Arab Gulf Journal of Scientific Research, 25 (1/2): 67- 70 (2007)

Technicnal Paper Ref. No 2424

A Cost-Effective Method to Map the Top of Shallow Groundwater Systems

طريقة فعالة منخفضة التكاليف لتحديد السطح العلوي لأنظمة المياه الجوفية الضحلة

Mohammad Makkawi and Abdullatif Al-Shuhail

محمد مكاوي وعبداللطيف الشهيل

Earth Sciences Department
King Fahd University of Petroleum and Minerals
Dhahran 31262, Saudi Arabia

ABSTRACT: This paper presents an integrated GPR-OK procedure to detect the depth to a water table below the ground surface. The study evaluates the applicability of this approach to locate a water table using an inexpensive and efficient procedure. The proposed methodology may be utilized to map the surface of a shallow groundwater resource or detect the spatial extent of groundwater contamination. A pilot study was conducted in a small area of an inter-dune terrain in the Jaforah Desert system of Eastern Saudi Arabia to test the approach. The hydrogeologic data was acquired by a 300 MHz antenna of a SIR-2 GPR system. A velocity of 0.15 m/ns was used for time-to-depth conversion. Preliminary analysis indicates that the depth to water table lies in the range of 65 cm to 68 cm. The result indicates that this method may be employed in larger scale projects to assess new groundwater resources or monitor and manage the extent of groundwater pollution.

Keywords: *Groundwater, Ordinary Kriging, Geostatistical model, GPR, Saudi Arabia.*

المستخلص : تقدم هذه الورقة طريقة GPR-OK المتكاملة لكشف عمق مستوى المياه تحت سطح الأرض، وتقيم الدراسة قابلية تطبيق هذه الطريقة لتحديد منسوب المياه الجوفية باستخدام إجراءات غير مكلفة وفعالة. ويمكن استخدام المنهجية المقترحة لرسم خارطة سطح المياه الجوفية الضحلة او لكشف الحدود المكانية لمدى تلوث المياه الجوفية. ولاختبار هذه الطريقة اجريت دراسة تجريبية في مساحة صغيرة بين الكثبان الرملية في منطقة الجافورة الصحراوية الواقعة شرق المملكة العربية السعودية، وتم الحصول على البيانات الهيدروجيولوجية بواسطة هوائي بذبذبة 300 ميغاهيرتز من نظام SIR-2 GPR . وباستخدام سرعة 0.15 متر/نانوثانية في عملية تحويل الوقت إلى العمق. واشارت التحاليل الاولية إلى ان عمق مستوى المياه الارضية يقع ما بين 65 سم إلى 68 سم. وتبين النتيجة ان هذه الطريقة يمكن استخدامها في مشاريع ذات مساحات كبيرة سواء لتقييم موارد مياه جوفية جديدة او لرصد وإدارة مدى تلوث المياه الجوفية.

كلمات مدخلية : *مياه جوفية، طريقة كريج العادية، نموذج جيو-إحصائي، المملكة العربية السعودية.*

INTRODUCTION

The endeavor to explore groundwater resources, protect aquifer environment and construct civil structures, necessitates identifying the position of the underneath water table accurately. To generate dependable watertable maps, Depth to Ground Water (DGW) data is required. Usually these data are obtained by installing a considerable number of monitoring wells at different locations, particularly when dealing with branching alluvium aquifers and groundwater systems under urban or restricted areas. This is a difficult and expensive task that consumes a lot of time.

Several techniques were tested to detect shallow groundwater systems and aquifer boundaries. One of these exploration methods was the Ground Penetrating Radar (GPR). Utilization of GPR in detecting shallow groundwater systems is advantageous because of its high-resolution output, economic implementation, rapidity, and portability of field instruments. The GPR employs the concept of dielectric constant and electrical conductivity contrasts to differentiate hydrogeologic units like the top of a groundwater system from the vadose zone.

The objective of this paper is to map the surface of a shallow groundwater system by a cost-effective GPR-OK (Ordinary Kriging) method. The procedure used in this study aims at constructing a network of "imaginary monitoring wells" and observes the DGW in each «well». DGW observations will be used as control points to accurately map the surface of a shallow groundwater system using the OK procedure.

STUDY AREA AND DATA SET

The study was conducted in a flat small area of the Jaforah Desert about 5 km SE of Abqaiq city, Eastern Saudi Arabia (Fig. 1). Several water ponds were observed in the area that intersect a shallow groundwater system. The system is most probably associated to the buried "Abqaiq River" (Weijermars, 1999). A small pond of about 12 x 7 x 1 m dimensions is located 8 m to the E-SE of the study area. Water level in the pond was about 70 cm below ground surface. A water sample was analyzed in the field and indicated a brackish water quality with a TDS value of 5500 mg/L.

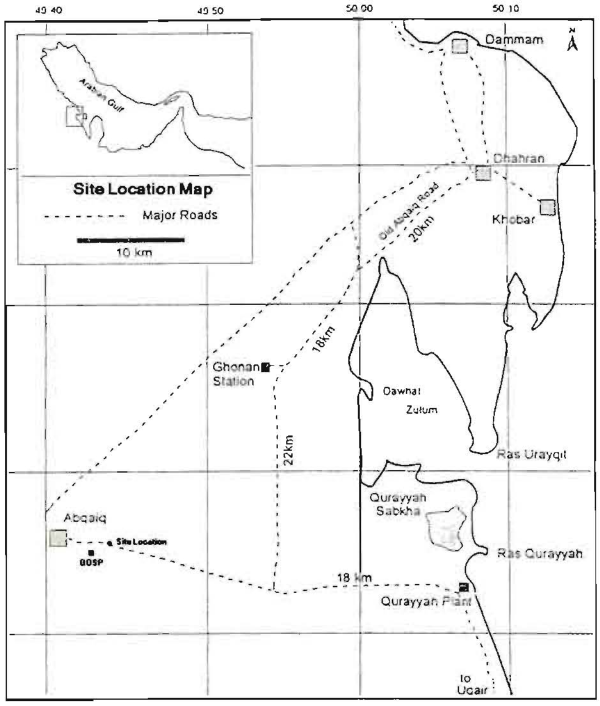

Fig. 1. Location map of the study area.

A 300-MHz GPR antenna was used to acquire DGW data. Figure 2 shows the locations of the "imaginary monitoring wells" that are distributed on a regular grid network of 1.5 x 1.5 m. In each trace or """well", a two-way travel time was measured. Based on a field experiment, the velocity value of 0.15 m/ns was used for time-to-depth conversion. DGW values were calculated for each trace and used to map the surface of the existing shallow groundwater system.

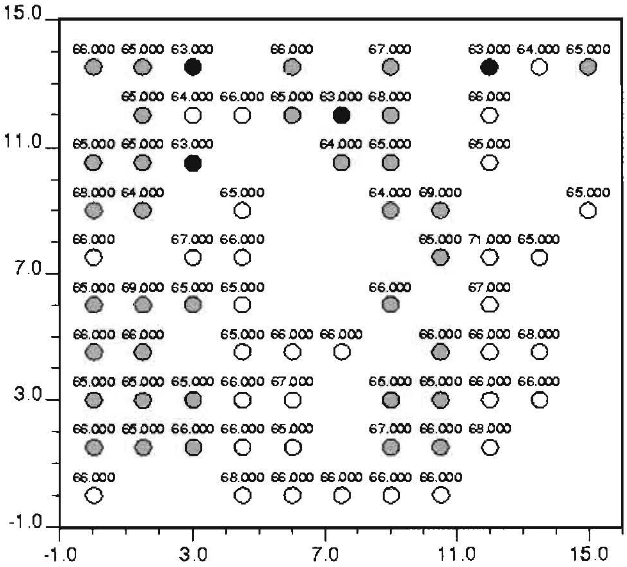

Fig. 2. Plan view of the «imaginary monitoring wells - IMW». The number on top of each IMW indicates the DGW surface detected by the GPR.

METHODOLOGY

The DGW data set was analyzed using statistical methods to show population characteristics (Davis 2002). A probability plot was constructed to identify data normality and investigate the presence of outliers. This step was essential in selecting the appropriate geostatistical modeling procedure (Kim 1988).

The spatial behavior of DGW was characterized by constructing experimental semivariograms. An appropriate model was fit to the experimental semivariogram using mathematical parameters. Correct model parameters were considered important factors in generating reliable estimates as mentioned in Deutsch & Journel (1998). The OK system was then employed to generate griding points and to build the geostatistical model for the spatial extent of the water table.

RESULTS

A straight line on a normal-probability plot reflects the statistically normal behavior of the data set as shown in Fig. 3. Horizontal experimental semivariograms along four principle directions are shown in Fig. 4. These semivariograms represent the spatial behavior of the DGW variable along N-S, N45E, E-W, and S45E directions. Isotropic behavior was assumed; hence, an average single semivariogram has been considered for model-fitting purpose. A linear mathematical model was fitted to the experimental semivariogram with the following parameters: nugget variance of 1.72 cm^2, model power value of 1, and model slope of 0.59.

The modeled domain was divided into 0.375 x 0.375 m cells at which the DGW values were estimated by the OK procedure. The generated map for the shallow groundwater system surface is shown in Fig. 5. The depth to water table is estimated at about 68 cm below ground surface in the E & SE regions and about 65 cm at the NW regions. The estimated hydraulic gradient is about 0.001 from W-NW to E-SE. To evaluate OK model results, a model estimate at a specific location (trench) was compared to a field measurement. The estimated DGW value was 66.4 cm while the field observation value was 68 cm with an estimation error of 2%. This departure may be referred to moisture content rise within the capillary fringe of the unsaturated zone.

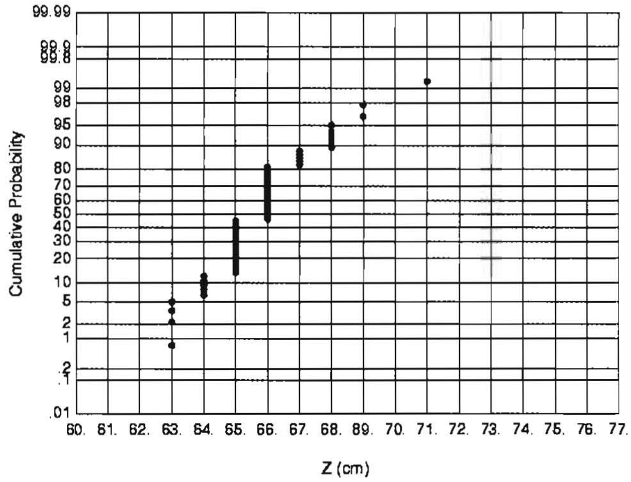

Fig. 3. Normal probability plot of the DGW (i.e. Z in cm) data set.

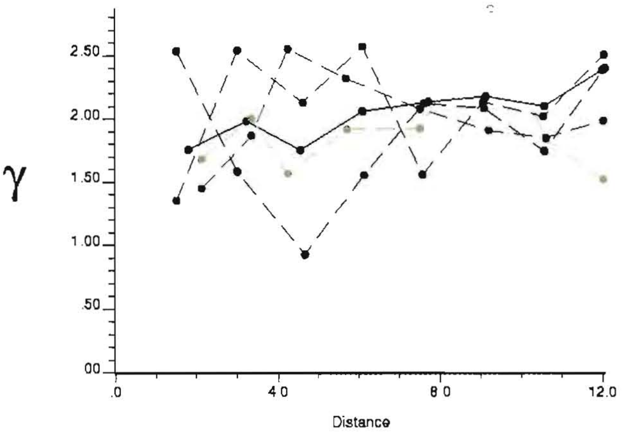

Fig. 4. The horizontal experimental semivariograms along four principle directions. The solid line shows the average semivariogram.

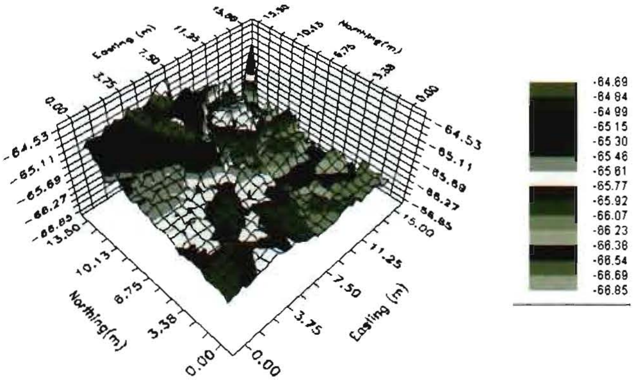

Fig. 5. The horizontal experimental semivariograms along four principle directions. The solid line shows the average semivariogram.

CONCLUSION

Results of this study indicate that the spatial extent of shallow groundwater surface has been estimated reliably. The modeled watertable has been obviously imaged at depths between 65 cm and 68 cm, which approximately in agreement with field observations. This conclusion reflects the reliability of the tested approach to generate a detailed map for the surface of a shallow groundwater system. The application of this method may be considered in large scale projects to explore new groundwater resources and define the extent of contaminants in shallow aquifers.

REFERENCES

Davis, J, (2002) *Statistics and Data Analysis in Geology*. John Wiley and sons, Inc., New York. USA.

Deutsch, CV and **Journel, AG** (1998) *GSLIB: Geostatistical Software Library and User's Guide*. Oxford University Press, New York, USA.

Kim, Y C (1988) *Advanced Geostatistics for Highly Skewed Data. Department of Mining and Geological Engineering*, The University of Arizona, Arizona.

Weijermars, R (1999) Quaternary evolution of Dawhat Zulum (half moon bay) region, beastern province, Saudi Arabia. *Geo. Arabia,* **4**: 71-90.

Ref. (2424)

(Paper selected and revised from the seventh Gulf Water Conference: Water in the GCC... Towards an Integrated Management. Water Science and Technology Association (WSTA), State of Kuwait, November 19-23, 2005)