REMOTE SENSING AIDS TO GROUND WATER EXPLORATION IN EGYPT'S DESERTS

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INTRODUCTION

In September 1992, we initiated a research project to be conducted jointly between the Boston University Center for Remote Sensing (BU/CRS) and the Desert Research Center (DRC) in Cairo, Egypt. It was one of the International Cooperative Agreements of the National Agricultural Research Project (NARP), which was administered by the U.S. Department of Agriculture and sponsored by the United States Agency for International Development (AID) in Cairo, Egypt.

During the nearly three-years of work, all the satellite images of the Sinai Peninsula were enhanced and interpreted. Data from several field excursions were conducted, many with team members from both BU/CRS and DRC, were integrated with image data using Geographic Information Systems (GIS) methodologies. The research resulted in the recognition of a dozen sites with potential for ground water exploration (Morency, 1995). Three have already been drilled and produced water.

In addition, work was done in the southeastern part in the Eastern Desert near the border with Sudan, and the Kharga Depression south of Baris, with similar results. These results prove beyond doubt the applicability of remote sensing to ground water exploration particularly in arid regions.
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METHODS AND TECHNIQUES

The research emphasized the topographic characteristics of the deserts of Egypt, their drainage patterns (including paleodrainage), and the patterns of faults and fractures, particularly in the Sinai Peninsula. These features were believed to be directly relevant to ground water exploration. Relating these features to each other and to geologic maps and geophysical data was accomplished utilizing GRASS GIS.

In selecting sites for ground water exploration, it was important to establish a water divide and runoff patterns for surface water. Since the deserts of Egypt are hyperarid and receive only occasional rain, it was important to establish the runoff pattern in the recent past, at least during the last few tens of thousands of years (El-Baz, 1995).

Drainage patterns were directly mapped from satellite images, with the aid of available aerial photographs. These patterns were important in establishing the pathways of surface water and their potential relationship to fractures and faults in the exposed rocks (Kusky et al., 1994).

Thematic maps of faults in the study areas were made from the resulting geologic/structural maps. These were compared to lineament maps based on the study of satellite photographs. Comparisons between the two were checked in the field by team members from the DRC. The final product of mapping and field checks was a map of potentially open fracture zones that might host ground water resources.

All the collected data were correlated using a GIS. This allowed the easy storage, retrieval and comparison of the different data sets and the production of correlation maps.

Based on the above information, sites were selected in order of priority for ground water exploration. The DRC communicated the results to decision makers in the Government of Egypt, and particularly to the Governors of North Sinai, South Sinai, and El-Wadi El-Gedid Provinces. Furthermore, the drilling rig of the DRC was also utilized in test drilling of high priority well sites to confirm the result of the research.
RESEARCH RESULTS

First Year

Efforts were directed at accomplishing four main goals including: 1) acquisition and cataloging of remotely sensed images and geologic and topographic maps of the Sinai Peninsula; 2) interpretation of drainage patterns, fracture traces, and regional structural geology from these images; 3) correlation of the image interpretations with geological maps of the region; and 4) selection of potential ground water well drilling sites for further detailed study and analysis.

Towards these goals the drainage and fracture patterns were analyzed on nine 1:100,000 scale Landsat RBV images, and seven 1:250,000 scale Landsat MSS images of the Sinai Peninsula. We also formulated a model relating fracture frequency and drainage density to ground water potential. High fracture and intersection frequency and low drainage density indicate an increased fracture porosity of the rock, thus favoring surface water infiltration and transmission. Conversely, zones of low fracture and intersection density but high drainage density are characteristic of impermeable rock types (Koch and El-Baz, 1992).

Second Year

In north-central Sinai tectonic activity has resulted in a network of young fractures that increased the capacity of the near-surface rocks to absorb and store runoff in this secondary porosity. Advances in the field of image segmentation allowed automated delineation of drainage networks from Landsat images. These data were used for correlation with structural data, specifically areas of intense fracturing, which were considered to be potential ground water storage areas.
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Ground water flow is significantly affected by regional structures, including folds in northern Sinai, and major (and related minor) faults in central Sinai, including the Ragabet El-Naam and Minsherah-Abu Kandu Faults.

The Precambrian basement terrain of the southern Sinai represents a particularly good fractured reservoir, because of its high density of fractures, relatively high precipitation (compared to elsewhere in the Sinai Peninsula), and low concentrations of dissolvable salts. Irregularities in basement topography, particularly dikes, are important for impounding water supplies up-gradient from the dikes. This has been shown to be particularly important in the Wadi Feiran, Gebel Maghara, and El-Hasana areas.

GIS techniques were used to apply the "megawatersheds exploration model" (Figure 2), in which area characterized by high fracture density and low drainage density are thought to represent potentially high ground water recharge areas. Similarly, Digital Elevation Models (DEM's) were used to automatically extract large amounts of land surface parameters, and to delineate drainage basins and drainage channel flow paths (Figure 3). DEM's were also useful in overlaying and visualizing thematic maps including topography, geology, drainage, precipitation, land cover, among others.

Combined use of image processing and GIS techniques proves to be a rapid and accurate method for hydrological and structural characterization of inaccessible arid regions. The Laplacian filter, a high-pass filter available in PCI image-processing software, proved to be particularly effective for delineating drainage lines and structural features such as faults and fractures. In addition, rock types were differentiated in places that lack vegetation and cultural features. Combining different sets of GIS and image processing software products resulted in increased analytical power, including the ability to: 1) simultaneously store and analyze different types of data at different resolutions; 2) obtain specific watershed parameters such as ground water flow direction and magnitude; and 3) consider the interaction of numerous watershed parameters.
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Figure 2
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Figure 3
including fracture density, drainage density, rainfall, number and length of stream segments of different orders, among others.

Ten sites in north-central Sinai were recommended for further study and preliminary drilling after the second year of our work. Results of this test drilling will have implications for the urban and agricultural development of the area between Nekhl, El-Arish, and the Israeli border.

**Third Year**

We constructed an extensive database on the geology, structure, hydro-geology, geochemistry, and geophysics of the Sinai Peninsula (Morency, 1995). Significant gaps in the database, however, hinder a complete understanding of the flow regimes. The main issues remaining to be addressed are: the elevations of wellheads, referred to a common datum; and a standardized suite of geochemical parameters, for which samples are gathered during a short time interval from wells purged of at least one well volume. To be documented are the time of sampling, sampled depth intervals, temperature, pH, and conductivity. Furthermore, the gathering and compiling of these data should be coordinated by a single agency with specific expertise in Egypt’s hydrogeology.

The database includes digitized layers of the topography of the Sinai Peninsula at 1:100,000 (3 topographic sheets remain missing), geology of the Sinai Peninsula (at 1:250,000), and digitized layers including interpreted lineament and drainage patterns from Landsat MSS and RBV images at several scales, and by several different investigators. This database forms a valuable asset for future studies including ground and surface water modeling, detection of topographic lineaments, and superimposing topographic, geologic, and other datasets in a GIS. In addition, DEM’s can be constructed, which can yield useful information on slope, surface runoff, aspect, and establish drainage divides and other parameters.

It is recommended that this type of research is continued in the future to fully utilize the potential. High resolution Landsat Thematic
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Mapper (TM) images covering the whole peninsula should be analyzed and the results should be added to the database and correlated to serve the needs of ground water exploration in the future.

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