A Cost-Benefit Analysis of Groundwater Supply through Pumping Well Technology※

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Abstract

In Korea, there are 1,474 thousand pumping wells nationwide which account for about 12% of total water use in 2012. As much as 39 hundred million tons of groundwater were used while 333 hundred million tons of total water were supplied in 2012. Because the water management authority projects that water demand will exceed supply by 2021, the authority is planning to extensively expand groundwater use in accordance with economic feasibility. Using the basic frameworks of cost-benefit analyses of the World Bank and the US Environmental Protection Agency (US EPA), the objective of this study is to examine the costs and benefits of the expansion of Korea's groundwater extraction through pumping wells. We conclude that the BC ratio of the groundwater pumping wells is 2.98. This signifies that the benefits are 2.98 times higher than the costs. The benefits include use and non-use values of pumping wells while the costs include the installation and maintenance of new wells, in addition to the restoration and pollution costs of abandoned wells, as well as fees for water quality tests, etc.
Keywords: Pumping well, Cost-benefit analysis, Groundwater

국문요약

전국의 지하수 관정은 2012년 기준 1,474 천 개소이며 지하수 이용량이 총 용수 이용량의 12%를 차지하고 있다. 수자원장기기본계획은 2021년 전국 용수 수요가 공급을 초과할 것으로 전망하고 있어 지하수 이용이 더욱 중요한 과제가 되고 있다. 우리나라는 지하수 활용을 위한 인공함양이나 강변여과 보다 관정에 크게 의존하고 있으므로 관정의 경제성에 대한 평가가 우선적으로 이루어져야 할 것이다. 따라서 본 논문은 관정에 의한 지하수자원 활용이 경제적인지 아닌지를 분석하는 것에 목적을 둔다. 관정의 편익은 크게 3가지로 나누어 첫째, 활용가치로 음용수 및 농공용수의 공급가치, 둘째 비활용 가치로 잠재활용 대비 미래를 위한 부존가치를 포함하고 있다. 또한 비용은 관정의 설치비용 및 교체비용, 관리비용, 그리고 폐공의 환경오염 비용 등을 모두 포함한다. KDI의 수자원사업 예비타당성 가이드라인과 미국 환경청 그리고 세계은행의 지하수자원 비용-편익분석 모델을 원용하여 관정의 비용편익 비율을 계산하였다. 그 결과 지하수 관정의 편익이 비용보다 2.98배 높아 지하수 관정에 의한 지하수자원 공급이 경제성이 있는 것으로 나타났다.
주요어 : 관정, 비용-편익분석, 지하수

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Ⅰ. Introduction

1. Background and objective

Surface water and groundwater are both important resources not only for humans but for ecological systems as well. Since world-wide use of surface water has remained constant or increased slowly, the increase in global water use in recent years has been primarily based on groundwater (Calzadilla, et. al. 2010). In Korea, 88% of water use comes from surface water while the remaining 12% comes from groundwater. According to the Korean Ministry of Construction and Transportation's projection, water demand is expected to exceed the supply by 2021 (Ministry of Construction and Transportation, 2005). Therefore, the share of groundwater use has to be increased to meet this increasing demand for water. To ensure a more sustainable management of water resources, water policies need to be focused more on developing groundwater resources. Among the various means of extracting groundwater such as artificial recharge and river-basin filtration projects, we heavily depend on pumping wells in terms of the amount of groundwater extracted. However, before constructing more pumping wells, it is necessary for the water authority to verify that benefits for developing pumping wells exceed the costs in the long run.

The objective of this study, therefore, is to examine the costs and benefits of the expansion of Korea's groundwater extraction through pumping wells (hereafter called 'groundwater project'). Based on the guidelines of the Korea Development Institute (KDI) and frameworks of the World Bank and the US Environmental Protection Agency (EPA), the benefits include the use value of groundwater extracted from pumping wells and the non-use value of groundwater while the costs include the installation and maintenance of wells, in addition to the restoration and pollution costs of abandoned wells, as well as fees for water quality tests, etc.

2. Current status of pumping wells

Of the 1,475,000 pumping wells throughout the country in 2012, there were 771,000 pumping wells being used

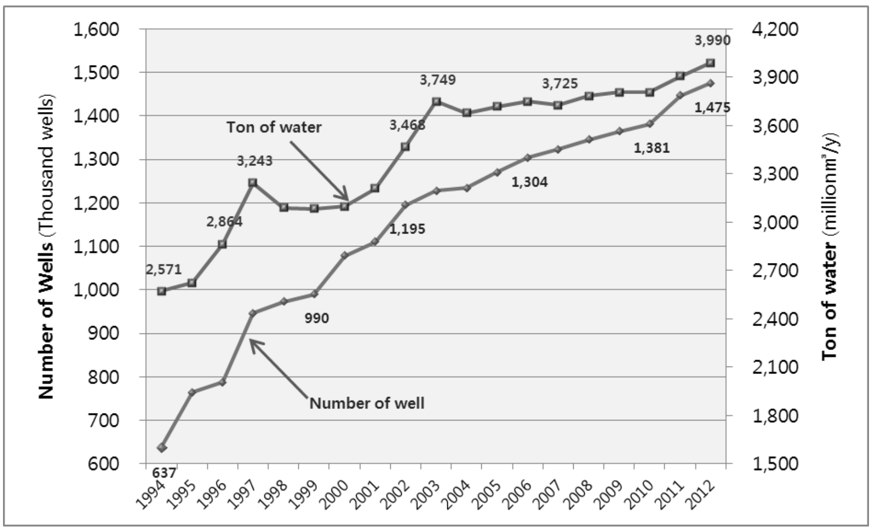

Fig. 1. Number of pumping wells and total amount of groundwater use
*source : K-Water (1995-2013), Yearbook of Groundwater

for household use (or 57.2% of the total), 561,000 pumping wells for agricultural use (41.6%), 13,000 pumping wells for industrial use (1%), and 3,000 pumping wells for other uses (0.2%) (K-Water, 1995-2013). Between 1994 through 2012, the number of pumping wells was increased from 637,000 to 1,475,000, and the amount of groundwater use was expanded from 2,571 million tons to 3,990 million tons accordingly. (Fig. 1)

Ⅱ. Model

1. A framework for the economic analysis of groundwater

In regard to the framework of the cost and benefit analysis, the US EPA model is used in order to compare the effect of the groundwater project on the quality and quantity of underground water resources, both before and after the initiation of the groundwater project, as well as to analyze any changes in the underground water supply and its economic value. As stated in the EPA report, we use the term value in a generic sense, in which the values associated with reductions in groundwater quantity or quality may be considered losses and, conversely, increases are deemed benefits. Given *ex post* or *ex ante* standing, we need to develop a technical definition of the reference condition of groundwater and identify whether the increment of change is an enhancement or diminishment of the quantity and quality of groundwater. Valuing groundwater requires a clear definition of the groundwater "commodity (US EPA, 1995)." Figure 2 summarizes the technical data required to define a groundwater

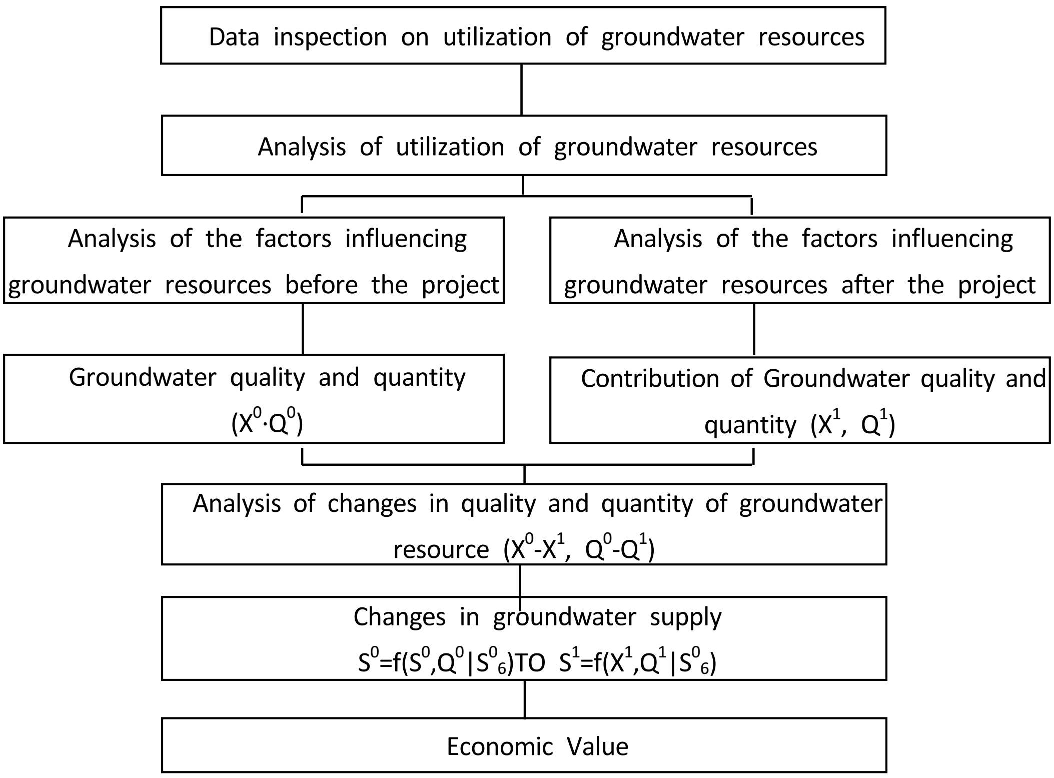

Fig. 2. Outline of the cost-benefit analysis of development of groundwater resources
*source : US Environmental Protection Agency (1995), A Framework for Measuring the Economic Benefits of Ground Water, EPA 230-B-95-003.

commodity. The first step is monitoring to assess the current or baseline aquifer condition in quantity and quality. The next step is to assess how the current quantity and quality of groundwater will change "with" and "without" increasing the number of pumping wells, which is the groundwater project that we are analyzing. The results of the assessments provide estimates of the reference (without project) water quantity (X^0) and quality (Q^0), and the subsequent (with project) water quantity (X^1) and quality (Q^1). Given estimates of the reference and subsequent groundwater conditions, we define the change in water quantity and quality (X^o - X^1, Q^0 - Q^1). The steps and linkages illustrated primarily involve the work of hydrologists, geologists, engineers, ecologists, soil scientists, and other physical and biological scientists. Investigations of groundwater conditions by these specialists must be sufficient to identify changes in groundwater services linked to the prescribed policy in a manner that facilitates the estimation of economic values.

2. Model and assumptions

Based on the above framework of the EPA and the KDI's guidelines (KDI, 2008), this study applies the benefit-cost ratio method (BCR) out of three major alternatives of cost-benefit analysis: that is, NPV (Net Present value), IRR (Internal rate of return) and benefit-cost ratio (BCR). A benefit-cost ratio represents the discounted gross benefit and the discounted total cost expressed in its present value for 50 years. Additionally, the BCR represents the cost and benefits that can be generated in the future, converted into a present value by dividing the present value of benefit into the present value of cost. A ratio value between benefits and cost exceeding one is considered a financially feasible project. Thus, the larger a benefit-cost ratio is, the more the project in question is economical. Finally, a sensitivity analysis is performed regarding the effects of the discount rate fluctuation in order to correct the various errors of estimators used in the economic analysis.

As suggested in the KDI's guidelines, a social discount rate is applied to calculate net present values of benefits and costs, and the ratio of benefits and costs is calculated with the following formula:

where B: Benefit, C: Cost, r: Discount rate, t: Time

As the cost-benefit ratio indicates how much the benefit will be per one unit of costs for the project, this method would be helpful in deciding whether the authority launches the project or not under budget constraint.

For the cost analysis, the cost items for developing a project are drawn, and then the final cost items are determined according to their logical validity. Finally, the total cost is calculated together with opportunity costs and externality costs. For the benefit analysis, too, the primary benefit items are explored first and the final benefit items are chosen depending on their logical validity (Kim, 2003). It estimates the total benefits including not only direct benefits but also indirect benefit items. The direct benefits of this project refer to use value and non-use value of groundwater resources while the indirect benefits are values provided to the ecosystem (Kim et. al., 2013).

According to the KDI's guidelines, there are several assumptions for this analysis (KDI, 2008). The first assumption regards the timespan of the groundwater project. This study assumes the time-frame for the development of the groundwater project to be from 2011-2015, and its exploitation to run from 2016-2065, i.e., 50 years after construction is completed. In other words, benefits have been assumed to be generated for 50 years after the completion of construction. The next assumption is about the social discount rate of cost and benefit. The KDI suggests 6.5% as a social discount rate for common public investment projects but argues a relatively low interest rate should be employed in the water resource project in order to bring long-term benefit. Applying the 6.5% discount rate, we accept the suggestion and apply the discount rate of 5.0% for the initial 30 years.

3. Benefits Analysis

As shown in Table 1, the World Bank's framework for the analysis of groundwater resources is employed for the benefit analysis of pumping wells (World Bank, 2007). The World Bank noted the following three major benefits of groundwater resources: (1) the supply of both drinking water and agricultural and industrial water as use value, (2) an endowment for potentially usable water in future as non-use value, and (3) a supply into the ecosystem i.e., lakes as well as rivers as indirect value.

Table 1. Use, Non-use, and Indirect Value of Groundwater Resources

Value	Benefit Sector
Use Value	Supplies drinking water as well as agricultural and industrial water
Non-Use value	Secure the potentially usable water and reserves for the future
Indirect (Ecosystem) Value	'Provides for the ecosystem, lakes and rivers

*Source : World Bank (2007), Sustainable Groundwater Management, Briefing Note Series, Note 9, p. 54.

For calculating the use value of groundwater, we measure values of drinking water, agricultural and industrial water. Employing the willingness-to-pay method, Lee (2006) derived a value function of water by quantity of drinking water (Lee, et. al., 2006). We calculated the value by plugging quantity of drinking water in the equation of the value function. To calculate the value of industrial water, we applied the above industrial production function linking total production and quantity of water used in industry. A production function of the agricultural sector is derived to calculate the value of agricultural water. As stated in the above framework, we actually calculated the values of the change in groundwater quantity and quality (X^o - X^1, Q^0 - Q^1).

The non-use value of groundwater can be calculated through a survey of the willingness-to-pay method. According to Sohn (2009), each household is willing to pay 5,654 won per month in securing the potentially usable water and reserves for the future. (Table 2)

Table 2. Benefits Items of groundwater resources

Use		Effects
1	Supply of drinking water	- Changes in welfare by the changes in quantity of supply of drinking water
2	Supply of agricultural water	- Changes in production value and production cost of crops
3	Supply of industrial water	- Changes in industrial product price and production cost
4	Maintenance and inheritance of national water resources	- Changes in individual utility

*source : Kim, Sun. G. (2013) Cost-Benefit Analyses of national groundwater resources, Research Report, Ministry of Construction and Transportation, pp. 95-157.

As shown in Table 3, net present value of benefits of pumping wells is 80,374,549 million won including use value 30,737,656 won and non-use value.

Table 3. Net present value of benefit by item

(unit: million won)

Benefit items	Net Present Value
1. Use value	
- value of drinking water	30,737,653
- agricultural productivity of agricultural water	18,620,974
- industrial productivity of industrial water	11,756,060
2. Non-use value	
- total non-use value of groundwater (existing value, value of inheritance)	19,259,862
Total	80,374,549

*source : Kim, Sun. G. (2013) Cost-Benefit Analyses of national groundwater resources, Research Report, Ministry of Construction and Transportation, pp. 95-157.

4. Costs

Developing underground water involves various costs needed for the installation and maintenance of wells and the restoration of abandoned wells. (Table 4)

Table 4. Cost items

Cost item	Item details	Data
Installation costs	Initial Installation cost	- Construction cost of wells by depth
Maintenance costs	Electricity charge	- Electricity charge by use
	Replacement cost (30years)	- Life-span of wells (survey and interview) - Estimation of the number of wells by year (2011-2060, 50years), (OLS analysis)
	Pump replacement	- pumping price by horsepower (survey and interview) - Lifespan of pumping by year (survey and interview) - Estimation of demand of pump by year
Restoration cost for abandoned-well	Removal cost of wells' caps	- Unit cost of removal cost of wells' caps - Unit cost of removal cost of casing and the imprint per meter - Unit cost of refilling by depth
	Removal cost of submersible motor pump	
	Removal cost of casing and the imprint	
	Cost of indexing and refilling	
Fee for water quality test	Water quality test for drinking water	- Cost of water quality test for drinking water
	Water quality test for other uses	- Cost of water quality test for other
Cost of groundwater's contamination (WTP)	Estimation of WTP of groundwater's contamination costs	- WTP survey of prevention expenses of underground-water's contamination per household in pumping-wells areas

*source : Kim, Sun. G. (2013) Cost-Benefit Analyses of national groundwater resources, Research Report, Ministry of Construction and Transportation, pp. 95-157.

As shown in Table 5, the net present value of the costs is 26,918,611 million won including the installation and maintenance costs of wells, the restoration costs for abandoned wells, the cost of water quality tests, and the cost of groundwater contamination.

Table 5. Net present value of cost by item

(unit: million won)

Cost items	Net Present Value
Installation cost of wells - Initial installation cost	 9,663,444
2. Maintenance cost of wells - electricity charge - replacement cost of wells - replacement cost of pump	 13,223 4,753,933 4,172,761
3. Restoration cost for abandoned wells - Removal cost of wells' caps - Removal cost of submersible motor pump - Removal cost of casing and the imprint - Cost of indexing and refilling	 30,067 2,054,193 2,819 110,561
4. Cost of water quality test - Cost of water quality test for drinking water - Cost of water quality test for other	 2,463,562 3,466,367
5. Cost of groundwater contamination - Willingness to pay for preventing groundwater contamination	 187,676
Total	26,918,606

*source : Kim, Sun. G. (2013) Cost-Benefit Analyses of national groundwater resources, Research Report, Ministry of Construction and Transportation, pp. 95-157.

III. Results and Implications

1. BC ratio and sensitivity test

Employing frameworks of cost-benefit analyses of the World Bank and the US Environmental Protection Agency, we conclude that the BC ratio of groundwater in Korea is 2.98. This signifies that the benefit is 2.98 times higher than the cost. The benefit includes use and non-use values of groundwater while the cost includes the installation and maintenance of new wells, in addition to the restoration and pollution costs of abandoned wells, as well as water quality tests.

We have done a sensitivity test to build confidence in the model by studying the uncertainties that are often associated with parameters in our BC model. Sensitivity analysis is used to determine how "sensitive" a model is to changes in the value of the parameters of the model and to changes in the structure of the model. In this paper, we focus on parameter sensitivity. Parameter sensitivity is usually performed as a series of tests in which the modeler sets different parameter values to see how a change in the parameter causes a change in the BC ratio.

For the sensitivity test of our model, we increase the target supply of groundwater by 20% as of 2060 and explore how sensitive the ratio is to change in groundwater use. The result is that the BC ratio in the new model is 3.00 as we increase usage of the amount of groundwater by 20%. This is because a higher supply of groundwater results in greater benefits than costs.(Table 6)

Table 6. Results of BC Ratio

(Unit: Million won)

Benefit		Cost	B/C Ratio
80,374,549		26,918,606	2.98
Sensitivity Test: 20% increase of groundwater supply	87,859,057	29,270,511	3.00

*source : Kim, Sun. G. (2013) Cost-Benefit Analyses of national groundwater resources, Research Report, Ministry of Construction and Transportation, pp. 95-157.

2. Implication and concluding remarks

The above BC ratio implies that the current trend of constructing pumping wells is economical, and also that the more groundwater we use the higher benefits we can acquire in the long run. From the result of the sensitivity test, we can conclude that expanding the number of pumping wells nationwide is one of the viable policy options the water authority can take to address the problem of greater water demand in the future.

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