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Selection of Optimal Locations of Groundwater Tubular Wells based on Spatial Statistical Analysis Techniques

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Abstract

Objectives: To find optimal locations for groundwater tubular wells by analyzing the spatial areas of influence in GIS to assess groundwater tubular wells and analyze their development potential. **Methods/Statistical Analysis**: The candidates of new tubular well development was selected according to the procedure of the GIS spatial analysis based on the spatial data of location, contamination vulnerability, current land usage, and topographic map of tubular wells, the GIS analysis results based on overlapping and analysis of area of influence, union data, dissolve data, clip data, and DRASTIC index. **Findings**: The rational development and utilization of groundwater tubular wells, which are an approach to secure local water supply and are expected to offer a relatively stable water supply, is a very important topic to decision-makers at local governments. Previous studies on the development of groundwater focused on the contamination and utilization features of groundwater and can thus be used as important findings to solve environmental issues, but they do not reflect the needs of groundwater development from the perspective of supply right by putting together the local characteristics. This study thus set out to evaluate old tubular wells by analyzing the spatial areas of influence of subject areas and select optimal locations for tubular wells by analyzing their development potential, thus proposing candidate locations for tubular well development and water supply amounts and providing basic data needed to make plans for local water supply. **Improvements/Applications**: The meaningful findings regarding groundwater development can serve the staff members in charge of the affair at local governments as basic data.

Keywords: DRASTIC Index, GIS, Groundwater Tubular, Spatial analysis, Topographic Map

1. Introduction

Changes to the social, economic, and natural environments are bringing about rapid climate changes and considered as major causes of frequent flash floods, heavy snow, and droughts. Such disasters, most of all, affect the right to and quality of life of citizens and thus require long-term effective countermeasures for active responses. In recent years, the frequent occurrence of national or local droughts and resulting shortage of water are opening the eyes of the people to the importance of securing water supply and managing water resources at the local level and raise a need to secure and manage water resources in a stable fashion[1,2]. It is especially needed to conduct systematic research on the development and management of groundwater to compensate for the problems of surface water, which has geographical limitations with water supply[3,4]. In South Korea, water supply depends on dams filled with rain, reservoirs, and rivers in most cases. Its annual average precipitation, however, reaches only 72% of an average year (2015 Report on Abnormal Climate by the Korea Meteorological Administration) with some areas suffering severe droughts and resulting damage of all sorts. Trying to help to solve the problems of water shortage, In [5] conducted a study on efficient utilization plans for local agricultural water related to climate

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changes. There was a study to propose required amounts and supply alternatives for emergency water on islands where the water supply system was relatively unstable compared with urban areas[6,7]. It was a very meaningful attempt to review ways of water supply during a drought by linking and managing surface water and groundwater in response to the periodic occurrence of drought and increasing demand for river water supply[8]. In addition, a study was carried out to set the priorities of groundwater contamination management to provide basic data for groundwater development and utilization according to local water shortage. Those previous studies, however, focused on water supply and environmental aspects[9–11]. Recently groundwater is regarded as an important means for water supply, but studies focus on the environmental aspects[12,13]. Groundwater tubular wells are subjected to the possibility of reckless and thoughtless development for their ease of development and to the possibilities of secondary damage according to environmental contamination and groundwater level[14,15]. They also have limitations in that they do not reflect the needs of total groundwater development and management rights from the policy- and decision-makers of local governments[16,17]. The purpose of the present study was to find optimal locations for groundwater tubular wells by analyzing the spatial areas of influence in a geographical information system to assess groundwater tubular wells and analyze their development potential as a way to secure groundwater supply according to the social and environmental conditions demanded by local governments based on the research system of Figure 1.

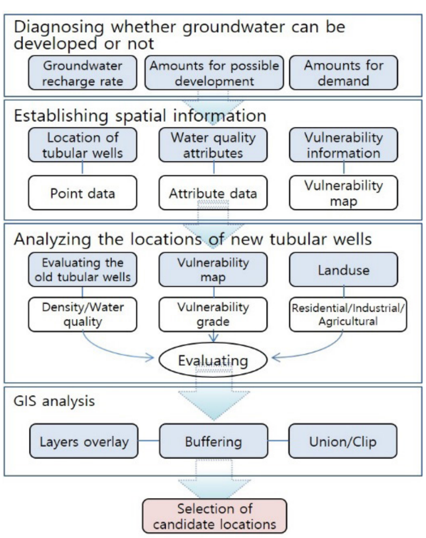

Figure 1. Research procedure diagram.

2. Securement and Evaluation of Groundwater Supply

The waterworks statistics of the Ministry of Environment show that the national average revenue water ratio (the ratio of water charged with a fee in the water supply) amounts to only 84.2%. The government is also expanding the central-focus supply system for its water supply policy by closing down local water sources (they dropped by 20% from 369 in 2002 to 309 in 2013) and drawing water from multipurpose dams. It is, however, needed to develop additional local water sources to increase the efficiency of water supply in addition to improving the water pipe network and managing the water supply system in a systematic manner. That is, there should be active efforts to secure local water supply to maintain and support a stable local water supply system. The systematic development and management of groundwater, which is capable of stable water supply compared with surface water sensitive to climate changes, is especially in need. The nation's basic plan for groundwater management (2012) also encourages the systematic development and usage of groundwater to enable the stable quantity and quality of groundwater as a sustainable water resource. The possible amounts of groundwater supply should be estimated by considering both the potential amounts of groundwater and its vulnerability to contamination. The potential amounts of groundwater supply refer to the capacity or possible water intakes of tubular wells located in the concerned area. Vulnerability of groundwater to contamination refers to its sensitivity according to the hydro geological characteristics of the aquifer. The contamination possibilities of groundwater are usually analyzed with the DRASTIC system, which is a standardized system to evaluate the contamination possibilities of groundwater in a relative fashion developed by the Environmental Protection Agency (EPA) in the United States. When trying to assess the contamination of groundwater, one needs to take into account the current state, type and other contamination vulnerability elements of sources of contamination as well as the characteristics of local media related to the spread and movement of contaminants in the aquifer. A (aquifer media), C (hydraulic conductivity of the aquifer), D (depth to groundwater table), I (impact of the unsaturated zone media), R (net recharge), S (soil media), and T (topography slope) are particular hydrogeological factors capable of tracing with GIS information and can be used to evaluate the relative influences of groundwater contamination (DARSTIC index, Equation 1).

$$DRASTIC_{index} = \sum [(D]_g \cdot D_w, R_g \cdot R_w, A_g \cdot A_w, S_g \cdot S_w, T_g \cdot T_w, I_g \cdot I_w, C_g \cdot C_w) \quad (1)$$

Here, g refers to the grade, and w to weight. The index based on the calculations with the seven DRASTIC factors reflects the contamination vulnerability of groundwater and is used in areas to assess the relative contamination vulnerability of groundwater caused by various sources of contamination in certain areas. In addition, the system can also be used as basic data to select optimal locations of groundwater wells and landfills. The present study selected the entire area of Cheonan City, Chungcheongnam Province as the research area to analyze the potential water intakes and contamination vulnerability of groundwater. As of 2015, Cheonan has a population of 571,377, an area of 636.07㎢, and a waterworks supply rate of 53.29% and 96.38% for eups and myeons (12) and dongs (18), respectively. As of 2014, the city has approximately 21,000 facilities to develop and use groundwater. Table 1 shows the current state by administrative unit. Its annual usage of groundwater is 14,267,766 ㎢ with an annual development potential of 80,481,000 ㎢ in Table 2. In an effort to analyze the current state of ground water in Cheonan based on spatial information, the study converted the locations of groundwater tubular wells into a geographical coordinate system and then a 2D point coordinate system. Those spatial data were established by linking the attributes databases of depth, planned water intake amounts, drinking purpose, and alluvial aquifer of groundwater tubular wells as shown in Figure 2. As the data show the total water supply of Cheonan is approximately 98,191,000㎢ a year with the capacity of water supply facilities recording about 136,467,000㎢ a year, which indicates that the city has enough capacity to meet the water supply needs. The recent meteorological phenomena have, however, exerted huge influences on the water reserve rate of Daecheong Dam, the major source of water supply for the city, and brought about big changes to its water reserve rate. As a matter of fact, the water reserve rate of Daecheong Dam fluctuated between 32.7% and 92.5% for the last decade with its pondage changing by approximately 891.000 (million ㎢) from 487.599 (million ㎢) to 1378.372 (million ㎢). The biggest problem is that the dam remained at about a 41% water reserve rate during the monsoon season in the summer of 2015 and stays out of the normal level (response stage) for 272 (74%) days a year. Furthermore, it slipped below the normal level for 22% of the last decade. Those numbers point to a need for proper plans to secure water supply. A space distribution map of contamination vulnerability was drawn to analyze the contamination vulnerability of groundwater used in Cheonan as shown in Figure 3. The attributes included in the space data contain the contamination characteristic factors as in Equation 1 and thus can be used to evaluate the contamination vulnerability of groundwater according to the contamination risk level. The administrative unit of the highest contamination vulnerability was Seonghwan-eup (28.15㎢), which was followed by Ipjang-myeon (22.83㎢) and Jiksan-eup (22.64㎢) in that order as shown in Table 3. The percentage of high contamination vulnerability area in the entire area, however, was the highest in Cha-am-dong (99.43%), which was followed by Eopseong-dong (99.35%) and Seongseong-dong (78.08%) in that order. That is, residential and commercial districts turned out to be vulnerable to groundwater contamination.

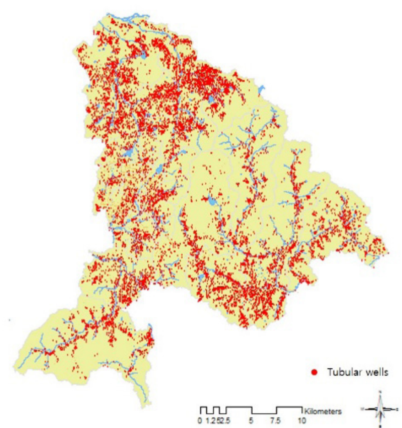

Figure 2. Current state of groundwater tubular wells in Cheonan.

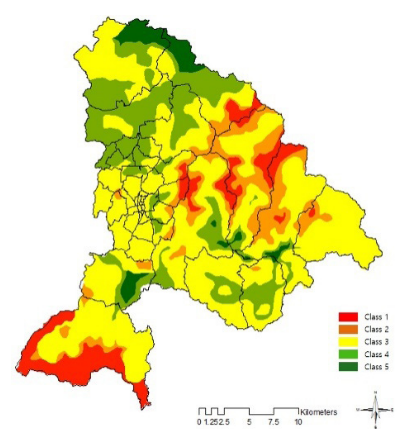

Figure 3. Contamination vulnerability of groundwater in Cheonan.

Table 1. Current state of tubular wells by administrative unit in Cheonan

Dong	Gwan - gdeuk	Guseung	Dong	Dujeong	Mokcheon	Baekseok	Byeon - gcheon	Budae	Buk	Samryong
Wells	1,476	134	945	116	1,052	170	1,012	92	904	95
Dong	Seonggeo	Seongnam	Seong - seong	Seong - jeong	Seonghwan	Susin	Sindang	Sinbu	Anseo	Eopseong
Wells	1,563	1,514	114	120	3,004	1,340	66	80	76	109
Dong	Wonseong	Yuryang	Ipjang	Jiksan	Chaam	Cheon - gdang	Cheongsu	Pungse		
Wells	181	237	3,040	2,271	149	129	10	991		

Table 2. Current state of water supply by area in Cheonan

Items	Total	Water for living	Water for industry	Water for agriculture and others
Water supply(㎢/year)	83,923,789	37,790,024	22,739,128	23,394,637
Groundwater (㎢/year)	14,267,766	2,944,768	2,363,945	8,959,063
Water intake stations	Namgwan/ Byeongcheon	Daecheong	Yongkok/ Byeongcheonwater purification plant	Simple water supply
Water supply capacity (㎢/day)	42,300	294,300	30,000	7,283

Table 3. The current distribution of contamination vulnerability of Cheonan by administrative unit

Dong	Gwangdeuk	Guseung	Dong	Dujeong	Mokcheon	Baekseok	Byeon-gcheon	Budae	Buk	Samryong
Area(㎢)	0.69	0.78	0.15	1.97	12.39	0.058	4.75	1.88	2.92	0.98
Dong	Seonggeo	Seong - nam	Seongs - eong	Seongj - eong	Seonghwan	Susin	Sindang	Sinbu	Anseo	Eopseong
Area(㎢)	13.25	6.66	2.65	0.012	28.15	9.44	2.07	0.31	1.10	3.20
Dong	Wonseong	Yuryang	Ipjang	Jiksan	Chaam	Cheon - gdang	Cheongsu	Pungse		
Area(㎢)	0.99	0.82	22.83	22.64	2.47	0.002	0.001	10.74		

3. Developmental Potential of Tubular Wells

In the past, groundwater tubular wells were developed for various purposes including agricultural and industrial water supply and ground survey for development. The old tubular wells, however, reveal a lot of problems with their systematic management and utilization since they were not developed with the environmental and social perspective in mind. The present study thus identified the elements needed to develop new tubular wells based on the old information of water supply and groundwater development. The development of new tubular wells requires the selection of optimal locations to meet the needed supply amounts for water demand and the environmental and economic perspectives Figure 1.The study analyzed the old tubular wells for location and density to select the optimal locations of new tubular well development. The number of groundwater tubular wells per unit area was 38.19/㎢. That is, the density of tubular wells was very high compared with the national average (13.9/㎢), which was applied to determine the density of new tubular wells with a radius of 150m set as the standard distance between tubular wells. The standard was also applied between an old and new tubular well in Figure 4. Excluded in the study as groundwater development candidates were the areas whose grade was 3 or higher (whose contamination vulnerability was intermediate or lower and whose

Table 4. Current state of candidates of new tubular wells

Dong	Gwan-gdeok	Guryong	Guseong	Daga	Daeheung	Dong	Dujeong	Mokcheon	Munhwa	Baekseok
Area(㎢)	58.78	1.86	1.48	0.11	0.02	22.07	0.19	35.00	0.03	1.41
Dong	Byeon-gcheon	Bongm - yeong	Budae	Buk	Buldang	Sajik	Samn-yong	Seonggeo	Seongnam	Seongs - eong
Area(㎢)	35.43	0.33	0.47	40.00	1.94	0.07	1.58	8.44	11.94	0.10
Dong	Seong - jeong	Seong - hwan	Seon-ghwang	Susin	Sindang	Sin - bang	Sinbu	Ssang - yong	Anseo	Eopseong
Area(㎢)	0.39	10.57	0.10	4.58	0.71	1.89	0.80	1.30	4.12	0.00
Dong	Yeong-seong	Oryong	Wachon	Yonggok	Wonseong	Yur-yang	Ipjang	Jiksan	Chaam	Cheon - gdang
Area(㎢)	0.01	0.00	0.03	0.78	0.05	2.95	12.25	2.18	-	1.14
Dong	Cheongsu	Pungse								
Area(㎢)	0.10	10.41								

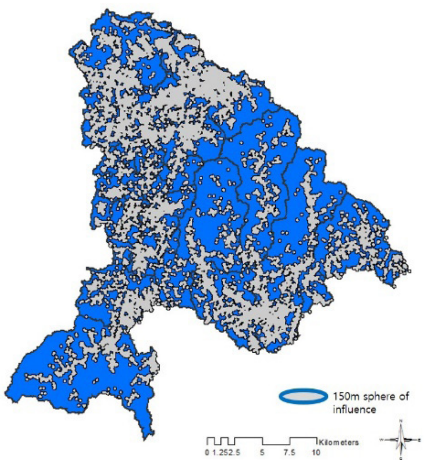

Figure 4. External areas of 150m zone of influence from a tubular well.

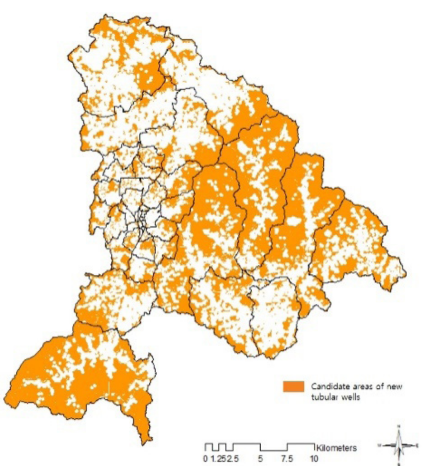

Figure 5. Candidate areas of new tubular wells.

DRASTIC was ≦ 2) on the map of contamination vulnerability (the Korea Water Resources Corporation) to assess the contamination vulnerability of groundwater, as well as the residential, industrial, river, and park districts that were the potential sources of groundwater contamination according to the current land usage. The final candidates of new tubular well development were selected according to the procedure of Figure 1 based on the spatial data of location, contamination vulnerability, current land usage, and topographic map of tubular wells, the GIS analysis results based on overlapping and analysis of area of influence (a polygon of area of influence was made for the surroundings of input data based on a certain distance), union data (geometric union calculations of input spatial data), dissolve data (consolidation of certain attribute values of spatial data), and clip data (extraction of input data with the spatial scope of overlapping clip data) as shown in Figure 5. The analysis results reveal that the candidate areas of new tubular wells were approximately 275㎢, accounting for 43.3% of the entire area of Cheonan Table 4.

4. Results and Analysis

The study conducted analysis to select the locations of new tubular wells by administrative unit of Cheonan with the spatial information and GIS analysis techniques. The analysis results were as follows: the administrative unit of the least distribution of candidate tubular wells was Chaam-dong (0%), which was followed by Eopseong-dong (0.06%), Oryong-dong (1.05%), and Wonseong-dong

(2.23%) in that order as shown in Figure 6. The administrative unit of the biggest distribution of candidate tubular wells was Gwangdeok-myeon (72.79%), which was followed by Buk-myeon (68.68%), Byeongcheon-myeon (55.43%), and Mokcheon-eup (35.00%) in that order. The administrative units that were assessed to have a relatively wide distribution of candidate tubular wells were characterized by big spatial scope (area), land usage as forests, low contamination vulnerability of groundwater, and low density of tubular wells as shown in Figure 7. The ones that were assessed to have a relatively low distribution of candidate tubular wells were, on the other hand, characterized by a broad distribution of urban and residential districts, high contamination vulnerability of groundwater, and high density of tubular wells. Those findings seem to reflect the social and environmental factors related to water demand and supply. Based on the

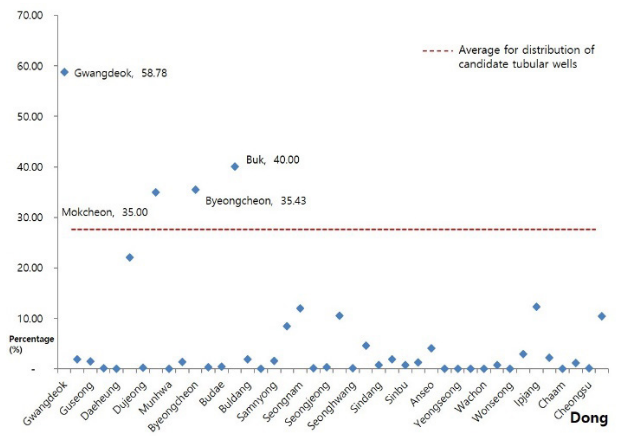

Figure 6. Distribution of candidates of tubular well development by Dong.

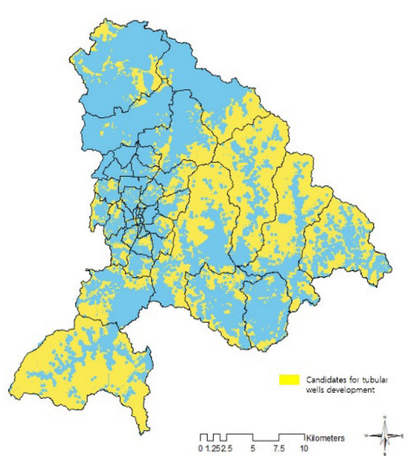

Figure 7. The distribution of candidates for tubular well development in Cheonan.

possible development area of tubular wells at 275.603㎢, it was analyzed that there could be approximately 3,800 tubular wells developed according to density (national average of 13.9/㎢). Since a tubular well had an annual usage of about 590㎥, the possible water supply from a new tubular well would amount to the same. Those results are, however, mere arithmetical calculations, which mean the local government should review the development of new tubular wells fully.

5. Conclusions

Previous studies on the development of groundwater focused on the contamination and utilization features of groundwater and can thus be used as important findings to solve environmental issues, but they do not reflect the needs of groundwater development from the perspective of supply right by putting together the local characteristics. The present study made an attempt at identifying the candidates (optimal locations) of groundwater tubular wells needed for water supply in Cheonan City, Chungcheongnam Province based on the groundwater-related spatial information and GIS analysis techniques, reaching the following conclusions: First, the findings indicate that the distribution of candidates of tubular well development was closely related to land usage by area and that the possible area of new tubular well development in the city was 275.603㎢.Secondly, the study was able to propose the number and possible water supply of new tubular wells to be developed based on the analysis results of candidates of new tubular well development. It is, however, required to apply the analysis results only after reviewing them carefully by taking the local features into consideration. Finally, the meaningful findings regarding groundwater development can serve the staff members in charge of the affair at local governments as basic data. In spite of such an achievement, however, the present study faced limitations derived from the shortage of data fit for its objectives including the difficulty with securing the accuracy of groundwater raw data and the lack of water quality data. Future study needs to supplement those limitations and conduct and expand more empirical research efforts.

6. Acknowledgement

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7. References

1. Pathak DR, Hiratsuka A, Awata I, Chen L. Groundwater vulnerability assessment in shallow aquifer of Kathmandu Valley using GIS-based DRASTIC model. Environmental Geology. 2009 Jun; 57(7):1569–78.
2. Neshat A, Pradhan B. An integrated DRASTIC model using frequency ratio and two new hybrid methods for groundwater vulnerability assessment. Natural Hazards. 2014 Nov; 76(1):543–63.
3. Sadat-Noori M, Kumars E. Groundwater vulnerability assessment in agricultural areas using a modified DRASTIC model. Environmental Monitoring and Assessment. 2015 Dec; 188(1):1–18.
4. Bai L, Wang Y, Meng F. Application of DRASTIC and extension theory in the groundwater vulnerability evaluation. Water and Environment Journal. 2012 Sep; 26(3):381–91.
5. Song SH, Choi GJ. An appropriate utilization of agricultural water resources of Jeju island with climate change (I). Journal of Korean Society of Soil and Ground Water Environment. 2012 Apr; 17(2):62–70.
6. Iqbal J, Gorai AK, Katpatal YB, Pathak G. Development of GIS-based fuzzy pattern recognition model (modified DRASTIC model) for groundwater vulnerability to pollution assessment. International Journal of Environmental Science and Technology. 2014 Nov; 12(10):3161–74.
7. Lee HJ, Park EEG, Kim GJ, Park GH. A joint application of DRASTIC and numerical groundwater flow model for the assessment of groundwater vulnerability of Buyeo-Eup area. Journal of Soil and Groundwater Environment .2008 Jan; 13(1):77–91.
8. Cha G, Jung TS, Ko IH. Validation of the surface-ground waters interaction and water supplying to upper region of Geum river basin by optimal method for drought season. Journal of the Korean Society of Civil Engineers. 2007 Jan; 27(5):507–13.
9. Kim DM. Plans for advanced cadastral content by combining cadastral information with disaster information. Journal of Cadastre. 2011 Dec; 41(2):119–37.
10. Lee MJ, Hyun YJ, Kim YJ, Hwang SH. Priority assessment for groundwater contamination management using Analytic Hierarchy Process (AHP) and GIS Approach. Journal of Soil and Groundwater Environment. 2013 Oct; 18(5):26–38.
11. Lee SR, Kim J. Analysis of groundwater pollution potential and risk using DRASTIC system. Journal of Korea Spatial Information Society. 1996 Apr; 4(1):1–11.
12. Kang JH, Park EG. A comparative application of DRASTIC and SINTACS models for the assessment of groundwater vulnerability of Buyeo area. Journal of Soil and Groundwater Environment. 2010 Dec; 15(5):32–9.
13. Mimi ZA, Mahmoud N, Madi MA. Modified DRASTIC assessment for intrinsic vulnerability mapping of karst aquifers: A case study. Environmental Earth Sciences. 2011 Jul; 66(2):447–56.
14. Yang YS, Wang L. Catchment-scale vulnerability assessment of groundwater pollution from diffuse sources using the DRASTIC method: A case study. Hydrological Sciences Journal. 2010 Oct; 55(7):1206–16.
15. Assaf H, Saadeh M. Geostatistical assessment of groundwater nitrate contamination with reflection on DRASTIC vulnerability assessment: The case of the Upper Litani Basin, Lebanon. Water Resources Management. 2008 Jul; 23(4):775–96.
16. Packialakshmi S, Deb M, Chakraborty H. Assessment of groundwater quality index in and around Sholinganallur area, Tamil Nadu. Indian Journal of Science and Technology. 2015 Dec; 8(36):1–7.
17. Singh G, Kamal RK. Assessment of groundwater quality in the mining areas of Goa, India. Indian Journal of Science and Technology, 2015 Mar; 8(6):588–95.