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Original article

A Study on Optimal Site Selection for the Artificial Recharge System Installation Using TOPSIS Algorithm

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Abstract

This paper is intended to propose a novel approach to select an optimal site for a small-scaled artificial recharge system installation using TOPSIS (Technique for Order Preference by Similarity to Ideal Solution) with geospatial data. TOPSIS is a MCDM (Multi-Criteria Decision Making) method to choose the preferred one of derived alternatives by calculating the relative closeness to an ideal solution. For applying TOPSIS, in the first, the topographic shape representing optimal recovery efficiency is defined based on a hydraulic model experiment, and then an appropriate surface slope is determined for the security of a self-purification capability with DEM (Digital Elevation Model). In the second phase, the candidate areas are extracted from an alluvial map through a morphology operation, because local alluvium with a lengthy and narrow shape could be satisfied with a primary condition for the optimal site. Thirdly, a shape file over all candidate areas was generated and criteria and their values were assigned according to hydrogeologic attributes. Finally, TOPSIS algorithm was applied to a shape file to place the order preference of candidate sites.

Keywords : Artificial Recharge, GIS, DEM, Local Alluvium, TOPSIS

1. Introduction

The basic mechanism of groundwater utilization as a water supply resource is doing the injection of spare water to groundwater during the rainy season followed by a recovery during the dry time of a year. The artificial recharge scheme using this fundamental water circulation structure has been widely used in the developed world as well as in developing countries in a dry climate (Kim and Kim, 2009). The artificial recharge can be also used in water supply system as an ideal alternative means in the case of South Korea, where precipitation is concentrated during the summer monsoon season. This issue is discussed and considered as a useful method of adapting to climate anomalies around the world in terms of water resource management (Kim and Kim, 2010).

The artificial recharge technology can be used in a variety of purposes. Particularly, it can be also used as a secondary option to supply water on an island or mountainous area where establishing water supply systems can be difficult due to poor accessibility (Lee *et al*., 2015a). The artificial recharge site, however, has to satisfy specific topographic conditions favouring the recharge system installation hydrogeologically. In other words, different hydrogeologic factors including drainage degree in areas where water injection is performed, hydraulic conductivity, and depth from ground to water level have to be considered.

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Accordingly, this study aims to define the topographic shape favourable to the artificial recharge system based on a hydraulic model experiment and to select an appropriate region in the vicinity of Goseong-gun, South Korea for system installation using GIS (Geographic Information System) data and TOPSIS algorithm.

In the research cases regarding groundwater development using remote sensing and GIS techniques, Lee *et al*. (2006) have constructed a spatial database pertinent to hydrogeology considering numerous geological and surface features, and then performed a GIS spatial analysis to map the groundwater resources potential in Pohang, South Korea. Seo *et al*. (2011) have evaluated potential artificial recharge site using GIS with hydrogeological and social factors. In addition, Lee *et al*. (2015b) have proposed fundamental methods for the site selection of the small-scaled artificial recharge system installation considering topographic shapes that overlap soil maps, DEM, and watershed segmentation images. The integrated use of remote sensing data and GIS technology for the exploration of potential groundwater sites is very frequently found in India. The hydromorphogeological maps were produced by a combination of linearments, geological features, slopes and drainages extracted from IRS-LISS images to identify ground water recharge sites in alluvial plains (Chaudhary *et al*., 1996) or in hard rock terrains (Saraf and Choudhury, 1998). In Iran, geoelectrical method is applied to select a suitable groundwater recharging site using the specific characteristics of resistivity that the hydraulic conductivity of groundwater is variable depending on the configuration of alluvium and lithological factors of object areas (Taheri, 2008). A possible place for the installation of a well was found by extracting a linearment map generated from Landsat 7 ETM+ 7 band images that present the smashed areas used for the route of groundwater inflow (Burnett *et al*., 2011).

So far, the main approaches for groundwater development were focused on the use of large-scaled satellite and aerial images for the broad district in order to map potential groundwater regions, while this paper aims to select an optimal site for small-scaled artificial recharge system installation. Also, while research trend tends to focus on searching groundwater resource based on an in-depth rock aquifer, this study is based on alluvium which is relatively a shallow alluvial aquifer.

2. Study Method

In the first, DEM of Goseong-gun is extracted from digital maps to make a slope map with less than 2 degrees. Then, alluvial map, slope map with less than 2 degrees, and administrative demarcation map are registrated for the application of morphology operation to extract a lengthy and narrow topographic shape. In the next step, a shape file representing suitable regions for the artificial recharge system installation is generated through vectorization and, its attributes are assigned according to hydrogeologic features. Lastly, TOPSIS algorithm is applied to a shape file to place the order preference of candidate sites. The workflow is illustrated as shown in Fig. 1.

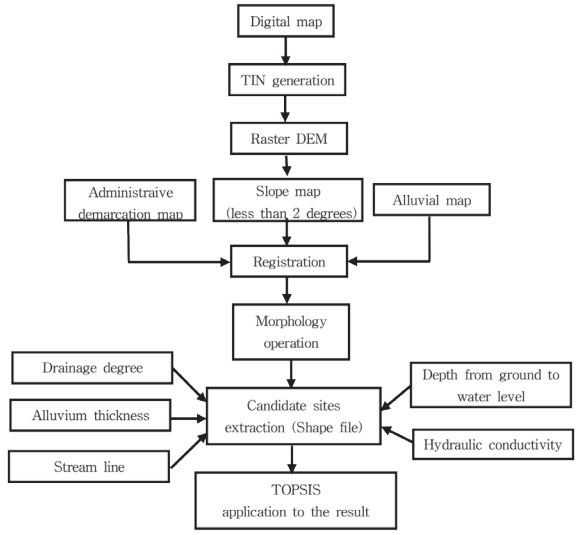

Fig. 1. Study workflow

3. Data Processing for Extraction of Candidate Areas

3.1 Study area

Although the method of optimal site selection for the artificial recharge system has to be aimed at many and unspecified regions, it is difficult to process GIS data covering

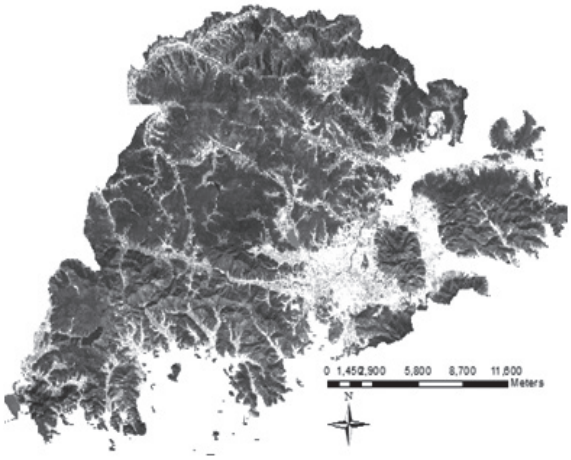

Fig. 2. Orthoimage of Goseong-gun

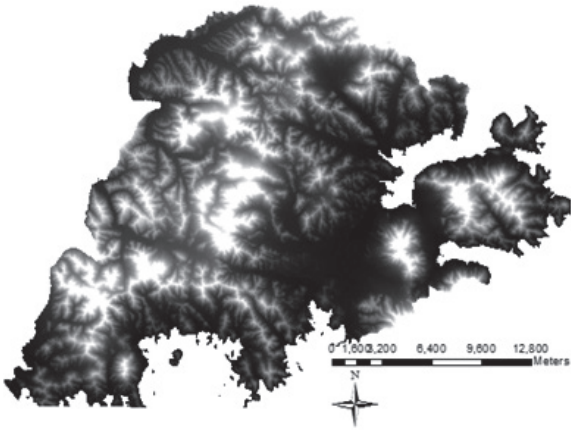

Fig. 3. DEM of Goseong-gun

the entire country. In addition, the site selection method over broad regions with an automatic way is nonexistent in the world. Therefore, the method proposed in this paper is applied to relatively small areas including Goseong-gun, South Korea. This study area is classified as mountainous areas except a few plain areas, identified on the orthoimage in Fig. 2 as well as on DEM in Fig. 3. The plain areas consist of rice paddies and farms, and water supply for a person per day is 127L, which falls short of half compared to an average of Korean water supply of 282L. The corresponding area has a lot of mountainous regions which pose difficulty in installing water supply facilities. Thus, most of the water supply systems are depending on small drinking water system.

3.2 Topographic condition for the artificial recharge site

The underground water artificial recharge site selection technique is identifying suitable areas hyrdogeologically favourable for the artificial recharge system with rainy season injection and dry season recovery to secure quality water resources. Because the geographical condition of injection areas are reflected to increase the efficiency of recovery, numerous factors such as hydraulic gradient for the procurement of an appropriate under current period, topographic shape, hydrogeologic conditions have to be considered. The artificial recharge system has an optimal recovery efficiency in a specific topographic shape. Recovery amount of artificial recharge has increased by 30% compared to the recovery amount in a natural state without injection in the shape of lengthy and narrow alluvium (Lee *et al*., 2015a). From this, the topographic shapes favourable to the artificial recharge system are defined as shown in Fig. 4.

Fig. 4. Topographic shape of optimal site

One advantage of the artificial recharge system is a self-purification capability through underground water retention. Thus, an appropriate hydraulic gradient has to be considered. As a result of examining a relationship between hydraulic features of alluvium and a geology map, less than 2 degrees is a suitable hydraulic gradient (Lee *et al*., 2015a). Therefore,

an alluvial map overlapped with a slope map extracted from DEM (Fig. 3) is shown in Fig. 5 with a black color as the first step of classification.

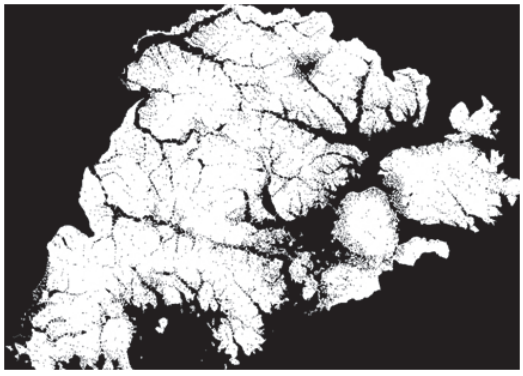

Fig. 5. Slope map with less than 2˚

3.3 Morphology operation

A morphology operation is an image processing technique to detect and extract specific features in the images such as lines, boundaries or block areas using edge operators. The suitable site for the artificial recharge system has a lengthy and narrow shape on alluvium layer marked with circles

Fig. 6. Alluvial map (Original Image)

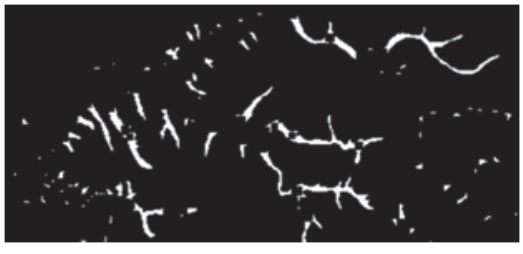

Fig. 7. Candidate areas applied with morphology operation

Fig. 8. Candidate areas (shape file)

shown in Fig. 6. Those shapes were extracted from an alluvial map in a semi-automatic way with a morphology operation. Implementation was performed using Matlab 2014 version, and the result is shown in Fig. 7. The used kernel size for an erosion and a dilation operation is fixed with 20m by 20m considering 5m cell size of the alluvial map. This is for the purpose of extracting the alluvial area with less than 100m width and larger than 40m width which is an optimal value of candidate sites (Lee *et al*., 2015a).

In next step, the extracted result of alluvial areas was transformed to a vector format with *.shp extension as shown in Fig. 8. And then the orthoimage of Goseong-gun is overlapped with 77 candidates areas extracted from an alluvial map through a morphology operation as shown in Fig. 9. The red-colored areas are the 77 candidate areas with a lengthy and narrow shape.

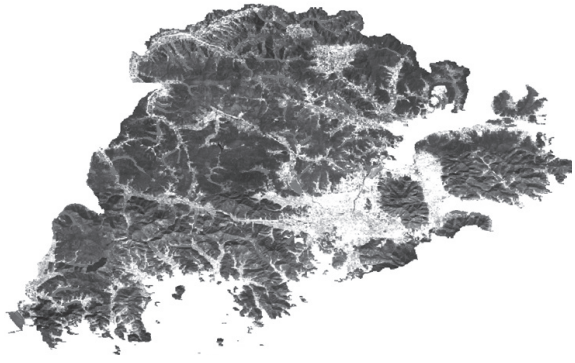

Fig. 9. Candidate areas overlapped with orthoimage

3.4 Hydrogeologic factors for the candidate sites

Some 700 polygons are originally extracted as candidate sites, most of them were represented as noises consisting of

Table 1. Hydrogeologic attributes

Administrative district	Depth from ground to waterlevel (m)	Hydraulic conductivity	Alluvium thickness (m)	Streamline	Drainage
Ga-cheon ri1	11	0.362787	5.198801	3	5
Ga-cheon ri2	8	0.416529	5.2	1	5
Na-seon ri	39.677261	0.38977	5.3	1	5
:	:	:	:	:	:
:	:	:	:	:	:
Myoeng-seong ri	23.794273	0.230534	3.176863	1	5
Sam-deok-ri1	25.025627	0.218017	7.076643	2	5
Sam-deok-ri2	212.215729	0.218152	7.026894	2	5

points. These were removed in a manual way with ArcGIS. Then, hydrogeologic criteria and their values were assigned to a shape file based on the report regarding the groundwater basic investigation in Goseong-gun (Jeong *et al*., 2013) as shown in Table 1.

Here, since deeper depth from the surface to the water level equates to an increased amount of groundwater retained, sites with deeper depth are favourable to installing the artificial recharge system. Fig. 10 shows the distribution of depth from ground to water level in Goseong-gun.

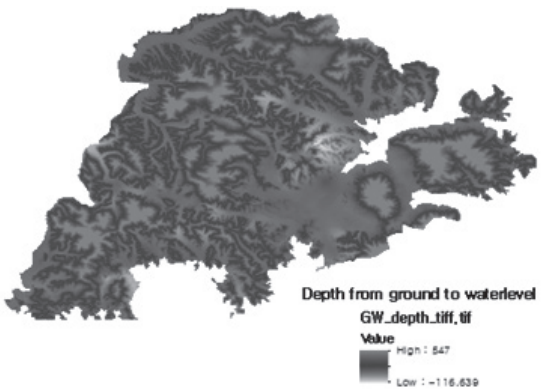

Fig. 10. Depth from ground to waterlevel

The hydraulic conductivity is defined as water permeability in the rock or soil and the higher the hydraulic conductivity, the easier it is for the groundwater to flow. According to the hydraulic model experiment (Lee *et al*., 2015a), in the case of having the highest hydraulic conductivity, the region is the most suitable site for the artificial recharge system installation. Fig. 11 shows the distribution of hydraulic conductivity in Goseong-gun.

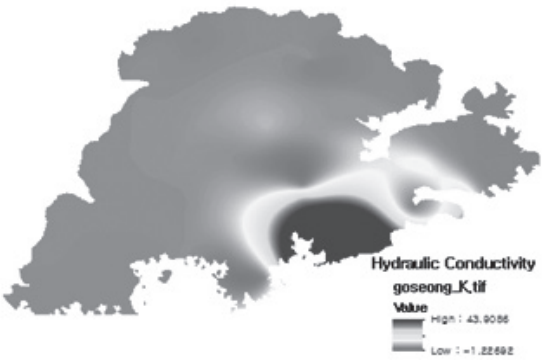

Fig. 11. Hydraulic conductivity

Alluvium is typically made up of a variety of materials, including fine particles of silt and clay and larger particles of sand and gravel. These areas have a very high probability of becoming an optimal site for the artificial recharge system installation because groundwater flow occurs through these areas and presents the moving path of groundwater. Therefore, the thicker the alluvium is, the more areas are favourable to the artificial recharge system installation. Fig. 12 shows the distribution of alluvium thickness in Goseong-gun.

The existence of a streamline in candidate sites has more positive values in TOPSIS algorithm because of the possibility of water resource in the case of precipitation. If the streamline passes along with alluvium, the value is assigned to 1, and if it

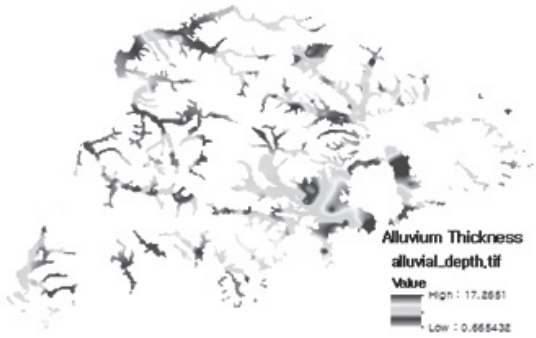

Fig. 12. Alluvium thickness

passes by alluvium, the value is 2, and it cuts cross alluvium, the value is 3. Lastly, if it does not exist around alluvium, the value is 4. Drainage attribute is to describe the degree of drainage. The more surface water drains to underground, the more candidate areas are favourable to the artificial recharge system installation due to a lot of water retention. Therefore, soil drainage degree is assigned as shown in Table. 2 with reference to a soil drainage map from Fig 13. These factors are based on a report regarding the groundwater basic investigation in Goseong-gun (Jeong *et al*., 2013)

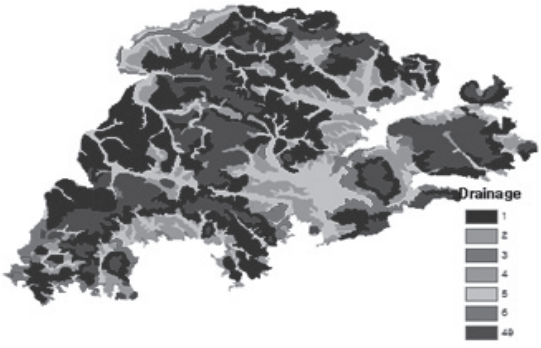

Fig. 13. Drainage degree

Table 2. Drainage level

Value	Description	Value	Description
1	Very well	5	Poor
2	Very well or well	6	Very poor
3	Well	49	Rock exposure area
4	Moderately well		

4. Optimal Site Selection Applying with the TOPSIS Algorithm

4.1 TOPSIS algorithm

TOPSIS is a technique that prioritizes the order of preference by identifying similarities. This ideal solution maximizes the benefits criteria/attributes and minimizes the cost criteria/attributes. The negative ideal solution maximizes the cost criteria/attributes and minimizes the benefits criteria/attributes. In other words, the so-called benefit criteria/attributes are for maximization and the cost criteria/attributes are for minimization. The best alternative is the one which is closest to the ideal solution and farthest from the negative ideal solution (Monjezi *et al*., 2012). On the other hand, the site selection for the artificial recharge system installation is to place the order preference of candidate sites extracted with a morphology operation based on hydrogeologic factors. The procedure for Multi-Criteria Decision Making with TOPSIS method is as follows (Monjezi *et al*., 2012).

The normalized decision matrix or R matrix is calculated with r_{ij} as the normalized value:

$$r_{ij} = \frac{x_{ij}}{\sqrt{\sum_{i=1}^{n} x_{ij}^2}} \quad i = 1, \ldots, n, j = 1, \ldots, m \tag{1}$$

The weighted normalized decision matrix with v_{ij} as weighted normalized value is calculated as:

$$v_{ij} = w_i r_{ij} = W \times R \; j = 1, \ldots, n, i = 1, \ldots, m \tag{2}$$

To determine the positive ideal and negative ideal solution:

$$A^+ = v_1^+, \ldots, v_2^+ = \{(\max_j v_{ij} | i \in I), (\min_j v_{ij} | i \in J)\} \tag{3}$$

$$A^- = v_1^-, \ldots, v_2^- = \{(\min_j v_{ij} | i \in I), (\max_j v_{ij} | i \in J)\} \tag{4}$$

Where I and J are associated with benefit and cost criteria, respectively. To calculate the separation measures, n-dimensional Euclidean distance is used. The separation of each alternative from the ideal solution is given as:

$$S_j^+ = \sqrt{\sum_{i=1}^{n} (v_{ij} - v_i^+)^2} \quad j = 1, \ldots, n \tag{5}$$

Similarly, the separation from the negative ideal solution is:

$$S_j^- = \sqrt{\sum_{i=1}^{n}(v_{ij} - v_i^-)^2} \quad j = 1, \ldots, n \tag{6}$$

To calculate the relative closeness to the ideal solution, the relative closeness of the alternative A_j with respect to A^+ is defined as

$$C_j = \frac{S_j^-}{S_j^+ + S_j^-} \quad j = 1, \ldots, n \tag{7}$$

Then, the alternatives are ranked according to their relative closeness to the ideal solution. The higher the C_j, the better is the alternative A_j. The best alternative is the one with the greatest relative closeness to the ideal solution.

4.2 Application

The attributes for depth from ground to water level, aquifer (or alluvium) thickness, streamline distribution, hydraulic conductivity, and drainage degree were defined for 77 candidate sites extracted with a morphology operation. The most optimal site is determined by calculating separation measures with these attributes, and then calculating the relative preference order through each TOPSIS step. Decision matrix is shown in Table 3, and positive ideal solution and negative ideal solution are shown in Table 4. Weight was equally assigned as 0.2, and experts' opinions from participating in Goseong-gun groundwater basic investigation are reflected to the determination of this value.

TOPSIS algorithm was applied to 77 candidate sites to place the order preference, and result is shown in Table 5. Here, Maximum value (0.82227) was shown in Dae-dok ri, and this region is regarded as the best ideal area for the artificial recharge system installation.

Table 3. Decision matrix

Weight	0.2	0.2	0.2	0.2	0.2
Administrative district	Depth from ground to water level (m)	Hydraulic conductivity	Alluvium thickness (m)	Streamline	Drainage
Ga-cheon ri1	11	0.362787	5.198801	3	5
Ga-cheon ri2	8	0.416529	5.2	1	5
Na-seon ri	39.677261	0.38977	5.3	1	5
:	:	:	:	:	:
:	:	:	:	:	:
Myoeng-seong ri	23.794273	0.230534	3.176863	1	5
Sam-deok-ri1	25.025627	0.218017	7.076643	2	5
Sam-deok-ri2	212.215729	0.218152	7.026894	2	5

Table 4. Positive and negative ideal solution

	Depth from ground to waterlevel (m)	**Hydraulic conductivity**	**Alluvium thickness (m)**	**Streamline**	**Drainage**
IDEAL SOLUTION	0.263199658	0.243935	0.03721994	0.040562	0.00511143
NEGATIVE IDEAL	3.8889E-05	0.00029021	0.00516961	0.0049	0.031025261

Table 5. Candidate site with TOPISIS

Priority	Administrative district	Depth from ground to waterlevel (m)	Hydrologic conductivity	Alluvium thickness (m)	Stream line	Drainage	TOPSIS result
1	Dae-dok ri	1	9.764747	5.080619	2	3	0.82227
2	Bong-hyun ri	3	0.371143	1.067126	1	4	0.77399
3	Hwa-dang ri	1	4.787321	7.0806	2	3	0.57418
4	Shin-yong ri	2.835378	1.638716	6.207847	2	3	0.55954
5	Sam-deok ri1	212.2157	0.218152	7.026894	2	5	0.52822
6	Sam-deok ri2	25.02563	0.218017	7.076643	2	5	0.4394
7	Byeong-san ri	4.939758	2.915955	5.611542	1	5	0.42598
8	Su-yang ri	1	0.34995	3.648398	1	5	0.40255
9	Sam-lak ri	1	0.848517	4.096068	1	5	0.36161
10	Doo-ho ri	1	0.426816	4.141301	1	5	0.34854

5. Consideration

The optimal site for the artificial recharge system installation with maximum recovery amount is defined as the regions surrounded by rocks with one course of outflow based on alluvium with a lengthy and narrow shape. All 77 candidate sites were able to be generated in a semi-automatic way with a morphology operation, and then a shape file was made with hydrogeologic factors based on the report regarding groundwater basic investigations in Goseong-gun (Jeong *et al*., 2013). From this, final 10 candidate sites were selected with TOPSIS method. In the meantime, the priority for artificial recharge system installation is based on the areas with an insufficient water supply such as mountainous areas. Therefore, a close investigation of the areas with inadequate water supply system facilities is required through field surveys. In addition, the determination of weight value in the process of TOPSIS has to be based on experts' questionnaire because the value can vary depending on the terrain and the result of questionnaire.

6. Conclusion

Alluvium is important soils used as a route of groundwater flow, thus the artificial recharge system has to be developed based on alluvium. These areas were able to be extracted from an alluvial map in a semi-automatic way through a morphology operation, and 77 candidate sites were able to be generated by overlapping with a slope map with less than 2 degrees of surface slope. A shape file was generated through vectorization, and its attributes were assigned based on groundwater basic investigation in Goseong-gun consisting of 5 hydrogeologic factors. Finally, because site selection for the artificial recharge system installation is a matter of MCDM methods, the TOPSIS algorithm was used to place the order of preference of 10 candidate sites.

Acknowledgment

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