and Metallurgical Engineering.

Delany, F.M. (1952) *Recent Contribution to the Geology of the Sudan,* Chrons, Mines Colon, 197.

Grabham, G.W. (1934) Water supplies in the Sudan, *Sudan Geol. Surv. Bull.* No. **2,** 45 p.

Ibrahim, K.E., Hussein, M.T. and **Gido, I.M.** (1992) Application of combined geophysical and hydrogeological techniques to groundwater exploration: a case study of Showak-Wad Elhelew area, Eastern Sudan, *JAES,* **15**(1): 1-10.

Imam, T.H. (1983) *Hydrogeological and Geophysical Study of Abu En Naja Water Field,* M.Sc. Qualifying Report, Univ. of Khartoum (unpublished).

Kheir, O.M. (1980) *Hydrogeology of Gedaref Basin, East Central Sudan,* M.Sc. Thesis, Univ. of Khartoum (unpublished).

O'Neil, D.J. (1875) Improved linear filter coefficient for application in apparent resistivity computations, *Bull. Aust. Soc. Explor. Geophys.* **6**(4): 104-109.

Ruxton, B.P. (1956) *An Account of the Geology of the Sennar and Gedaraf Area,* M.Sc. thesis, Univ. of Khartoum (unpublished).

Suleiman, Y. (1968) Hydrogeology of part of Eastern Sudan (Gedaref District), *Sudan Geol. Surv. Bull.* No. **16,** 50 p.

Telford, W.M., Geldart, L.P., Sheriff, R.E. and **Keys, D.A.** (1976) *Applied Geophysics,* Cambridge Univ. Press, 860 p.

Whiteman, A.J. (1971) *The Geology of the Sudan Republic,* Oxford Univ. Press, 290 p.

Wilcockson, W.H. and **Taylor, W.H.** (1933) On an area of ultrabasic rocks in Kassala Provinee, *Sudan. Geol. Mag.* **70:** 305-320.

القياسات الكهربائية الأرضية لتقييم الماء الجوفي في منطقة القضارف ، السودان

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المستخلص . جُمعت بيانات الجَسّ الكهربائي العمودي والبيانات الهيدروجيولوجية من منطقة القضارف في السودان ، وتم تحليل هذه البيانات واستقراؤها لاختبار إمكانات وحدود استعمال الجس الكهربائي العمودي للكشف عن الماء الجوفي وتقييمه .

أظهرت النتائج ، التي وضعت على شكل خرائط للمقاومية الكهربائية ، ملوحة الماء الجوفي ، وللمقاومة العرضية توافقًا قريبًا مع الظروف الهيدروجيولوجية العامة في المنطقة . وتعتبر النطاقات ذات المقاومة العرضية القصوى أفضل مواقع لحفر آبار المياه العذبة . كما تمت المضاهاة بين المقاومية الكهربائية للطبقة الحاملة للماء وملوحة الماء الجوفي . يُمكن تطبيق المضاهاة المستعملة في هذه الدراسة لتقييم احتمالات وجود الماء الجوفي في مساحات جديدة في المنطقة أو في مناطق أخرى .