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A Study on the Extraction of Groundwater Potential Area Utilizing the Remotely Sensed Data

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Abstract

The study is aimed at the extraction of the groundwater potential areas utilizing the remotely sensed data from satellites. The results of the study are summarized as follows.

Analyses of the existing operational wells for groundwater supply indicate that 81% of them are related with lineaments and 51% of them are located at the intersections of lineaments. Thus the features of lineaments are considered to be one of the most important parameters to extract a high potential area of groundwater. Taking into acount features of lineaments, high potential points were extracted from Landsat TM data based on the theory developed in this research, then verifications were made through actual drilling. The result of verification indicates that 9 points produces more 200 cubic meter/day which is the amount required from economical point of view for an operational use.

Since the actual boring was not made on the recommended points for 4 points due to the difficulty of access to the exact points and of the approval for boring, they did not yield enough output. The result might have been improved if the exact points were bored and if the boring had been made deeper, since the maximum depth of boring was limited to 62 meters.

1. Introduction

Groundwater is used not only as an important water resource in dry areas but also as a crucial element to meet the rapidly increasing requirements of water resource caused by industrial development and the improvement of standard of living recently. Since much more labor and expense is required for developing surface water, more stress on utilizing the groundwater that could be developed in a very short time has been placed. Efficient methods to probe groundwater in the regional areas have to be advanced because the traditional ones such as hydrogeological survey and electrical sounding survey consume lots of labor and expense.

In this paper, a method for extracting potential areas of groundwater was developed by undertaking vertical electrical sounding survey after selecting potential areas of groundwater through correlational analysis between the established wells and lineaments extracted from remotely sensed data. Based on this method, potential areas of groundwater were found, which are distributed in Gochang, North Chullado, Korea.

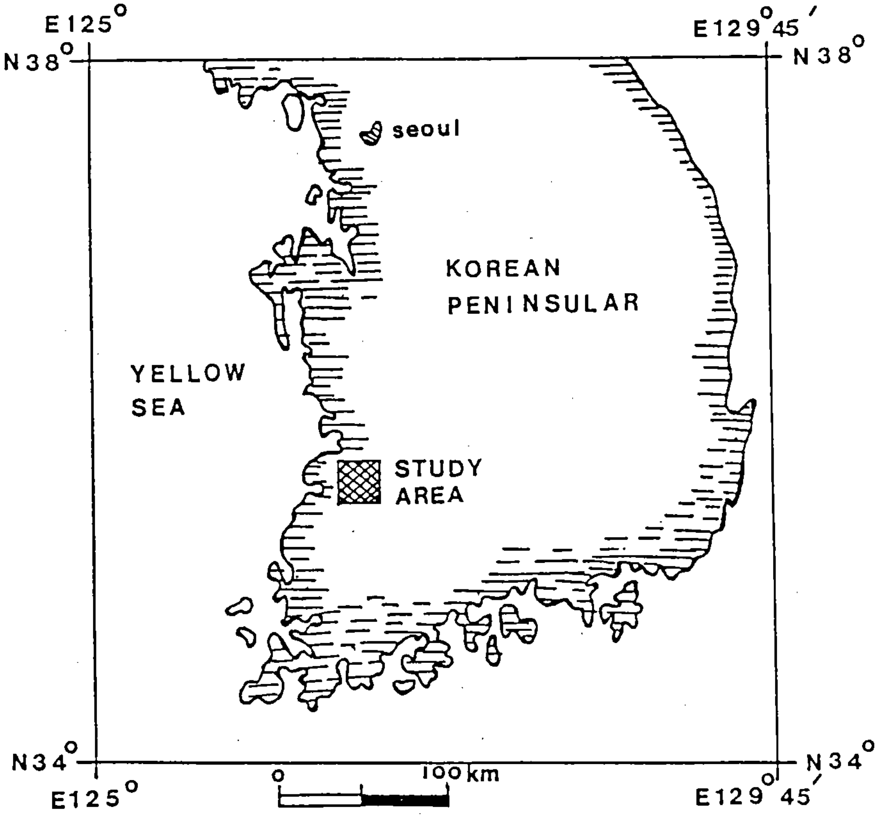


Figure 1. Location map of the study area.

2. Study Area

Gochang area of Figure 1 is located in 126° 30′-126° 45′ of longitude and 35° 15′-35° 30′ of latitude, southwest in Korea. The area was taken as a pilot study area because no area has more groundwater wells than Gochang area, which exhibits particular characteristics in geomorphological and geological context. As in Figure 2, geology distributed in Gochang area consists of Precambrian gneisses, age-unknown schists , Jurrasic granites, and Volcanics of Cretaceous period which is highly related to the conditions of forming a great deal of groundwater

Geomorphography is generally high in East and low in West, showing high relationship with the distribution of geology. Besides two-mica granite is distributed in central, southwest, and northeast areas, the areas of hilly districts and rice field. In southeastern parts of Gochang, mountain areas, Precambirian gneisses are distributed.

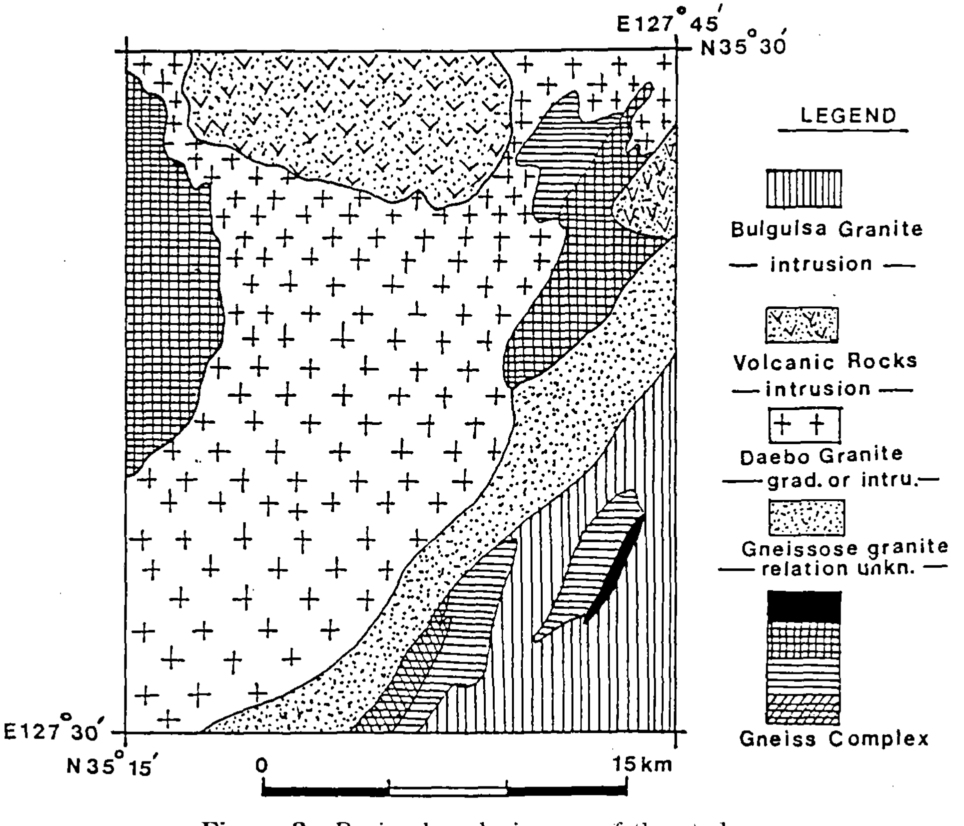


Figure 2. Regional geologic map of the study area.
(After Kwangju geologic map, scale 1:250,000)

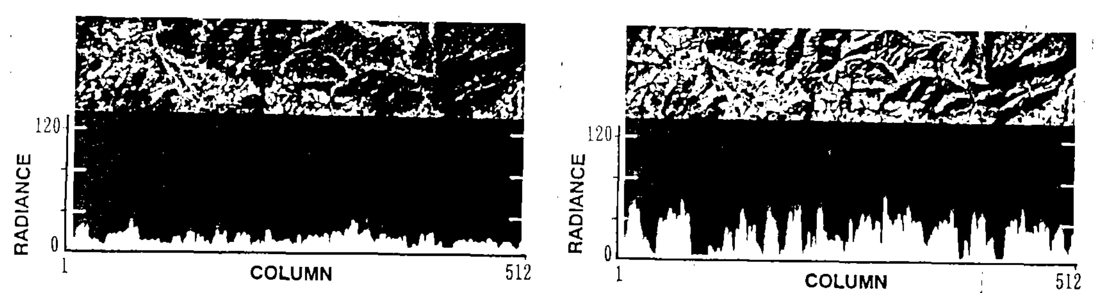
3. Geometric Correction and Spectral Band Analysis

The remotely sensed data used in this study is LANDSAT TM CCT of Path-Row 116-35(D) scanned in Dec. 11, 1986.

To select the effective ones among 7 bands of Landsat TM for geological interpretation and lineament extraction, histograms of each spectral band of TM were considered. Generally, in Bands 3 and 5 were turned out to show the maximum radiance range among visible spectral bands and near infrared spectral bands.

The comparisons and analyses of the radiational distribution of lineament cut vertically was followed by selecting the accurate areas where lineament has been distributed - where radiance texture reveals an abrupt transformation. Figure 3 shows the radiance distribution of bands 3 and 5 in line No. 80 in the northern parts of Gochang area.

In Figure 3(A), minimum radiance(DMN) of band 3 was 10 ; maximum radiance(DMX), was 44. In Figure 3(B), the range ΔD of band 5 was narrower than 76. Standard deviation of band 3 was smaller than that of band 5, 17.67. Band 5 was chosen for extracting detailed transformation because of the larger range of data.



(A) (B)

Figure 3. The profile of digital values of radiance along line 90 of Band 3 and Band 5 of Landsat TM.

4. Image Processing for Lineament Extraction

Some scholars reported an algorithm of extracting linear feature from Landsat data of roads, rivers, and lineament (Rosenfeld and Thurston, 1971; Vanderburg, 1980; Gurney, 1980; Tchiya and Chi, 1984; and Wang and Howarth, 1987). Wang and Howarth's algorithm uses an acuteness operator in which linear features are extracted by calculating the size and direction of each pixel through 5x5 windows of 8-direction vector. This algorithm is far more plausible while much time should be consumed for the calculation. In this study, therefore, Wang and Howarth's algorithm was simplified for extracting lineament that clearly reveals the characteristics and geomorphography of Gochang area.

The below equations show acuteness and size (MACU) of an arbitrary point (X,Y) on two dimensional right angled coordinate.

$$\begin{aligned} acu(x,y) &= \left(\frac{\sigma^2 f(x,y)}{\sigma r^2}\right) \\ MACU(x,y) &= \begin{pmatrix} acu & \text{if } acu \geq 0 \\ 0 & \text{otherwise} \end{pmatrix} \end{aligned} \qquad (4.1)$$

f(x,y) in the above equation is a pixel point correspoinding to radiance of a point (x,y) in image, while r lies in right-angled direction of lineament. The equation that MACU(x,y) = 0, when acu(x,y) < 0 indicates low radiance by small reflection of Landsat TM band 5 because the areas where lineament has been distributed possess much soil moisture in general. That is why acu(x,y) should certainly be positive. The following equation shows the directions, DACU(x,y), of acu(x,y).

$$DACU(x,y) = (\theta + \pi/2) \bmod \pi \qquad (4.2)$$

θ, an angle of intersection between X axis and r, goes counter clockwise from X axis. Theoretically, θ from 0 to 180 degrees points out calculated acu(x,y) and DACU(x,y) as an angle of the calculation. Since it is practically impossible to calculate these equations from each point, 4 codes (4 directions) were dealt by 3x3 mask. The maximum code was called MACU(x,y) and the code corresponding the MACU(x,y), DACU(x,y).

Even if calculated MACU shows linear features, lineament within 1 Km was ruled out because this study is aimed at lineament extraction appropriate for probing groundwater. In so doing, a proper threshold was established, over which MACU was regarded as a processing period.

To extract lineament from MACU of each point, based on MAXU(x,y), the point over the threshold came to be a starting point through finding the direction to which x and y increases from zero(0) respectively. Then starting point and ending point were connected after tracing DACU(x,y). The result that the peak value of histograms was considered as the first threshold was shown in Figure 4. Judging from the clearly indicated locations of lineament as in Figure 4, such a method was proved to be effective for the interpretation of lineament related to groundwater.

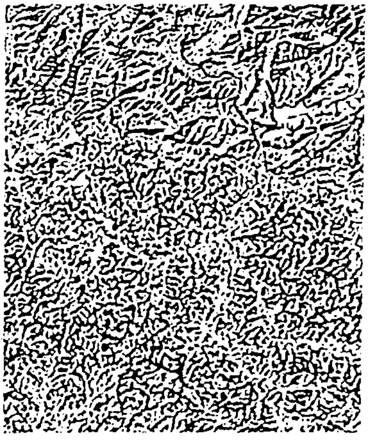


Figure 4. Lineament image obtained through application of the proposed algorithm.

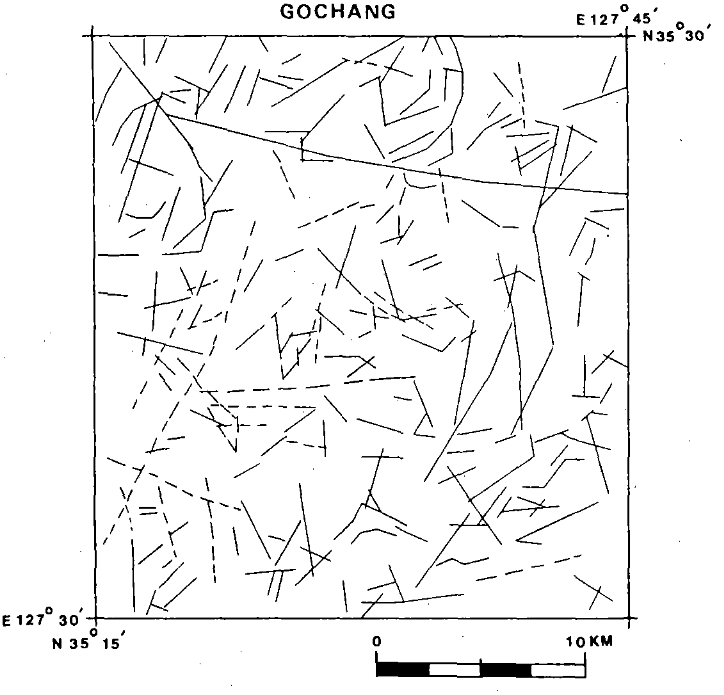


Figure 5. Lineament extracted from remote sensing data. Broken lines are pseudo lineaments

To determine a superiority of lineament extraction method, the following LEI(Lineament Extraction Index) was calculated.

$$LEI = h/\sigma \quad (4.3)$$

In the above equation, h and σ indicate edge contrast and standard deviation respectively. For the lineament image developed in this study, LEI in Figure 4, is 6.78. Comparing with Prewitt operater (Lipkin and Rosenfeld, 1970) which has been most frequently used for edge extraction, and by which LEI was 5.60, it is proved that the method developed in this study is superior for lineament extraction. The results of the interpretation were shown in Figure 5.

5. Lineament Analysis

Statistical analysis was undertaken for the frequency and length of lineament every 10 degrees of strike angles in the studying areas based on the lineament interpretation map in Figure 5. The result was shown in the rose diagrams in Figure 6. Figure 6 indicates that there are two distinctive directions of lineament: northeast to southwest and east-northeast to west-southwest. Especially distinctive directions are "N 40° - E 49° " with 10.9% of total frequency and "N 20° - W 29° " with 11.4% of total frequency. The two distinctive directions have a close relation to the geomorphography of the study area. Namely, the areas are located in south-southwest of Korean penisula, southwest side of Noryung mountains running to southwest. Lineament of "N 40° - E 49° " is developed in the same direction as China tectonic direction.

In Figure 7, the locations of on-going wells are indicated on the lineament interpretation map made in this study. The following facts could be induced from the rose diagrams in Figure 6 and the map in Figure 7. There are 79% of the wells which have a strike direction runs east and 21% of the wells parallel with the lineament of "N 40° - E 49° ", a distinctive direction, out of 19 wells are closely related to lineament.

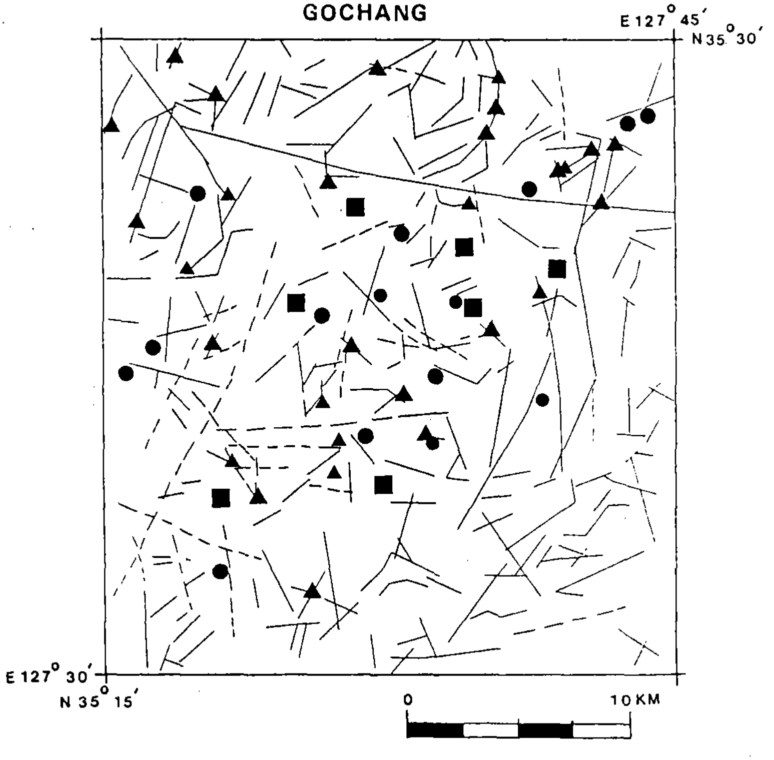


Figure 7. Roc's wells of groundwater supply plotted on the lineament map. The wells are developed and poerated by Rural Development Corporation, Korea.
▲: on lineaments, ●: near lineaments, ■: away from lineaments

6. The Characteristics of Lineament Effective for Proving of Groundwater

Lineament plays a role of a pathway of groundwater because it lies in the weakly zone of geology structure as mentioned above. Even though there is a great deal of lineament that can be extracted from remotely sensed data, a method to determine where we can obtain economical amount of water is required.

The following facts were discovered from Figure 7 in which the relationship between lineament extracted from remotely sensed data and the extablished wells is indicated.

(1) The studying areas have 37 locations that produce water more than 300㎥/day out of the on-going wells developed by Rural Development corporation(RDC). The results of the comparison and analysis of lineament interpreted from Landsat data and the locations of on-going wells proved that the wells are 51%, where lineament concurs with the intersection point of lineament - that is, there is a high relationship between the intersection point of lineament and groundwater.

(2) There are 11 locations, 30% of all the wells, which do not completely coincide with lineament but lay within less than about 300m from lineament.

Considering that around 81% of all the wells have something to do with lineament directly or indirectly, this study substantiated high relationship between the locations of wells and lineament.

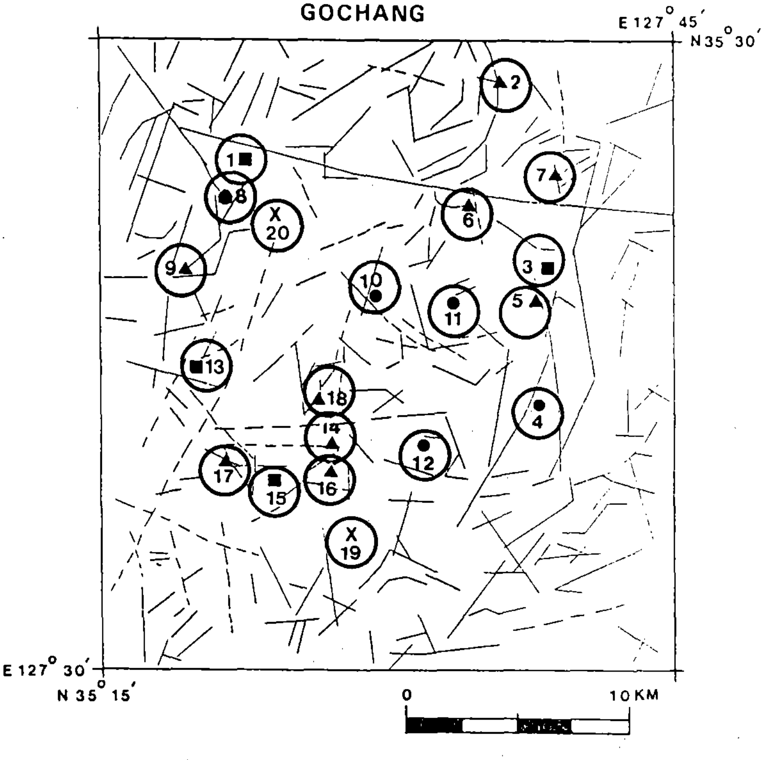


Figure 8. 20test boring sites selected in reference with featyres of lineaments. The dark triangles(▲) denote the wells with daily water output of more than 200㎥/day

7. The Extraction of Potential Area of Groundwater

Considering lineament intersection point from lineament interpretation map in Figure 5 to search for potential areas of groundwater using remotely sensed data, 20 expectant locations shown in Figure 8 were chosen for boring.

The problem is, however, that remotely sensed data virtually concerning about surface are not enough to find the boring locations. Thus, electronic resistance test, one of the Vertical Sounding Methods,was carried out with remotely sensed data to select the accurate locations, the state of underground geology, and the condition of aquifer about the 20 expectant locations for boring was fully equipped.

Table 1. Result of borings. AS to the locations see Fig. 7

Hole NO.	Geology (Depth, m)							Water Table	Pumping Rate (m^3/day)	Remark
	soil	sand	gravel	weath -ering zone	soft rock	hard rock	total			
B -1	2.5	-	-	9.5	43.0	16.0	71	10.0	30	
2	0.5	2.5	-	12.0	3.0	41.0	59	1.0	350	Shear zone
3	0.5	-	-	4.5	19.0	37.0	61	-	10	
4	0.5	-	2.5	6.0	6.0	57.0	72	0.7	80	
5	0.5	-	5.5	8.5	36.5	10.0	61	1.5	250	Joint
6	2.0	-	-	17.0	13.0	10.0	42	7.0	300	Joint
7	0.5	-	4.5	12.0	13.0	22.0	52	2.8	230	Joint
8	-	3.0	-	6.0	16.0	30.0	55	-	30	
9	4.0	-	-	12.0	16.0	29.0	61	2.1	400	Shear zone
10	0.5	-	-	5.5	2.0	50.0	58	-	5	
11	0.5	-	-	14.0	5.5	40.0	60	10.0	50	
12	1.0	-	2.5	1.0	5.5	52.0	62	3.0	50	
13	1.5	-	-	8.2	20.3	52.0	82	3.0	10	
14	4.0	-	-	14.0	32.3	35.0	85	7.0	350	Shear zone
15	3.0	-	-	13.0	4.0	45.0	65	-	5	
16	0.5	-	-	26.5	13.0	18.0	58	5.0	800	Weathering of Quarz vein
17	0.7	-	-	13.3	16.0	25.0	55	7.5	320	Shear zone
18	0.5	-	2.0	14.5	11.0	30.0	58	3.0	280	Shear zone
total	23.2	5.5	17.0	197.5	275.1	599.0	1,117	63.6	4,050	
aver -age	1.4	2.8	3.4	11.0	15.3	33.3	62.1	4.5	225	

Such a method is expected to raise the rate of extracting the accurate potential areas of groundwater. The Vertical Sounding Method on the 20 expectant locations for boring chosen from lineament interpretation map revealed anomaly of electronic resistance in 18 locations(●,■,▲) as in Figure 8. This study confirmed that the analyzed results of lineament and electronic resistance were almost the same.

In Table 1 are shown the results of boring the above expectant locations that turned out to be anomaly from the electronic resistance test. A shear zone has been developed in B-2, 5, 6, 7, 9, 14, 17, and 18 among the 18 expectant locations while a weathering zone, in B-16. The amount of producing water in these locations was from 230㎥/day minimally to 800㎥/day maximally.

These findings prove that groundwater exists in a shear zone or a weathering zone where all the conditions of aquifer has been fully equipped. The conditions can be attain from the analysis of lineament extracted from remotely sensed data.

The following facts were found from the analyzed results of lineament extracted from remotely sensed data and of electromic resistance test.

As a result of electronic resistance test on the 20 expectant locations selected based on the distribution map of lineament, 18 locations (90%) showed anomaly of electronic resistance. The results of boring 18 locations to confirm the state of underground geology and the existence of groundwater indicated that 9 locations (50%) could produce water more than 200㎥/day.

Such a low percentage(50%) was caused by boring the locations (B-4, 10, 11, 12) which is far about 300~500m from the expectant locations due to the problems concerning the installation of boring machines, permission for boring, and low boring depth of 62m on an average. The increase of the amount of producing water and the high probability of groundwater are expected through the boring in deeper depth.

8. Conclusion

Even if it is impossible for the method developed in this study to probe groundwater using remotely sensed data to apply to all the areas, the method must be one of the more economic and highly feasible methods than any other well-known ones. Geographic Information System as an alternative to remotely sensed data is also able to extract potential areas using the interrelationship among the factors closely related to the formation of groundwater.

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