*JKAU: Earth Sci.,* **vol. 11,** pp. 1-14 (1420 A.H. / 1999 A.D.)

# Groundwater Exploration in Western Saudi Arabia Using Landsat-TM Imagery

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Received: 1/4/97 Revised: 19/4/98 Accepted: 22/6/99

ABSTRACT. Structural lineament analysis of Landsat Thematic Mapper data was utilized to study the groundwater potentiality and recharge in the central part of the arid Arabian Shield. Fracture line-to-line intersection was found to be a good indicator for groundwater occurrence and recharge; the connectivity of intersected fractures may indicate potential areas for water occurrence. Because Makkah, Jeddah and Taif lie within the study area, results will benefit the groundwater exploration for these cities.

## Introduction

Satellite imagery is an important potential source of new information because it enables image analysts to view very large areas with the same observational parameters and achieve a regional perspective that is difficult to obtain from conventional ground surveys only. The application of satellite imagery for exploration and development of natural resources, especially for water resources surveying and mapping, is appreciably increasing. A number of researchers have been engaged recently in such applications in arid and semi-arid regions [El-Shazly *et al.* (1983); El Ghawaby *et al.* (1989); World Bank (1990), Engman and Gurney (1991); Drury and Berhe (1991); Krishnamurthy *et al.* (1992); Zevenbergen and Rango (1992)]. The primary objective of the present study is to develop and test procedures to locate groundwater occurrences in arid regions from Landsat Thematic Mapper (TM) imagery. Within the Arabian

Shield, groundwater occurrences are mainly restricted to the wadi alluvial deposits and to a lesser extent to the main fractures. The procedures we advocate herein targets groundwater in fractured crystalline basement rocks.

The studied area occupies the central part of the Arabian Shield, a hard-rock crystalline terrain that receives very low rainfall of sporadic nature. The surface water resources are also very limited and groundwater is thus of fundamental importance.

This studied area is covered by three full Landsat-5 TM scenes (Fig. 1). Each scene covers about 185 km × 170 km on the ground. Making a total aerial coverage of about 85,000 $km^2$. The TM scanner records six bands in reflected visible and infra-red wavelength region, with each pixel (picture element) representing 30m × 30m on the ground. It also records a seventh thermal infrared band in which each pixel represents 120m × 120m on the ground. False colour composite and black and white image prints were used throughout this study.

## Methodology

Visual interpretation and digital image processing methodologies were employed in this study. A map (Fig. 2) covering the studied area was prepared by delineating the major morphological and cultural features which include cities, wadis, road network, agricultural areas, watersheds, etc. A geological map, adapted from the map prepared by Johnson (1983), was also prepared for the studied area (Fig. 3). Basaltic lava flows and recent alluvial and eolian deposits cover about 30-40% of the study area. Other existing rock types include metamorphosed layered and intrusive rocks of the crystalline Precambrian Arabian Shield.

The definition of lineaments, in this study, followed that of O'Leary *et al.* (1976). They defined the lineaments as "mappable, simple or composite linear features of a surface, whose parts are aligned in a rectilinear or slightly curvilinear relationship and which differs distinctly from the patterns of adjacent features and presumably reflects a subsurface phenomenon". Lineaments and/or fractures were identified and delineated by visual inspection of the images and then recorded on transparent paper on an appropriate scale of 1:1,000,000 to produce a remotely sensed lineament map (Fig. 4).

The lineaments were then converted from the map format to a digital format using a table digitizer. The significance of the interpreted lineaments was analyzed using distribution curves for frequency and length (Fig. 5) following procedures described by El-Shazly *et al*. (1979).

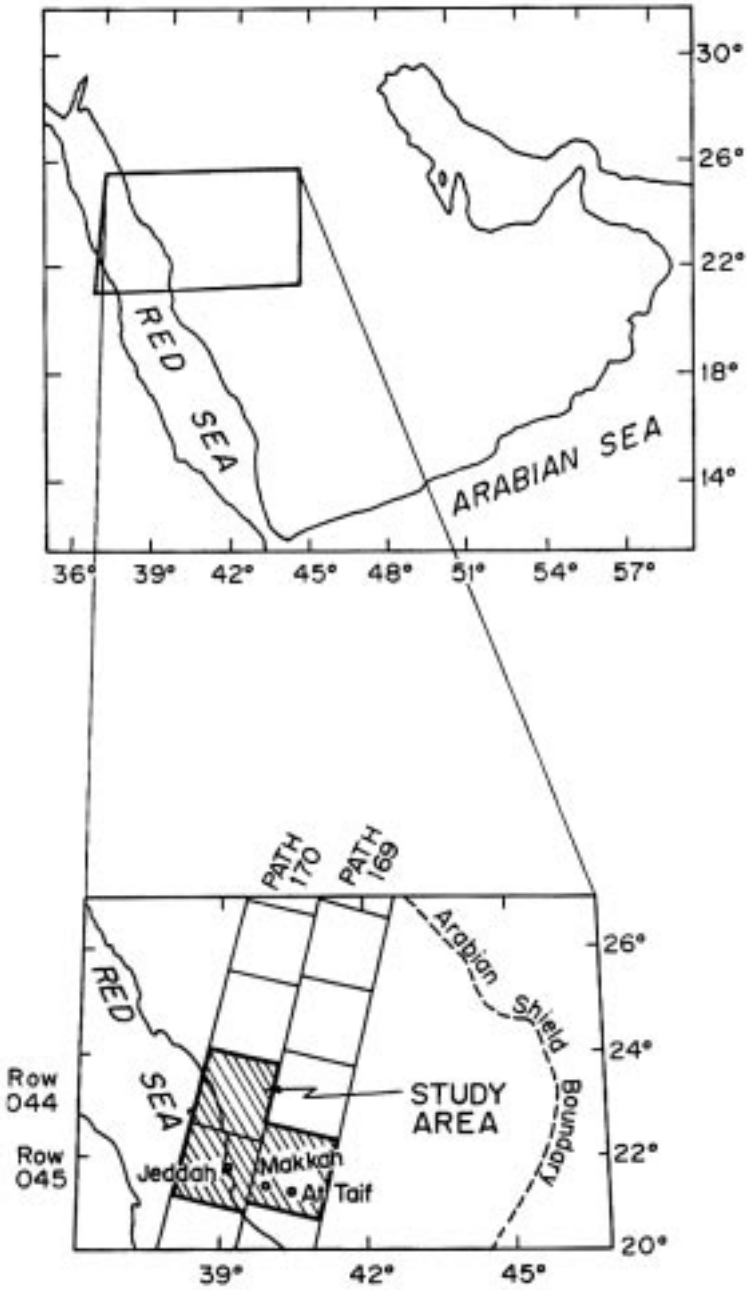


FIG. 1. Index map of the Landsat-5 TM scenes (Path/Row) covering the study area. (1) Path 170/Row 44, 11 March 1993 (Rabigh Area); (2) Path 170/Row 45, 15 June 1987 (Jeddah Area); (3) Path 169/Row 45, 9 Sept. 1992 (Taif Area).

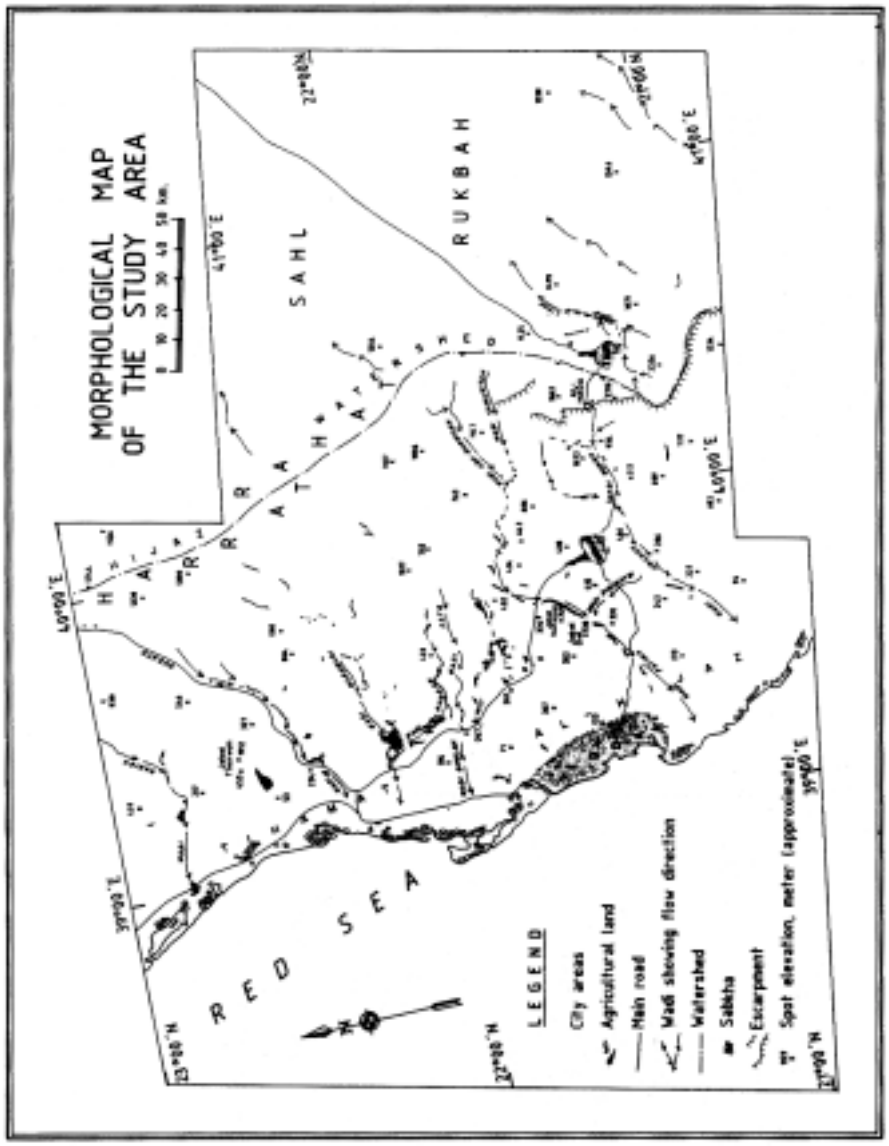


FIG. 2 Morphological map of the studied area.

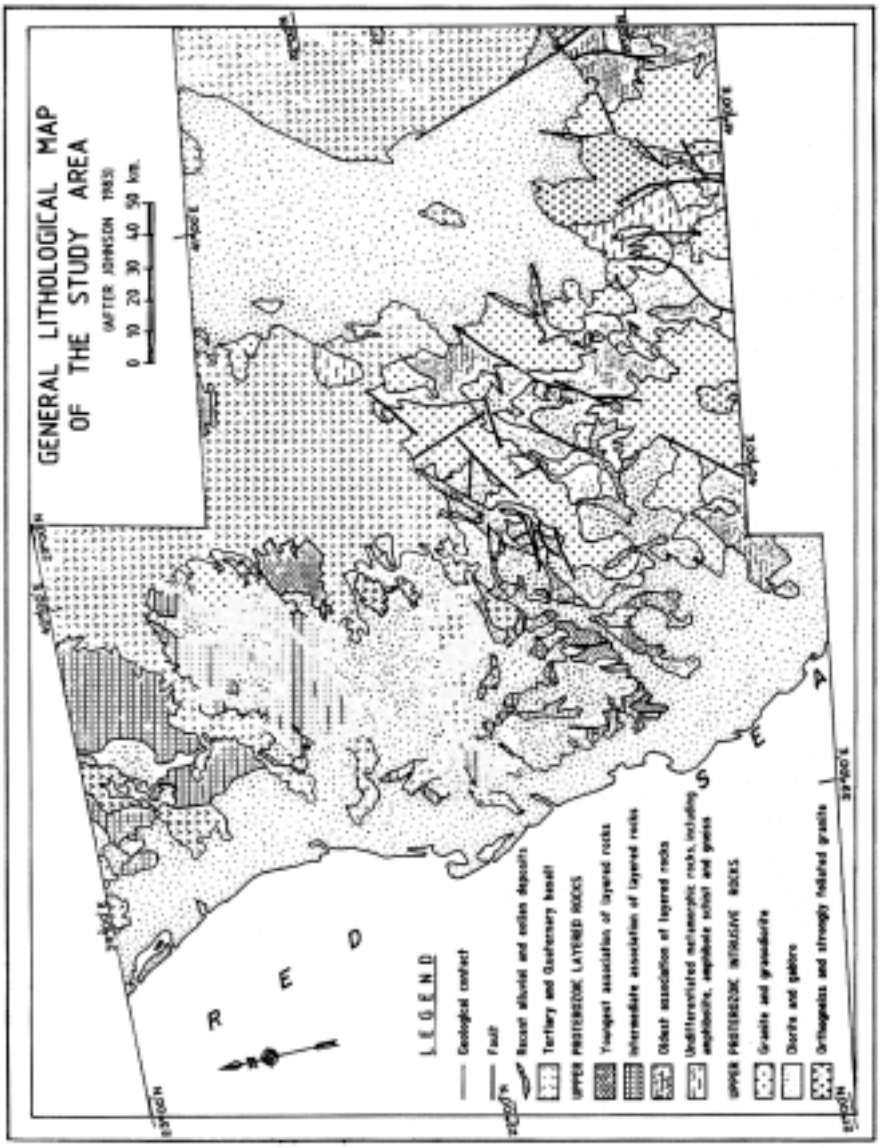


FIG. 3. General lithological map of the studied area.

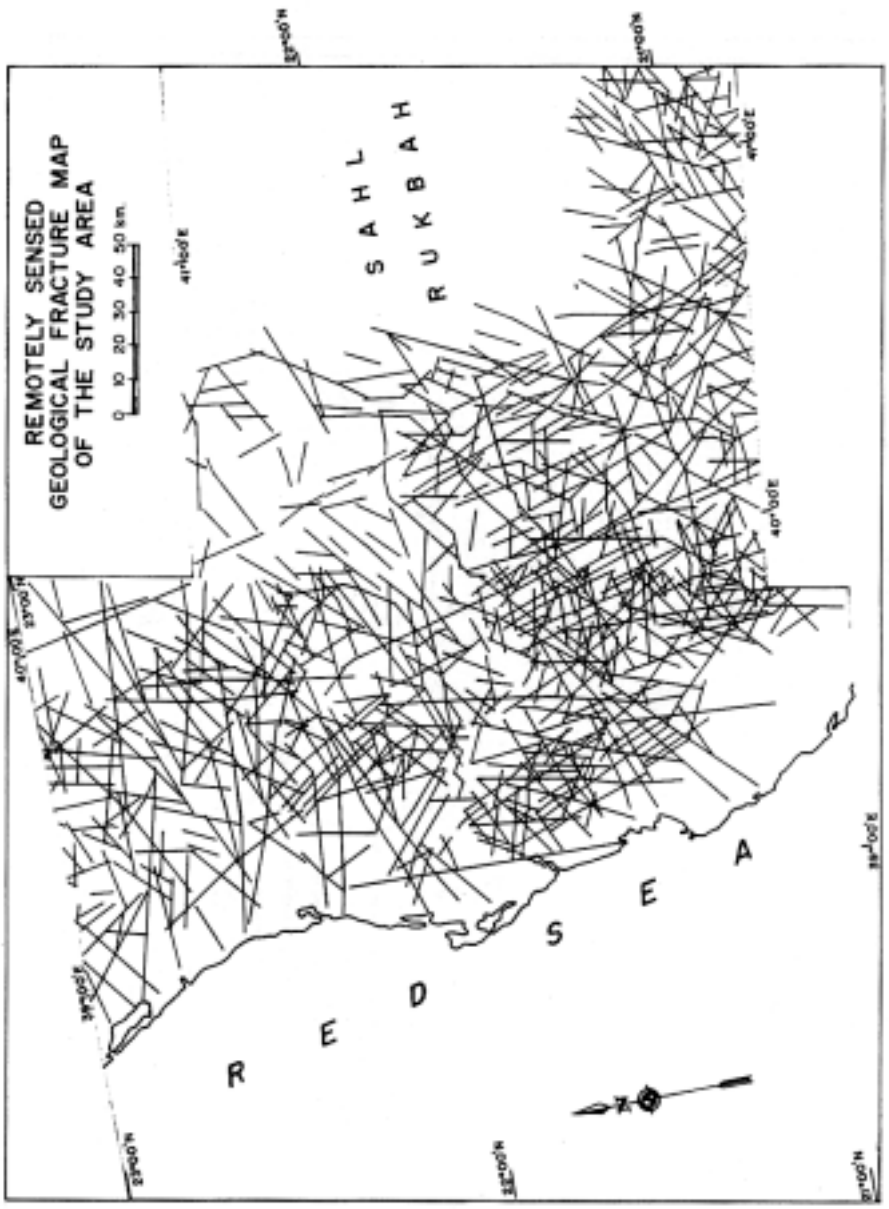


FIG. 4. Remotely sensed geological fracture map of the studied area.

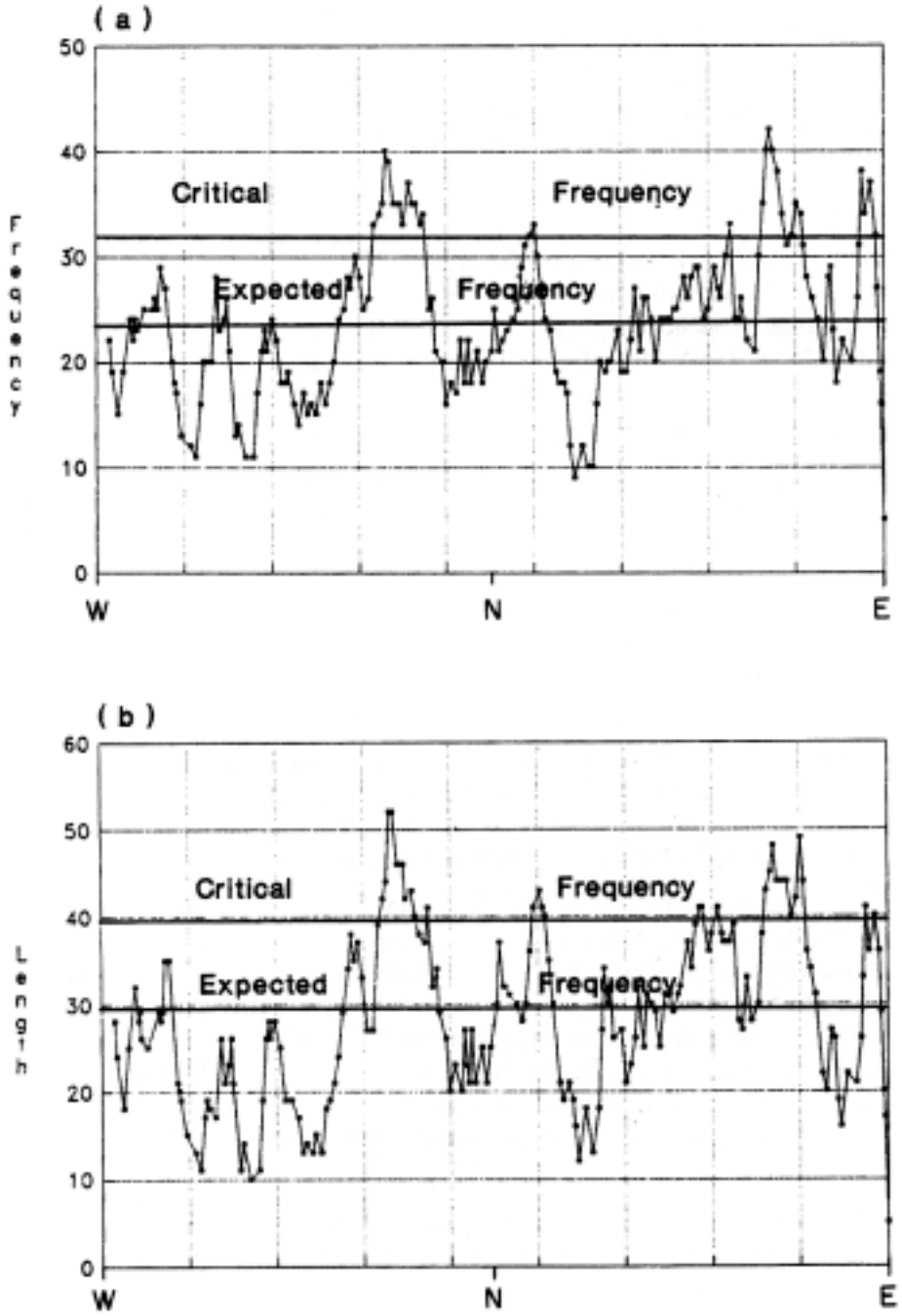


FIG. 5. Distribution curves of lineaments in the studied area and the significant trends calculated at 0.90 confidence level, (a) for frequency and (b) for length.

The lineaments shown in (Fig. 4) of the regional study area were counted on a 12.5 km × 12.5 km cell grid and analyzed following the steps described by Mostafa and Qari (1995). The total lineament density (Fig. 6), total length of lineaments (Fig. 7) and the number of line-to-line intersection (Fig. 8) maps were accordingly prepared.

## Discussion

Based on the calculations of the critical frequency above which peaks become significant, two major classes (trends) can be predicted for the area from the fracture frequency/length distribution curves (Fig. 5). These two classes are N 10 - 35 W and N 40 - 75 E. The first trend is parallel to the Red Sea and is relatively old while the second is a conjugate trend, perpendicular to the Red Sea direction, and is relatively young. Other minor classes include N10 E and N85E. When comparing the distribution curves for frequency and length (Fig. 5), one can observe their similarity and predict their conformity.

The total lineament density (Fig. 6) varies from 2 to 20 lineament per cell, while the total length of all lineaments within a cell varies from 1 to 9 (Fig. 7). The values 1 to 9 actually reflect variations in total length between 12.5 and14.5 km. The line-to-line intersections vary between 1 and 19 intersections per cell (Fig. 8).

Several points of concentrations were observed in the above mentioned contour maps, but the most important concentrations lie in the southwestern area. These areas of lineament concentration are thought to be potential sites for groundwater resources and recharge reception since the fracturing in the crystalline rocks usually induce enhanced porosity and transmissivity.

Moreover, the wadi system and the drainage pattern in the study area principally follow the two main trends of lineaments. Most of the main wadis that drain towards the Red Sea trend in the NE-ENE direction. The NNW direction is as important as its conjugate perpendicular trend for some of the main wadis follow also this direction. The areas that can be considered as potential groundwater direct recharge sites are the wadi alluvial deposits and the large mountain basins. Since the drainage system is generally controlled by the orientation of the lineaments in the area, it can be concluded that lineaments also control the groundwater recharge.

The line-to-line intersections can also be an additional criterion for groundwater recharge and consequently groundwater exploration. The line-to-line intersection contour map (Fig. 8) when overlaid on the morphological map (Fig. 2), shows that areas with high contour values conform to the pattern of the major wadis. In other words, the number of line-to-line intersections generally re-

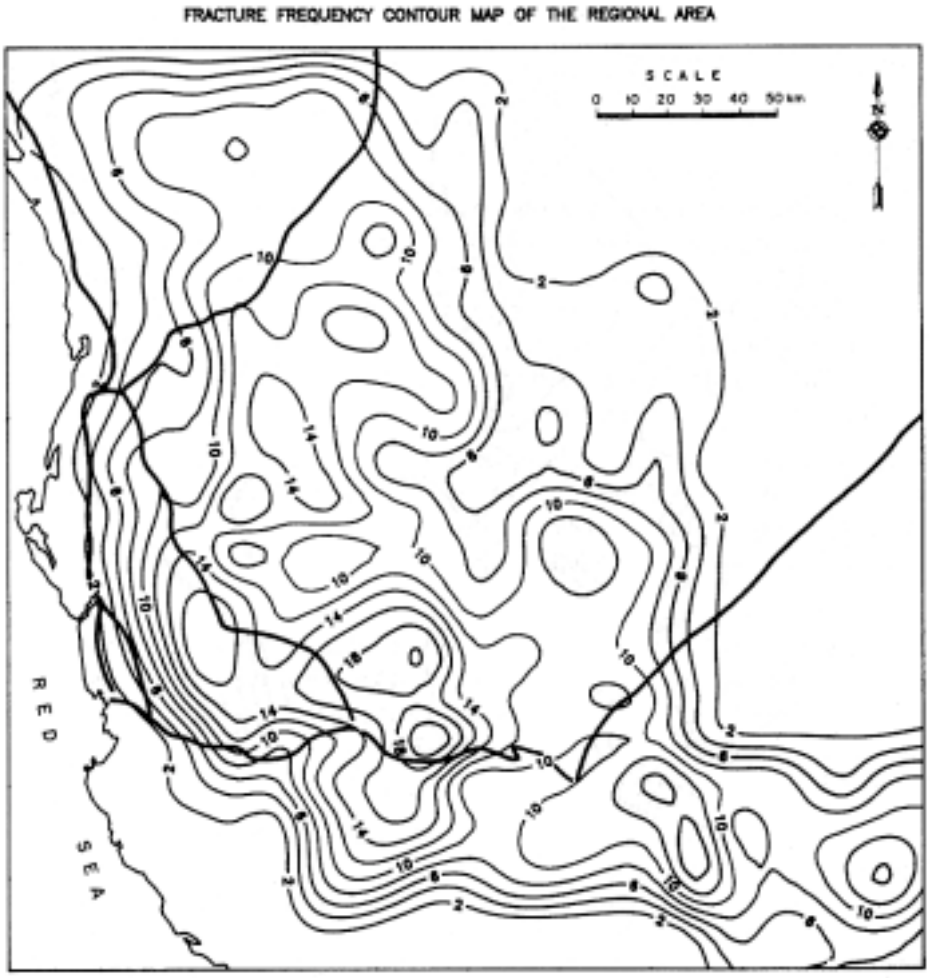


Fig. 6. Fracture density isopleth map expressed in number of fractures/156 km$^2$.

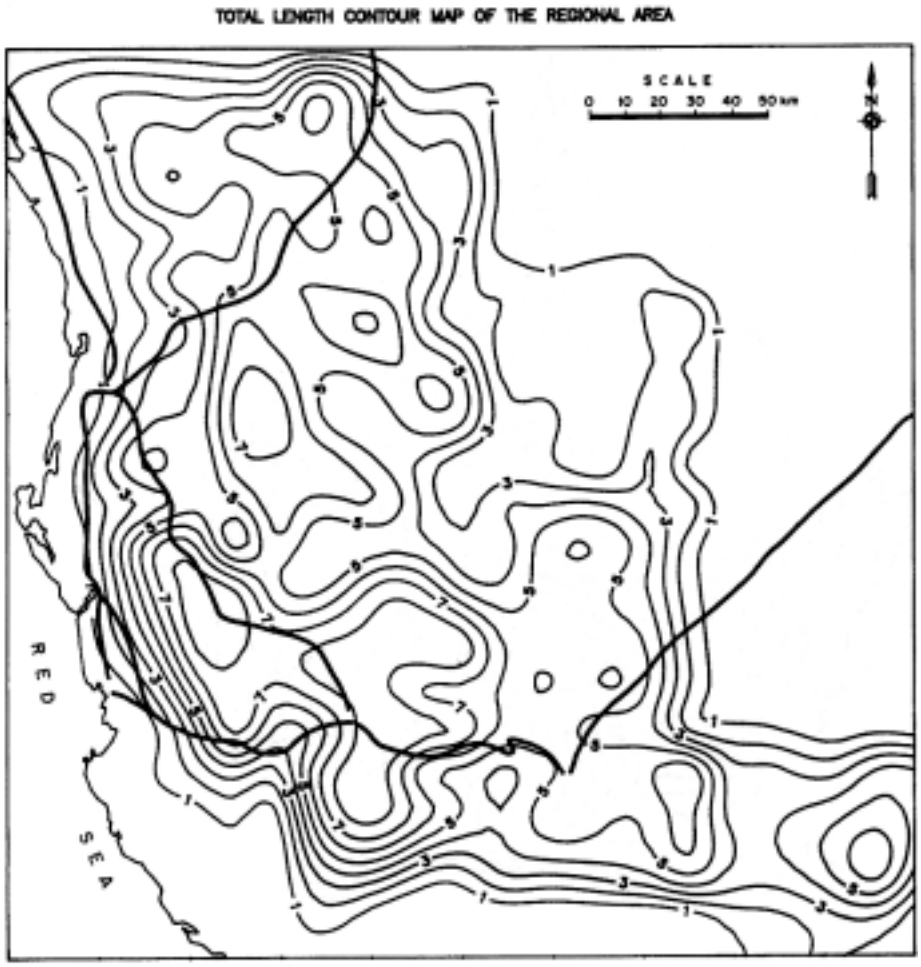


Fig. 7. Fracture length isopleth map expressed in total length of fractures/156 km$^2$.

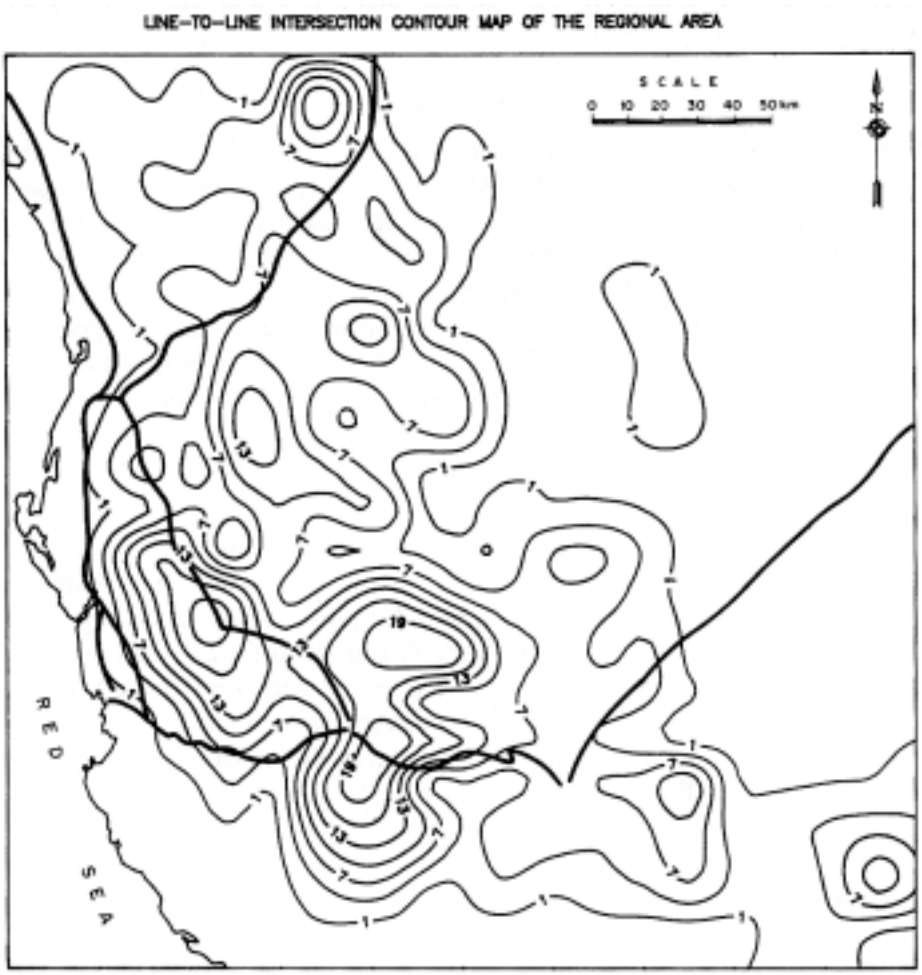


Fig. 8. Line-to-line intersection isopleth map expressing intersections/156 $km^2$.

flects both the surface courses and the flow directions. It can be an indication of higher recharge areas. Further field studies, in particular in the southwestern area, should be undertaken for their groundwater potential in order to verify the validity of this hypothesis

## Conclusions

Landsat-TM imagery visual interpretation has been applied to a part of the hard-rock terrain of the Arabian Shield of western Saudi Arabia. The main purpose was to identify certain criteria for potential occurrence of groundwater and recharge areas. The most significant criterion is the fracture system that controls the general pattern of the wadi alluvial deposits where groundwater is encountered. Lineament and/or fracture line-to-line intersection can be a good indicator for groundwater occurrence and recharge. The connectivity of the intersected fractures may indicate potential areas for groundwater occurrence and movement in fractured media.

### *Acknowledgement*

This study is part of Research Project No. 413/006 sponsored by the Directorate of Scientific Research, King Abdulaziz University. The Faculty of Earth Sciences is gratefully acknowledged for providing all laboratory, field and computer facilities. Prof. M. E. Mostafa is thanked for helping in matters relating to computer processing of data. The Saudi Center for Remote Sensing, King Abdulaziz City for Science and Technology (KACST), Riyadh is thanked for providing Landsat data. Copyright of Landsat data used herein rests with KACST and EOSAT.

### References

**Drury, S.A**. and **Berhe, S.M.** (1991) Remote sensing in ground water exploration in arid regions – examples from the Red Sea Hills of NE Africa. *Association of Geoscientists for International Development Newsletter,* No. 67/68: 17-22.

**El Ghawaby, M.A., Mostafa, M.E., El Shamy, I.Z., Khawasik, S.M., Shendi, E.H.** and **El Monsif, H**. (1989) Integration of remote sensing and aerogeophysics for groundwater exploration in Wadi El Arish. *Proc. 2nd. Conf. Geol. Sinai Develop.,* Ismailia, Egypt.

**El-Shazly, E.M., El Kassas, I.A.** and **Mostafa, M.E.** (1979) Comparative fracture analysis and its relation to radioactivity in the Pink Granite of Um Had Pluton, Central Eastern Egypt. *Egyptian Journal of Geology,* **23:** 95-110.

**El-Shazly, E.M., El-Rakaiby, M.M.** and **El-Kassas, I.A.** (1983) Groundwater investigation in Wadi Araba area, Eastern Desert of Egypt, using Landsat imagery. *Proc. 17th Intern. Symp. on Remote Sensing of Environment,* Ann Arbor, Michigan, U.S.A., **III:** 1003-1013.

**Engman, E.T.** and **Gurney, R.J.** (1991) *Remote Sensing in Hydrology.* Chapman and Hall, New York, N.Y., 225 p.

**Johnson, P.R.** (1983) A preliminary lithofacies map of the Saudi Arabian Shield. *Riofinix, Deputy Ministry of Mineral Resources, RF-Technical Record-03-2,* Ministry of Petroleum and Mineral Resources, Saudi Arabia.

**Krishnamurthy, J., Manavalan, P.** and **Saivasan, V.** (1992) Application of digital enhancement techniques for groundwater exploration in a hard-rock terrain. *International Journal of Remote Sensing,* **13-15:** 2925-2942.

**Mostafa, M.E.** and **Qari, M.Y.H.T.** (1995) An exact technique of counting lineaments, *Engineering Geology,* **39:**5-16.

**O'Leary, D.W., Friedman, J.D.** and **Pohn, H.A.** (1976) Lineament, linear, lineation: Some proposed new standards for old terms. *Geological Society of America Bulletin,* **87:** 1463-1469.

**World Bank** (1990) Satellite remote sensing for agricultural projects. *World Bank Technical Paper No.* **128.** World Bank Publications, Washington DC, U.S.A.

**Zevenbergen, A.W.** and **Rango, A.** (1992) Applying Landsat Imagery for groundwater development in Egypt. *Geocarto International,* **3:** 41-51.

# استكشاف المياه الجوفية في غرب المملكة العربية السعودية باستخدام صور لاندسات – TM

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*المستخلص .* تم استخدام تحليل الخطيات البنائية من بيانات لاندسات TM لدراسة تواجد الماء الجوفي ومصادر التغذية في وسط الدرع العربي الجاف ، ولقد وجد أن تقاطع تلك الخطيات يعتبر عاملا جيدا للدلالة على تواجد وتغذية الماء الجوفي ، لذلك يمكن اعتبار اتصال هذه الخطيات مناطق مهمة لتواجد المياه، ولأن مكة المكرمة وجدة والطائف تقع ضمن منطقة الدراسة فإن نتائج هذا البحث سوف يكون لها تطبيقا جيدا على استكشاف المياه الجوفية حول هذه المدن .