The relation between water-wells productivity and lineaments morphometry: selected zones from Lebanon

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Abstract Several approaches have been applied to groundwater exploration. In some instances positive results occur, but this is not always the case. This led hydrogeologists to look for a credible approach upon which they can rely during preliminary surveys for groundwater exploration. The development of remote sensing tools along with GIS methodologies gave rise to many new approaches. Most significant among these is the mapping of linear features (lineaments), which appear on satellite images. These features mainly reflect fracture traces, faults or lithologic boundaries and, therefore, are considered as major hydrogeologic parameters to be taken into account.

The aim of this paper is to define an empirical relationship between lineament morphometric properties and the productivity of water wells. The three major properties of lineaments, i.e. frequency (L_f), density (L_d) and fault-lineaments (F_l), were analysed using Landsat 7 ETM + images and GIS techniques. The resultant maps were correlated with the location of water wells in 90 sites from different regions of Lebanon. The resulting output showed an obvious relationship between productive wells and their proximity to fault lineaments. The closer the location of water wells to a ault trace the higher the water productivity. However, this hypothesis can be preliminary utilized in surveys for groundwater exploration, notably in a terrain with intensive rock deformation like that in Lebanon.

Keywords Land sat 7 ETM + ; Lebanon; lineaments; productive wells

Introduction

In Lebanon the number of water wells has recently been increased. For example, in the capital Beirut, the density of water wells ranges between 400 and 500 wells/km^2. Most of these wells are privately owned and are chaotically located. But not all wells produce water and wildcat boreholes often result. Therefore, hydrogeologists depend mainly on fracture systems to select the most favourable sites for groundwater. Consequently, if a relationship is found between fracture systems and water well sites, it would thus be considered as a rule that can be followed for further groundwater exploration.

In this regard, the development of remote sensing techniques allows detecting significant geological features in aerial photographs and satellite images. Certainly; these linear shapes, so-called *lineaments*, are extracted through several treatment processes. These features have attracted the attention of hydrogeologists who believe that lineaments perceived in remotely sensed images are reliable indicators of geologic structure. The genetic interrelation between linear features and rock fractures is proved by many studies (Mohammad *et al.* 1999; Degnan and Clark 2002). Therefore, studying these features is of great significance in hydrogeological studies, since they may reflect higher water recharge potentials (Shaban *et al.* 2005).

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The value of lineaments to groundwater exploration depends upon them being the surface expression of a subsurface feature. Many workers assumed that lineaments as fracture traces represent vertical zones of fracture concentration. Berger (1984) suggested that lineaments may be related to the subsurface manifestation of buried structures. Only Waters *et al.* (1990) considered that lineaments might, or might not, be the reflection of subsurface structures. However, field verification of linear features confirmed their genetic relation with fracture systems.

The role of linear features has been recognized in many hydrogeological studies, notably in areas where fracture systems are well developed (Ahmed *et al.* 1984; Edet *et al.* 1998; Gustafsson 1994; Shaban *et al.* 2005), and Lebanon has good examples. Normally, the identification of zones with fracturing systems is not an easy task to be conducted in the field, especially if it applies for large-scale areas. Therefore, aerial photographs and satellite images are helpful in this regard. Yet, the question remains: is there any coincidence between the location of lineaments and groundwater storage? If yes, what is the most affective morphometric character of these lineaments that can indicate groundwater accumulation? To attain a reliable hypothesis, identification of linear features, via remote sensing, should be achieved first. This would constitute a remarkable morphometric criterion that can be compared with productivity of drilled water wells, i.e. well discharge. Thus, this study aims to uncover a relationship between lineaments and successful location of water wells. This would facilitate and support approaches to groundwater exploration in a location of numerous unsuccessful water wells.

Concept of lineaments

The term “lineament” is a commonly used word in geological remote sensing studies. Nevertheless, it is still a matter of debate, because of the misleading interpretations created from similar features on images or aerial photographs. O’Leary *et al.* (1976) defined a “lineament” as a mappable, simple or composite linear feature of a surface, whose parts are aligned in a rectilinear or slightly curvilinear relationship. Woodruff *et al.* (1982) defined lineaments as a figure that (1) is perceived in an image of a solid planetary body, (2) is linear and continuous, (3) has definable end points and lateral boundaries, (4) has a relatively high length-to-width ratio and hence a discernible azimuth, and (5) is shown or presumed to be correlative related to stratigraphy or geologic structure. A “false lineament” is defined as a perceived lineament that meets all but criterion number 5 as described above. “False lineaments” could be cultural manifestations that do not coincide with linear topography, such as fence lines, roads, pipelines, railroads, and animal trails, etc. Lineaments are ambiguous because they cannot always be field-verified, nor are they precisely reproducible (Garza and Slade 1986). They could be (1) straight stream and valley segments, (2) aligned surface sags and depressions, (3) soil tonal changes revealing variations in soil moisture, (4) alignments in vegetation, (5) vegetation type and height changes, and (6) abrupt topographic changes. All of these phenomena might result from structural phenomena such as faults, joint sets, etc.

Groundwater and lineaments

Many assumptions have been made concerning the relation between lineaments and groundwater storage. The relationship between the occurrence of groundwater and fracture traces for carbonate aquifers is often cited, and in particular that lineaments are underlain by zones of localized weathering and increased permeability and porosity. Rauch and LaRiccia (1978) tested this theory in a limestone aquifer in Frederick Valley, Maryland. They reported that lineaments are usually associated with higher transmissivities, and thus greater water-well productivities. Many other attempts have been made on the same assumption (see

Kastning 1977; Bazynski *et al.* 1983; Buckly and Zeil 1984; Teeuw 1995; Travaglia and Ammar 2000). Therefore, great attention was given to the coincidence of lineaments location and highly productive wells. Nevertheless, erroneous results sometimes exist and thus lineaments are found to be poorly related to the productivity of water wells. Thus, others rejected the proportionality between lineament and water wells productivities (Parizek 1967). Even so, the same workers who primarily believed in this assumption were faced with inconsistencies after a time, such as Rauch and LaRiccia (1978). This was attributed mainly to the incorrect identification of lineaments from aerial photographs or satellite images or due to the failure of the applied manner of lineament behaviour expression, e.g. calculation of their density, morphometry, etc.

Furthermore, many supplementary factors were added to support this groundwater exploration approach (El-Shazly *et al.* 1983; El-Baz 1992; Per Sandra *et al.* 1996; Das 2000), including lithology, drainage, soil type, topography, etc.

From the above discussion, it is obvious that a contradiction exists, which may be summarized as follows:

1. In some cases, identification occurs of geologic-related linear features that appear on aerial photographs or satellite images
2. If the recognized lineaments are attributed to fractures, this will count only to the recharge potential of surface water into the subsurface media, and not to the storage of groundwater.
3. In many instances, the recharged water from the surface through fractures, i.e. recognized lineaments may flow along the bedding planes of rocks or along the faults or kastic cavities. Therefore, groundwater may accumulate anywhere and not exactly beneath the fracturing zones (Shaban *et al.* 2005).

Figure 1 shows an example of the erroneous selection of water-well sites in a dense lineament zone, which is defined by fractured terrain. It is clear in the figure that well No. 2 is located on a highly fractured zone, but drilling for water in that zone is not favourable,

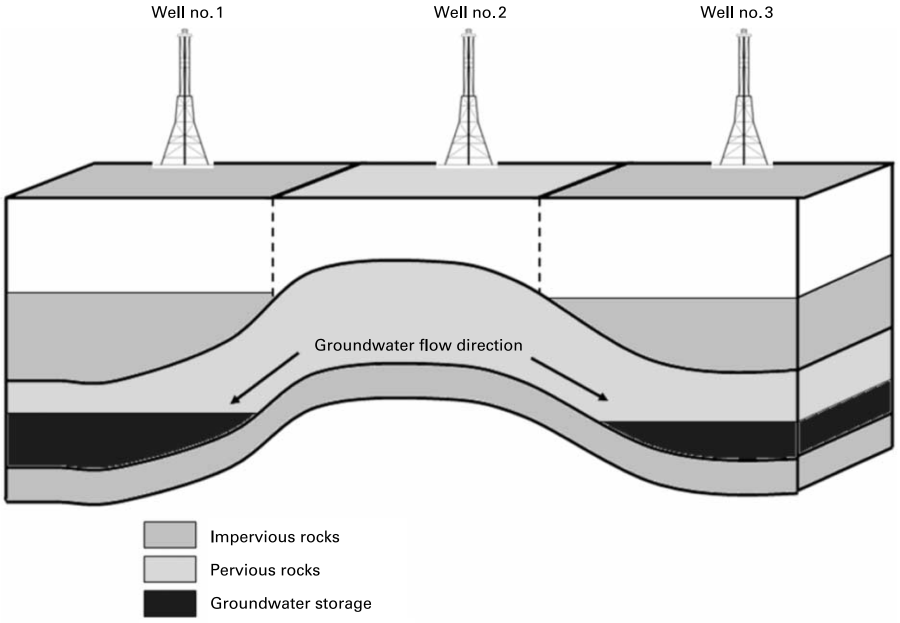


Figure 1 Schematic diagram showing the selection of water well sites on different fractured zones

because of the subsurface flow along bedding planes. Thus, drilling wells (i.e. wells Nos. 1 and 3) in zones of low-fractured zone might reach a groundwater accumulation.

Relying upon the above contradiction, this study attempts to clarify the creditability of using lineaments to located productive water-well sites.

Methodology

To reach a credible understanding of the relationship between lineament morphometry and water productivity in wells, four major steps were followed in this study:

1. Identification of dug wells, either productive or not.
2. Using satellite images to map lineaments in areas where these wells are located.
3. Analysing lineaments in order to determine their morphometric characteristics.
4. Applying a comparison approach to assess the relation between well productivity and lineament location with respect to different lineament morphometry.

For this purpose, four zones were selected in Lebanon (Figure 2). These zones comprise a miscellany of lithologic and physiographic characteristics, and constitute a domain area of about 1600 km^2 (i.e. 15% of Lebanon's area). In addition, the selection of these zones relied upon data availability on dug water wells in these zones.

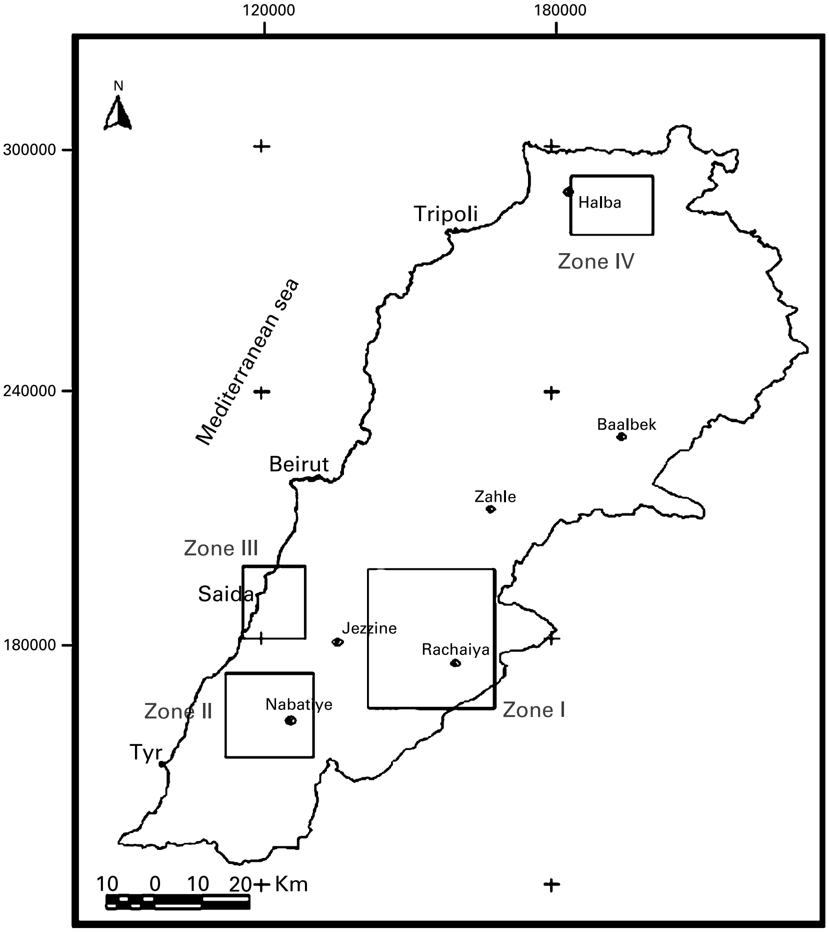


Figure 2 Location map of the selected areas from Lebanon

Water wells productivity

The aquiferous rock formations in Lebanon are ascribed for their secondary porosity (i.e. fractures and joints). This mainly applies to the carbonate rocks of the karstified limestone and dolomite. There are four major aquifers and six semi-aquifers that intervene with a miscellany of aquicludes and aquitards. The main aquiferous formations are attributed to the: Cenomanian (C_4), Upper Aptian (C_{2b}), Kimmeridjian (J_6) and Callovian (J_4). The Cenomanian rock formation is the most commonly exploited one, because it has the largest exposure in Lebanon (~ 40%). In addition, on this formation dense urban settlements are situated, which increases the demand for water.

Among the four selected areas of study, a field reconnaissance was conducted to determine the related information on water wells, notably the exact location, water discharge and aquifer type for each well. However, 90 water wells were considered in this study to cover different parts of the Lebanese territory. Most of these wells are dug in the aquiferous formations. They are distributed as: 60% in the Cenomanian, 9% Jurassic, 7% Eocene and 3% in the Upper Aptian. The rest are in semi-aquiferous rocks, i.e. Quaternary 15%, tuffaceous rocks 3% and 2% Lower Aptian. These aquiferous formations belong to confined hydrostratigraphic systems, which are often overlain by compacted marly rocks. The located wells in these formations show high static water level and depth exceeding some 250 m. Besides, the semi-aquiferous rock formations are due to unconfined systems with a relatively shallow depth not exceeding 100 m.

Lineaments identification

Satellite images of Landsat 7 ETM + (30 m × 30 m resolution) have the advantage to detect “edge” features, i.e. lines of small and large fractures. In this regard, the interpretation was done visually and in an automated way. For the visual study, all clear/unsuspicious linear features could be directly traced from the image. While the automated interpretation was achieved by applying a special feature in the software (ERDAS Imagine). In this application, various methodologies were applied, notably, directional filtering, contrasting and sharpness. In addition, single band and multi-band enhancement were carried out by interrelating each three bands as one set. Often, the combination of bands 2, 5 and 3 of Landsat 7 ETM + better identifies linear features. Accordingly, the thermal interpretation from thermal band, i.e. band 6 (120 m × 120 m resolution), was also undertaken. It provides optimum information for detecting wet horizons, which would differentiate fracture zones that are moist. Following the above interpretations, a lineament map was produced for each of the four selected zones.

The interpretation of lineament features in this study involves the plotting of all linear signatures on the image. Therefore, a dataset will initially include not only the geological features, but also all linear features, which may be spurious due to cultural (man-made), or system artefacts. In order to avoid such a contradiction of lineament’s origin, a systematic discrimination of linear features via remote sensing and Geographic Information System (GIS) techniques was conducted. All non-geologic features (e.g. roads, pipelines, etc.) are skipped over. This was based mainly on the overlapping of the produced lineament map with a topographic map. Therefore, a verified lineament map was produced. The latter was superimposed on the available geologic map (scale 1:50 000) by Dubertret (1953). Consequently, the following were noticed:

- An obvious coincidence between both maps with respect to the major faults.
- The suspicious extents of fault alignments present on the geologic map were completed from the lineament map.
- There is a large number of small-scale faults (linears) that did not appear on the geologic map.

Therefore, essential modifications and additions were based on the lineament map. These additions were verified in the field. An example of the lineament maps is shown in Figure 3.

Morphometric analyses

In order to compare between lineaments and the location of productive wells, morphometic criteria of lineaments must be established. This needs a diagnosis analysis of the derived lineament map. Usually, this analysis follows two principles, either by calculating the lineament density (Teeuw 1995; Edet *et al.* 1996) or lineaments frequency (El-Baz and Himida 1995; Shaban *et al.* 2004). In this study, both approaches were applied. Furthermore, lineaments, which represent faults, are also encountered, and are called "fault lineaments".

Lineaments density

Lineaments density (L_d) expresses the cumulative length of lineaments within a specific area (Greenbaum 1985). It is expressed as:

$$L_d = \sum \frac{L_l}{A}$$

where ΣL_l is the total length of lineaments and A is the area in km^2.

The morphometric analysis of lineament density followed the "*Sliding Windows*" method (Shaban 2003). This is done by dividing the area of study into grids for which a frame is produced (Figure 4). The size of a frame depends on the spatial distribution of the linear features. In this study, a frame of 3 km × 3 km (i.e. 9 km^2) was selected. The total length of lineaments in each frame was counted. Each obtained value was plotted in the middle of the frame. Therefore, for each four neighbouring frames, the average value was again calculated, and plotted in the middle of the "conjunction" resultant frame. The resulting midpoints

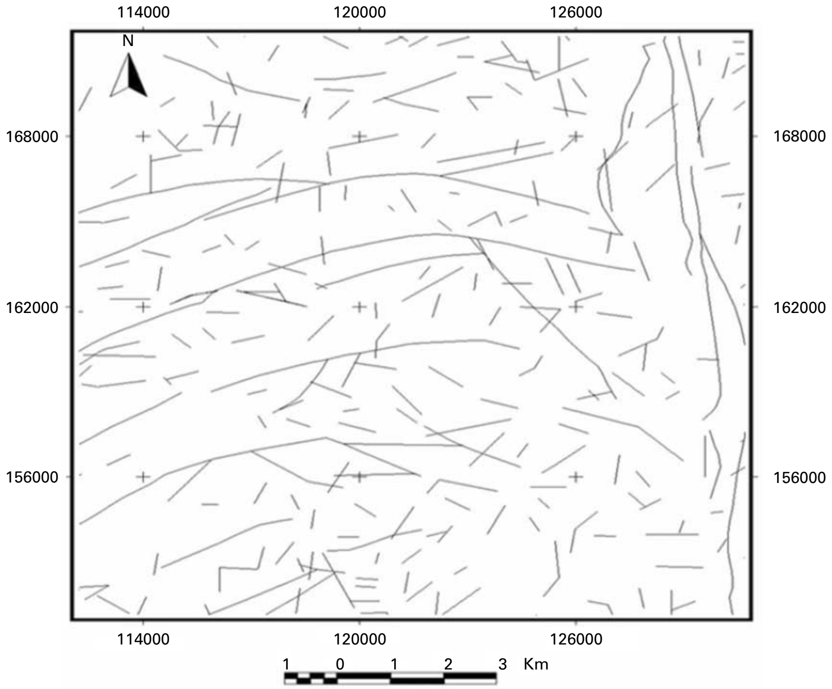


Figure 3 Example (for zone II) showing a lineament map as derived from satellite Landsat 7 ETM + images

represent the value of the lineament density. Therefore, these points are used to illustrate the contour lines that express the lineament density (Figure 4).

Lineament frequency

Lineament frequency (L_f) is the visible number of lineaments per unit area (Greenbaum 1985) and is expressed as

$$L_f = \sum \frac{L_n}{A}$$

where ΣL_n is the total number of lineaments and A is the area in km^2.

The aforementioned approach was applied, and thus a contour line map resulted (Figure 5).

Fault lineaments

Fault lineament (F_l) is another fundamental morphometric property of linear features considered by many authors (Buckly and Zeil 1984; Garza and Slade 1986; Briere and Scanlon 2001) who regarded the length of lineaments as long or short. The longer ones are often due to faults, while shorter ones represent fracture systems.

The discrimination of lineament origin (faults or fractures) from satellite images was achieved considering the following optical signatures:

1. Faults usually have acute and sharp shadows, while lineaments do not.

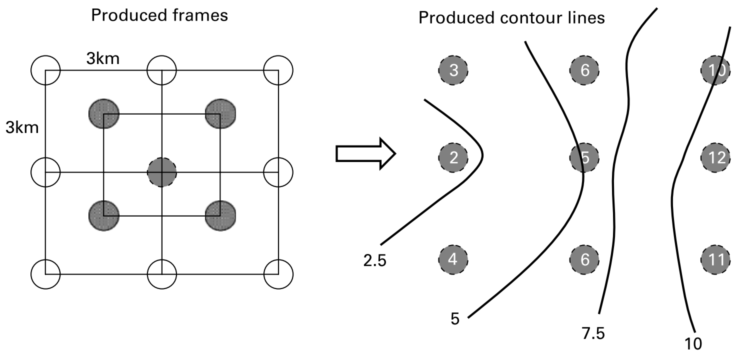


Figure 4 Example of “Sliding Windows” method using a frame of specific area to provide a contour map

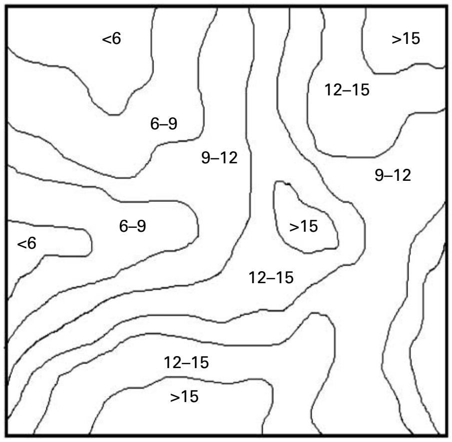


Figure 5 Examples (for zone II) showing the resulting contour map of lineaments frequency (km^{-2})

2. Faults always cross relatively long distances, i.e. several kilometres, whereas lineaments are usually short, i.e. <1 km.
3. Faults may cut two different lithologic units, while lineaments terminate at lithological contacts.
4. Faults tend to follow specific orientations and sets, e.g. same direction and parallelism, cut valleys, etc.
5. Lineaments usually have chaotic directional orientation, which is the case of some faults.

The above discrimination was verified in the field. Thus, faults were extracted and plotted in separated maps (Figure 6).

Correlation method

Having attained three morphometric criteria of lineaments (i.e. L_f, L_d, F_l), a particular coincidence (overlapping) must be applied separately for each one with respect to well productivity. Therefore, each of the four components (L_f, L_d, F_l and water productivity) was expressed in maps. Such overlapping was successfully done using a Geographic Information System (GIS). In this study the Arc-Info software was used for this purpose. Figures 7(a–c) show examples of this superimposition. Consequently, to homogenize this coincidence, each of the four components were classified into five classes, each class expressing a range of values as follows:

(1) For the properties of lineaments frequency and density five classes resulted from the previously mentioned "Sliding Windows" method. The intervals of the five classes were selected depending on the observed maximum and minimum values. Therefore, for lineament frequency, the intervals range from <6 to >15 segment per 9 km^2 (Figure 7(a)), while for lineament density, they range from <3 to >12 km per 9 km^2 (Figure 7(b)). Thus, the classes were described according to the lineament frequency or density as: very high, high, moderate, low and very low (Table 1).

(2) For the lineaments that are described as fault structures, i.e. fault lineament, the major principle taken into consideration is the closeness of water wells to fault lineaments, in other words, the distance of productive or non-productive wells to the location of fault lineaments. In this case, a synoptic classification was followed relying upon the location of wells in five buffer distances to the fault lineament (Table 2).

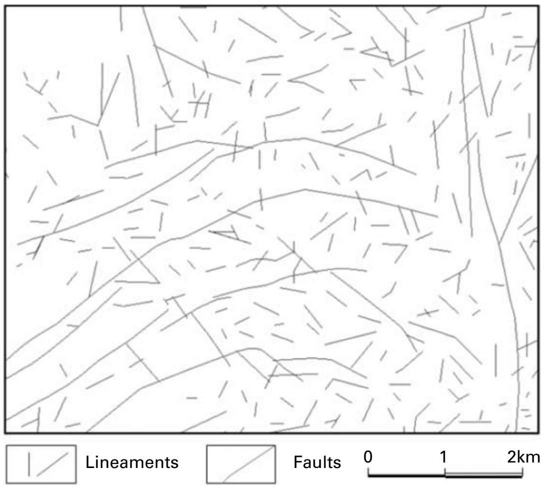
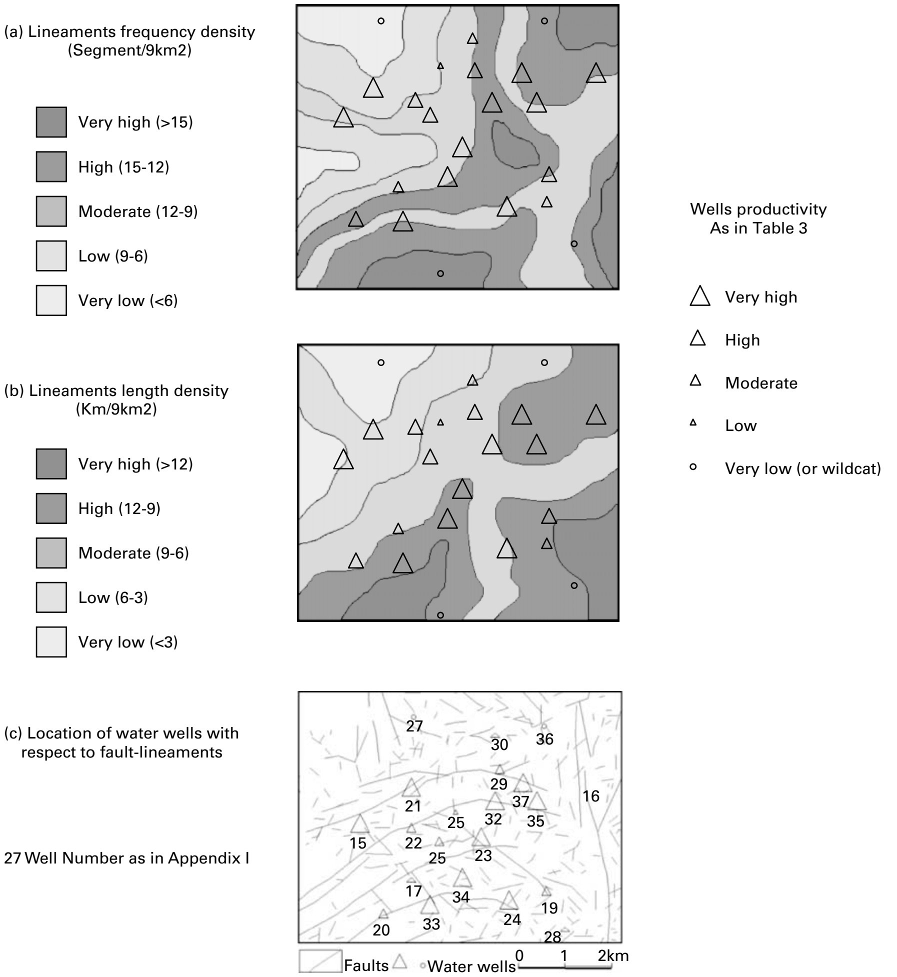


Figure 6 Example (of zone II) showing discriminated faults from a lineament map


(a) Lineaments frequency density (Segment/9km2)

(b) Lineaments length density (Km/9km2)

(c) Location of water wells with respect to fault-lineaments

27 Well Number as in Appendix I

Figure 7 Examples (for zone II) showing the location of water wells (of different productivity) with respect to lineament morphometric properties

(3) The productivity of water wells productivity was also divided into five classes, as shown in Table 3.

Accordingly, the geographic distribution of different wells in the classified zones of lineament criteria will signify the relation between them. For example, if the existence of highly productive wells is found in zones with high lineament frequency, this indicates a direct proportionality between them.

Table 1 Lineament frequency and length density categories

Lineament frequency density ranges (segment/9km^2)	Lineament length density ranges (km/9km^2)	Density
>15	>12	Very high
15–12	12–9	High
12–9	9–6	Moderate
9–6	6–3	Low
<6	<6	Very low

Table 2 Buffer distance of productive wells to fault

Buffer distance of productive well to nearest fault (m)	Distance
<100	Very close
100–200	Close
200–400	Moderate
400–600	Far
>600	Very far

Table 3 Classification of productivity rate from water wells in Lebanon

Productivity rate (l/s)	Description
>20	Very high productivity
19–15	High productivity
14–10	Moderately productive
9–5	Low productivity
<5	Very low productivity (or Wildcat)

Results and conclusion

The values resulting from the obtained maps and from field information on the 90 wells are listed in Table 4. These data were extrapolated into two approaches. First, for the lineament frequency and density (L_f and L_d), since they have no numerical data to be presented graphically, they were plotted in a number matrix (Tables 5 and 6). According to Congalton (1991) the number matrix is usually applied for result confirmation. In this matrix, water productivity ranges were compared with the estimated ranges of lineament frequency and density separately. For the frequency, Table 4 shows the number of coincided values (oblique column with shading) between frequency of lineaments and well productivity. The total of coincided values is 24 out of 90 water wells. Therefore, the ratio of reliable measures is:

$$\frac{24 \times 100}{90} = 26.6\%$$

while for the lineament density (Table 5) this ratio is

$$\frac{18 \times 100}{90} = 20\%.$$

According to fault lineaments, and since numerical data are available, these values were expressed graphically according to data in Table 2. Figure 8 exhibits the relation between water wells' productivity and their proximity to faults. It is obvious that there is an inverse proportionality between the parameters. However, in the selected areas of study, located wells at a distance less than 350 m from faults are found to have a water productivity exceeding 15 l/s, while those wells between 350–650 m from a fault often show productivity of around 10 l/s. In other words, more than 97% of wells at a distance less than 650 m from faults are productive wells with >10 l/s. Thus a clear decline in water productivity exists as the distance increases. This is regardless of whether there is a fracturing system or not, as indicated by the morphometric analysis of linear features.

From a hydrogeological point of view, lineaments corresponds with faults do not have the same influence as those attributed only to fracture systems. The explanation of this can be attributed to the fact that faults may act as transmission routes, hydraulic barriers or as groundwater storage zones. While fracture systems mainly serve increasing recharging rates,

Table 4 Properties of the investigated wells

				Description of lineament properties		
Well No./Zone	**Rock formation**	**Productivity (l/s)**	**Descriptive productivity ***	**(L_f)**	**(L_d)**	**(F_l)**
1*I*	Eocene	15	HP	H	M	210
2*I*	Ditto	21	VHP	H	M	75
3*I*	Ditto	4	VLP	H	H	1350
4*I*	Lower Aptian	15	HP	L	L	250
5*I*	Cenomanian	20	VHP	M	M	50
6*I*	Lower Aptian	4	VLP	L	M	775
7*I*	Jurassic	10	MP	M	H	650
8*I*	Jurassic	23	VHP	H	M	150
9*I*	Jurassic	21	VHP	VH	H	105
10*I*	Jurassic	5	LP	M	H	340
11*I*	Jurassic	4	VLP	M	M	850
12*I*	Jurassic	20	VHP	M	H	125
13*I*	Jurassic	16	HP	H	M	305
14*I*	Upper Aptian	8	LP	L	L	840
15*II*	Cenomanian	12	MP	L	VL	1200
16 *II*	Cenomanian	20	VHP	H	H	50
17 *II*	Cenomanian	11	MP	H	M	100
18 *II*	Eocene	0	VLP	H	VH	1500
19 *II*	Cenomanian	16	HP	M	H	20
20 *II*	Cenomanian	17	HP	H	M	500
21 *II*	Cenomanian	20	VHP	L	L	50
22 *II*	Cenomanian	18	HP	M	L	70
23 *II*	Cenomanian	22	VHP	H	H	110
24 *II*	Cenomanian	11	MP	L	L	220
25 *II*	Cenomanian	17	HP	M	M	10
26 *II*	Eocene	2	VLP	M	H	2500
27 *II*	Cenomanian	0	VLP	VL	VL	1200
28 *II*	Cenomanian	12	MP	M	H	650
29 *II*	Cenomanian	16	HP	M	M	20
30 *II*	Cenomanian	9	LP	M	M	1425
31 *II*	Cenomanian	7	LP	L	M	420
32 *II*	Cenomanian	22	VHP	M	M	10
33 *II*	Eocene	25	VHP	H	H	15
34 *II*	Cenomanian	21	VHP	M	H	5
35 *II*	Cenomanian	20	VHP	H	M	200
36 *II*	Cenomanian	0	VLP	H	M	1600
37 *II*	Cenomanian	22	VHP	M	H	15
38 *III*	Cenomanian	8	LP	M	H	370
39 *III*	Cenomanian	10	MP	L	H	465
40 *III*	Cenomanian	17	HP	L	M	270
41 *III*	Cenomanian	21	VHP	H	L	130
42 *III*	Cenomanian	10	MP	M	VL	365
43 *III*	Cenomanian	12	MP	M	L	780
44 *III*	Cenomanian	9	LP	M	L	955
45 *III*	Cenomanian	15	HP	VH	H	245
46 *III*	Cenomanian	11	MP	M	H	660
47 *III*	Cenomanian	10	MP	L	M	735
48 *III*	Cenomanian	7	LP	L	M	1835
49 *III*	Cenomanian	5	VLP	L	L	1645
50 *III*	Cenomanian	6	LP	L	L	1210

Table 4 – *continued*

Well No./Zone	Rock formation	Productivity (l/s)	Descriptive productivity *	Description of lineament properties		
				(L_f)	(L_d)	(F_i)
51 *III*	Cenomanian	6	LP	M	VL	1405
52 *III*	Cenomanian	6	LP	L	H	1350
53 *III*	Cenomanian	12	MP	L	M	620
54 *III*	Cenomanian	10	MP	VL	L	410
55 *III*	Cenomanian	6	LP	VL	L	525
56 *III*	Cenomanian	7	LP	H	M	565
57 *III*	Cenomanian	6	LP	M	M	505
58 *III*	Cenomanian	10	MP	M	H	515
59 *III*	Quaternary	11	MP	H	VH	550
60 *III*	Cenomanian	10	MP	VH	VH	405
61 *III*	Quaternary	6	LP	L	M	175
62 *III*	Quaternary	5	VLP	H	L	1815
63 *III*	Quaternary	7	LP	H	M	2075
64 *III*	Cenomanian	11	MP	VH	H	215
65 *III*	Cenomanian	15	HP	H	M	135
66 *III*	Cenomanian	16	HP	M	L	140
67 *III*	Cenomanian	15	HP	L	VL	50
68*IV*	Cenomanian	20	VHP	VH	H	80
69 *IV*	Cenomanian	35	VHP	M	M	20
70 *IV*	Cenomanian	35	VHP	L	H	10
71 *IV*	Cenomanian	22	VHP	L	M	55
72 *IV*	Cenomanian	16	HP	VL	L	95
73 *IV*	Cenomanian	10	MP	M	M	305
74 *IV*	Cenomanian	16	HP	M	H	225
75 *IV*	Tuff	17	HP	H	M	125
76 *IV*	Tuff	11	MP	H	H	195
77 *IV*	Tuff	12	MP	H	L	385
78 *IV*	Upper Aptian	12	MP	M	L	360
79 *IV*	Upper Aptian	12	MP	L	L	275
80 *IV*	Jurassic	15	HP	L	VL	200
81 *IV*	Quaternary	0.5	VLP	L	VL	1655
82 *IV*	Quaternary	0.5	VLP	VL	L	1675
83 *IV*	Quaternary	0.5	VLP	VL	M	990
84 *IV*	Quaternary	0.5	VLP	L	M	1098
85 *IV*	Quaternary	1	VLP	M	M	1955
86 *IV*	Quaternary	0.5	VLP	M	H	1123
87 *IV*	Quaternary	0.5	VLP	H	H	1345
88 *IV*	Quaternary	0	VLP	M	L	2790
89 *IV*	Quaternary	0.25	VLP	L	VL	1825
90 *IV*	Quaternary	0.25	VLP	M	VL	1635

*VHP = very high productivity; HP = high productivity; MP = moderately productive; LP = low productivity; VLP = very low productivity

in such cases consequent steps must be followed for groundwater exploration (Shaban *et al.* 2005). This could be reflected by the productivity of water wells through defining their location at different distances from faults and within the two major morphometric properties of lineaments.

This hypothesis can be applied to a region like Lebanon where fault structures are relatively common and most of them are of the strike-slip type. These, in turn, serve to abut

Table 5 Number matrix to evaluate the coincidence between wells productivity and lineaments frequency density

	Qualitative estimates of lineament frequency density					
Qualitative estimates of well productivity Category	Very high	High	Moderate	Low	Very low	Total
Very high	2	7	5	4	0	18
High	1	5	7	4	1	18
Moderate	2	4	10	8	1	25
Low	0	4	4	4	1	13
Very low	0	3	6	4	3	16
Total	5	23	32	24	6	24

Table 6 Number matrix to evaluate the coincidence between wells productivity and lineaments frequency density

	Qualitative estimates of lineament frequency density					
Qualitative estimates of well productivity Category	Very high	High	Moderate	Low	Very low	Total
Very high	1	9	6	2	0	18
High	1	3	8	4	1	17
Moderate	2	8	5	8	2	25
Low	0	3	6	4	0	13
Very low	1	3	6	2	5	17
Total	5	26	31	20	8	18

two rock formations of different hydrologic properties, thus creating hydraulic barriers for groundwater storage.

Furthermore, it is important to mention that the identification of these hydrologic elements, i.e. faults and fractures, can be accomplished utilizing remote sensing images, where both can be detected as linear features. Consequently, the use of satellite images (e.g. Landsat 7 ETM +) proved their utility to identify these surfacial features.

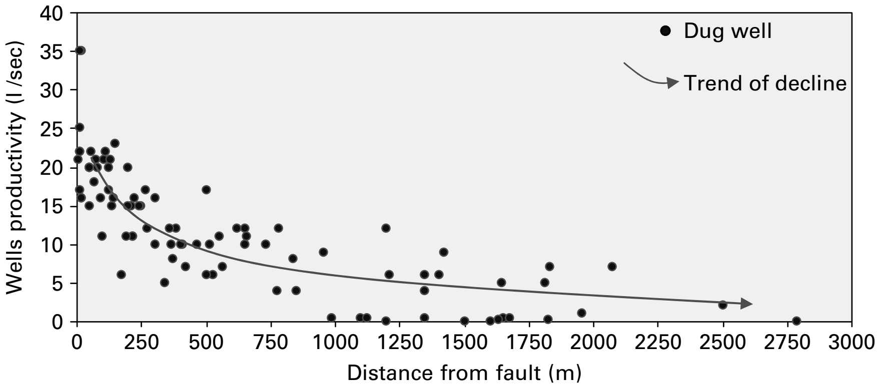


Figure 8 The relation between water wells productivity and their proximity to faults

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