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Identification of Groundwater Storage and Flow Through the Analysis of Fracture Systems from Space

Amin Shaban
Lebanese National Council for Scientific Research,
Remote Sensing Center, Beirut, Lebanon

Abstract

Groundwater shortage is well pronounced in arid and semiarid regions where precipitation rate is low. However, exploration of groundwater follows different approaches, but not all of them are successful. In this respect, new space techniques have been existed to analyze different satellite image, thus a miscellany of terrain features can be detected. Among these features are the "lineaments", which are observed as linears on satellite images and often represent fracture systems. This study introduces the procedure of identifying linear features and their interpretation with respect to different hydrogeologic phenomena. Thus, two types of satellite images (Landsat 7 ETM+ and ASTER) were used. They were processed using ENVI4.3 software, thus applied to different areas from Lebanon. The paper aims to reveal the role of linear features in recharge potential zoning, groundwater storage and water flow to the sea. This, in turn, creates a supplementary approach of analysis while making groundwater assessment studies.

Key words: Fractures, Groundwater, Lineaments, Satellite Images, Lebanon

Introduction

Water supply shortage has become a serious environmental problem in many regions of the world. Thus, demand for water has increased with the increase in the population size and the change in climatic conditions. This is well pronounced in arid and semiarid regions.

Normally, in determining groundwater potential zones as well as in delineating the flow regime of groundwater, geologists rely on several lithologic and structural elements. However, fracture systems are considered as a major indicative element in groundwater storage/or flow. This has been given concern in several studies, notably those which utilized the space tools, such obtained by El-Baz and Himida (1995); Teeuw (1995) and Per Sandra, et al. (1996).

Recently, the reliable procedures to delineate fracture systems are successfully achieved when using space tools, notably the processing of satellite images. Therefore, the identified linear features on satellite images are known as “Lineaments”. The detected lineaments, as being verified in the field, are attributed to rock fractures of different scales and types. They proved to have great significance in creating groundwater-transport routes, as well as they influence water input and output from /to the terrestrial environment. (Shaban et al., 2006).

The objective of this study is to introduce two major concepts. First is the procedure how to identify lineaments (fracture systems) from space, and second is to utilize these systems to assess groundwater regime. In this respect, the major hydrogeologic phenomena in Lebanon were diagnosed, thus explained in different examples.

Method of analysis

Identification of geologic-related linear features was adopted through the processing of Landsat 7 ETM+ and ASTER images, which were sujected to several digital advantages using ENVI-4.3 software. The most common used advantages to detect “edge” features (e.g. linears on satellite image) are: enhancement, stretching, colouring, slicing, directional filtering, and sharpness. In addition single band and multi-band enhancement were carried out by interrelating each three bands as one set.

Accordingly, the thermal interpretation from the thermal bands was undertaken. They are: band 6 (60 m resolution) in Landsat 7 ETM+ and bands 10-14 (90 m resolution) in ASTER images. The resulting lineament maps (example in Figure 1) show only to the geologic-related linear features, which were verified in the field..

According to the scope of this study, the resulting lineament maps were compared with major groundwater processes. This implies: 1) Recharge potential zones, 2) Groundwater potential zones and 3) Groundwater flow to the sea.

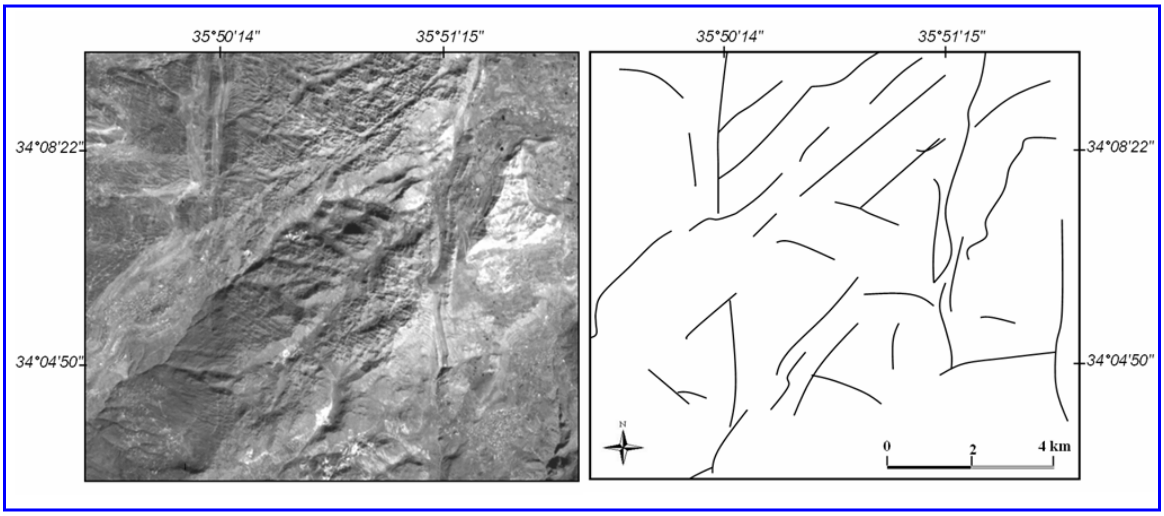

Fig. 1. ASTER image showing the extracted lineaments.

Results and Discussion

Recharge potential zones

These zones represent the terrain surfaces which have a good property to allow surface water percolating downward through rocks and soil. Hence, the surfaces with high recharge potential are considered as the first media to groundwater storage and flow. The role of lineaments (fracture systems) is well known in this hydrogeologic phenomenon.

The concept of lineaments in water recharge implies mainly the density of fracture systems. Therefore, the dense the fracture systems the higher recharge potential and vice versa. There are several approaches to measure the density of lineaments, but the most creditable one is that obtained by counting the number of linears within a specific area (El-Baz, and Himida, 1995). In order to characterize the lineaments density, an empirical classification has been followed according to Shaban (2003). In the followed classification, the number of lineaments was counted with a frame of 3 km x 3 km (i.e. 9 km^2).

Results show that approximately 57% of Lebanon is a terrain with very high to high recharge potential. The most effective recharge potential zones are found in regions where hard, fractured and karstified limestone and dolomite of the Jurassic and Cenomanian rock formations exist.

Groundwater potential zones

Percolated water through the identified recharge potential zones will continue flowing along fractures, conduits, lithologic boundaries and bedding planes until stores in a rock trap (area/or media where water does not able to move, thus stores). The rock traps can be of a stratigraphic/ or structural type.

Hydrogeologists must tackle the elements of water journey while making a decision in locating suitable sites for groundwater boreholes. Therefore, in groundwater exploration, three steps are followed. 1) Cartography of high recharge zones, 2) Delineating groundwater flows and 3) Determining trapping conditions in the subsurface media (Shaban, 2003).
Frequently, stratigraphic and structural traps can be observed on satellite images as indicative through the linear features, but with different orientations of linearity (Table 1).

Table 1: Identification of geologic traps fom the analysis of lineaments.

Geologic trap	Description	Observed lineament *
Stratigraphic	Permeable/impermeable superposition	Slightly curved lineament
	Facies change and formation boundary	Non-uniform lineament
	Alluvial deposits and paleo-drainages	Irregular, non-uniform and zigzag lineament
Structural	Folded structures	Curved lineament
	Fault boundary between permeable/ impermeable rocks	Very clear linear feature
	Karstic conduits	Intermittent, short lineaments along the same alignment

* The trap as viewed from a lineament on satellite images.

Groundwater flow to the sea

Groundwater discharge into the sea, the so-called "*submarine springs*" is a common hydrologic phenomenon in many regions of the world, where the maritime region along the eastern Mediterranean Sea is typical. From a hydrologic point of view, groundwater from land tends to move to the sea if one of four conditions exists (Shaban et a. 2005). These are:

- Fault system that spans from land into the sea,
- Acute dip of bedding planes,
- Karstic conduit channels to the sea floor,
- Fissured rocks that constitute coastal aquifer.

The role of lineaments in groundwater flow to the sea lies in identifying the linear features on satellite images that have delineation between land and sea. Therefore, several studies worked on this concept and proved the reliability of linear fractures in water flow to the sea. This helps identifying the source area of groundwater storage, which also might be a groundwater potential zone. Figure 2 exhibits an example of groundwater discharge into the sea through two strike-slip faults along Jouneih-Dbaeih, a central coastline of Lebanon.

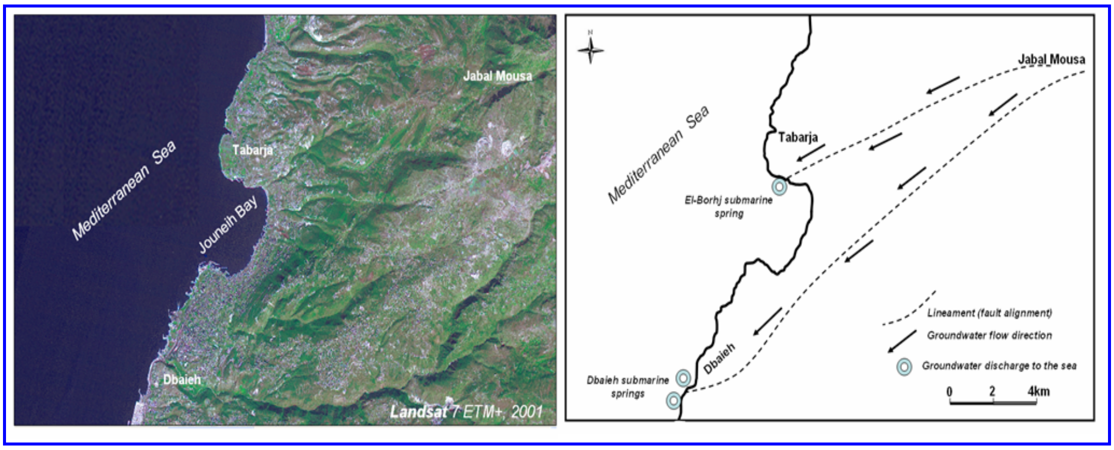

Fig. 2. Example showing groundwater discharge to the sea through faults along a selected stretch from the Lebanese coast.

Discussion

The advantages of space tools, certainly satellite imageries with high resolution, play an essential role in identifying a miscellany of terrain characteristics. This is the case in Lebanon where, remote sensing techniques have been recently involved in many disciplines, including terrestrial and oceanic study and monitoring purposes.

As one of the major signatures these tools can detect the linear features, which is tedious to be obtained accurately by conventional tools. The resulted lineament map, which was obtained by remote sensing, revealed added several modifications to the tectonic map of Lebanon. In this respect, GIS was utilized to superimpose the produced lineament map on the available tectonic map of Lebanon (scale 1:50000, obtained by Dubretert, 1953). Therefore, it was obvious that:

- There is a clear coincidence between both maps,
- The suspicious (hidden) extents of some fault alignments present on the geologic map were confirmed from the obtained lineament map,
- Several small-scale faults (linears) were plotted on the lineament map, which were not appear on the available tectonic map.

According to these phenomena, which are common in arid and semiarid regions, lineaments analysis followed different procedures. For example, in recharge potential zoning they were studies according to their density. While, in the case of groundwater storage, flow to the sea and seawater intrusions, lineaments were viewed from their linear extent either between different rock lithologies or between land and sea.

Table 2 reveals the resultant hydrogeologic phenomena that extracted from lineaments analysis, as applied to Lebanon. It shows the essential role of the lineaments to extend valuable hydrogeologic elements.

Table 2: Major Hyrdrogeologic phenomena in Lebanon as adopted from lineaments.

Hydrogeologic process	Main objective	Description	Procedure of confirmation
Recharge potential (RP) zones	Zones with ability to permit water entering substratum (infiltration capacity)	57 % of the Lebanese terrain owns high to very high RP	Previous studies that depended on measurables (UN, 1970)
Groundwater potential (GWP) zones	Zones suitable for productive groundwater boreholes (groundwater exploration)	> 65 % of the Lebanese terrain is characterized by GWP.	Successful water wells are almost located in the proximity of lineaments (Shaban et al. 2007).
Groundwater flow to the sea (GWFS)	Sites where groundwater seeps to the sea. (exploitation of these sources on-land)	51 major routs are transporting Groundwater to the sea	Geophysical soundings (CNRS, 2002) and field surveys
Seawater intrusions (SWI)	Alignments along which saltwater enters the adjacent aquifers (avoiding over-exploitation)	17 major routes along which saltwater enters to coastal aquifers	Geophysical soundings (Geofizika, 1965) and field surveys

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