Sustainability assessment of groundwater resources in Hanoi, Vietnam from an economic perspective

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ABSTRACT

In this study, the sustainability assessment framework of groundwater resources from an economic perspective is proposed for the first time with the focus on Hanoi current situation. An Analytical Hierarchy Process (AHP) approach here is used to generate the main components (aspects and indicators) of this framework because development of composite indicators is considered to be a unique approach for sustainability evaluation. To do this, we carefully review and explore the current problems of Hanoi groundwater resources to propose three main aspects (quantity, quality, and management) and appropriately construct their 9 macroeconomic sustainability indicators (MESI). As for the results, the sustainability indices of the quantity, quality, and management aspects were appropriately assessed as good, excellent and poor sustainability levels, respectively, resulting a good assessment for the final economic sustainability assessment.

Keywords: *AHP, MESI, Sustainability Assessment, Groundwater, Hanoi*

1. Introduction

"Act locally", but we need to "think globally". This concept has been critically emphasized for any economic sector to ensuring sustainable development of communities, cities, and countries. Water resources development is one of the major economic sectors which are nowadays getting more attention from both researchers and practitioners worldwide because ensuring safe and affordable drinking water for all is one of the universal targets of the 17 United Nations Sustainable Development Goals (United Nations, 2017).

In Hanoi, Vietnam, groundwater resources is the most important water supply sources (accounting 93% of domestic water use contribution, (HAWACO, 2014)) for the communities because most of the rivers and lakes here are seriously polluted due to the discharge of untreated industrial, agricultural, aqua-cultural, and domestic waste (Tong, 2008). The resource also significantly contributes to Hanoi industrial and service sectors with a high proportion of 77% (MONRE, 2016). Unfortunately, this groundwater recently become seriously degraded in both quantity and quality perspectives due to the rapid exploitation of the groundwater without an appropriate management. From a quantity point of view, we have not only explored the aquifer system and groundwater potential resources for Hanoi (Bui et al., 2012a) and the whole Red River Delta (RRD) where Hanoi is located (Bui et al., 2011) but also evidently showed the seriously declining groundwater levels in Hanoi central areas (Bui et al., 2012b). From a quality point of view, we have investigated the hydro-geochemical characteristics of groundwater in Hanoi and the RRD (Nguyen et al., 2014; Nguyen et al., 2015a), crucially supporting the hydro-geochemical assessment of groundwater quality during dry and rainy seasons for this target area (Nguyen et. al., 2015b) and the whole RRD (Nguyen et. al., 2015c). As for the results of a series of Hanoi groundwater quality assessment studies, the groundwater resource has been locally contaminated mainly by arsenic, coliform, and nitrogen (Berg et al., 2001; 2008; Bui et al., 2007). These serious quantity and quality degradations not only require a certain budget for groundwater abstraction and appropriate treatments but also are life-threaten the community's goal of ensuring sustainable groundwater development.

Therefore, it is necessary to measure sustainability of Hanoi groundwater resources. As one of the developing countries, economic benefits and development in Vietnam are always put at higher priorities compared to two other sustainable development goals (social and environment, Brundtland, G.H. (1987)). This research thus is first trial to assess sustainability of Hanoi groundwater resources from an economic perspective. In order to measure sustainability, the concept of sustainability assessment was defined as "...a tool that can help decision-makers and policy-makers decide which actions they should or should not take in an attempt to make society more sustainable" (Devuyst et al., 2001). Development of composite indicators is considered to be a unique approach for sustainability evaluation and sustainability indices are very useful in focusing attention and, often simplify the problem (Atkinson et al., 1997). Regarding sustainability assessment methodologies, Multi-Criteria Decision Making (MCDM) is considered to be the best approach (Boggia and Cortina, 2010), and Analytical Hierarchy Process (AHP), an outstanding MCDM, is usually used for various sustainability assessment projects including the mining sector (Bui et al., 2017; Singh et al., 2007), environmentally sustainable evaluation (Si et al., 2010), and regional water resources (Sun et al., 2016). The main advantage of those AHP applications is that they can categorize and identify the foremost components (aspects and indicators) that better reflect the significant performance. The indicator-based AHP approach is thus acknowledged as the most commonly used tool for sustainability assessment. However, there have been no studies dealing with the indicator-based AHP approach for groundwater sustainability assessment so far. It is, therefore, necessary to develop a macroeconomic sustainability indicator (MESI) set for groundwater based on the feasible AHP approach. Dealing with the abovementioned problems, this study aims to utilize the AHP concept to define an appropriate MESI set for the establishment of a groundwater sustainability assessment framework from an economic perspective. By carefully reviewing and exploring the current problems of Hanoi groundwater resources, we then appropriately assess economic sustainability of the resource and describe how the economic sustainability indices could reflect the actual situation of groundwater problems in Hanoi. The conventional AHP approach is modified to cope with the limited data availability in the target area. Finally, we discuss and suggest ideas on how to improve the sustainability assessment.

2. Study area

The geographical location and the main rivers and lakes of Hanoi are displayed in Fig.1. Hanoi is located in the northeastern part of Vietnam covering an area of 3324.5 km^2. Its population of more than 7.2 million (2015) accounts for almost 10% of Vietnam's total population, with a population density of more than 2,000 people/km^2 (General Statistic Office of Vietnam, 2015), the highest in Vietnam. Hanoi belongs to the tropical monsoonal area with two distinctive annual seasons, the rainy and dry seasons. The annual average rainfall is about 1,600 mm; the average humidity is about 80%; and the average temperature is about 24.3°C. Evaporation is quite high with an annual average of 933 mm (Bui et al., 2012a). Hanoi also has a dense river network (0.7 km/km^2) and is a part of the Red River of which the basin area is approximately 155,000 km^2. However, rapid urbanization has put great pressure on the river basin environment, and the surface water is seriously polluted (Bui et al., 2012a). Thus, groundwater becomes the most important water source, which is accounting for 93% of domestic water use contribution for the communities (HAWACO, 2014). Currently, up to 632,172 m^3/day of groundwater is exploited for water supply purpose (MONRE, 2016). Hanoi government now is trying to reduce this pressure on groundwater abstraction by establishing several surface water treatment plants to use the water resources from rivers in Hanoi and nearby.

Hanoi groundwater not only contribute to domestic water use but also contribute to industrial and service. According to MONRE (2016), approximately 693,572.7 m^3/day of groundwater is abstracted for industrial and service purposes; expecting that the industrial water demand will be about 82,000 m^3/day in 2020 (No.499/QD-TTg, March 21, 2013). According to HAWACO (2014), the largest water distribution company in Hanoi, 55% of the city's population, or 3.6 million users, have access to public water system, which is a quality-controlled source; the urban and suburban districts have 100% and 42% public water coverage, respectively. Although public water fully covers all the urban districts, about 30% of households still used freely accessed water from their private and community wells in 2010 without any quality standard (UNDP, 2010). The reason for this unreliable water use manner is due to not only the unstable water supply quantity but also their low monthly incomes compared to the monthly water bills (Lucía et al., 2017). These unexpected outcomes are as the certain consequences of inappropriate usage and management manners, threatening the economic sustainability of Hanoi City.

3. Methodology

Established in the 1970s by Saaty (2000), AHP is one of the most powerful and popular MCDM methods dealing with multifaceted and unstructured problems such as political, economic, social, and management sciences. So far, the AHP approach and its extension are usually used for sustainability assessment studies (Bui et al., 2017; Singh et al., 2007; Si et al., 2010; Yaylacı and Düzgün, 2016). The following part shows the four basic steps of AHP application and modification to assess sustainability in this study.

Step 1: Build up a sustainability hierarchy

The first step in an AHP application is to create a hierarchy by breaking it down into its aspects and indicators from the targeted MCDM problems of sustainability. In this step, the basic knowledge of the current situations, actual problems, and expected goal should be carefully considered (Randolph and Troy, 2008). To do that, decision-makers need to intensively review and study the current situation and the complex MCDM problems (in this case, economic sustainability of groundwater) to define each sustainability aspect (SA), which should cover all the features for the final goal, and break down the SA into the corresponding sustainability indicators (SIs). The SIs should be the smallest component in the hierarchy and physically measurable. Defining SAs and SIs is among the most challenging tasks in AHP sustainability application.

Figure 1. Study area and main rivers and lakes.

Step 2: Weighting process

Generally, the weights refer to the relative contributions of the components to the final goal of sustainability. The conventional way of determining these relative contributions is very tedious due to the need to (i) find the appropriate experts, (ii) wait for their big efforts to make the large series of pair-wise comparison judgments, especially in case of a large indicator set, and even (iii) ask the experts to repeatedly make the judgments until acceptably consistent judgments are obtained. In developing countries like Vietnam, however, carrying out such complicated surveys regarding groundwater sustainability seems to be difficult without enough financial support. Therefore, in our previous study (Bui et al., 2016), we modified the conventional AHP to make it simple by flexibly weighting the contribution of each SA and SI to the final goal. In this simple AHP approach, weights are derived as a function of the number of aspects and indicators. For the simplest weighting case, particularly in this study, the aspect and indicator weights are equally evaluated as the first trial by using the following equations, Eqs. (1) and (2):

$$W_A(i) = \frac{1}{N} \tag{1}$$

$$W_I(i,j) = \frac{1}{N_i} \quad (2)$$

with the constraints:

$$0 \le W_A(i), W_I(i,j) \le 1 \quad (3)$$

$$\sum_{i=1}^{N} W_A(i) = 1; \ \sum_{j=1}^{N_i} W_I(i,j) = 1 \quad (4)$$

Where $W_A(i)$: the weight of the i^{th} aspect; and $W_I(i,j)$: the weight of the j^{th} indicator in the i^{th} aspect. N: number of the aspects; N_i: number of the indicators in the i^{th} aspect; $i = 1 \ldots N$; $j = 1 \ldots N_i$;

Step 3: Data collection

The third step is to collect the data for indicator value evaluations. The raw indicator values vary; thus, in this step, a transformation method is usually needed to make the indicator values dimensionless and in the range of 0 to 1. The transformed indicator values then automatically have been considered as their sustainability indices for those raw indicators. In this study, we try to define the MESIs with their appropriate index-based definitions, the values of MESIs conceptually are in the range of 0 to 1. So that there is no need any transformation method as it is usually needed in the AHP sustainability assessment literature.

Table 1. Sustainability scale

No.	Sustainability level	Sustainability index
1	Very poor	$0 < \Omega_I, \Omega_A, \Omega \le 0.2$
2	Poor	$0.2 < \Omega_I, \Omega_A, \Omega \le 0.4$
3	Acceptable	$0.4 < \Omega_I, \Omega_A, \Omega \le 0.6$
4	Good	$0.6 < \Omega_I, \Omega_A, \Omega \le 0.8$
5	Excellent	$0.8 < \Omega_I, \Omega_A, \Omega \le 1.0$

Step 4: Sustainability assessment

The fourth step is to assess sustainability performance. Simply put, the final sustainability index is obtained from the indicator values and their derived weights. The sustainability index $\Omega_I(i,j)$ of the j^{th} indicator in the i^{th} aspect is evaluated based on the specific considerations for the aspects, indicators, and the sustainability goal. Once all the components of the sustainability hierarchy and SIF for indicators are determined, $\Omega_I(i,j)$ can be simply calculated according to the actual data. The sustainability index $\Omega_A(i)$ for the i^{th} aspect and the final sustainability index Ω are evaluated by using the following equations, Eqs. (5) and (6), respectively:

$$\Omega_A(i) = \sum_{j=1}^{N_i} W_I(i,j) * \Omega_I(i,j) \quad (5)$$

$$\Omega = \sum_{i=1}^{N} W_A(i) * \Omega_A(i) \quad (6)$$

Naturally, sustainability indices Ω_I, Ω_A and Ω are in the range of 0 to 1 and usually categorized into several classes known as sustainability scales. In this study, we adopt the sustainability scale, which is shown in Tab. 1 (Bui et al., 2016).

4. Economic Sustainability Assessment Framework for Hanoi groundwater resources

4.1. Quantity aspect and its index-based MESIs

As mentioned in the Study Area Section, Hanoi groundwater not only contribute to domestic water use but also contribute to industrial and service. It is apparently important to consider how much groundwater contributes to these economic sectors of Hanoi economic development from quantity aspect. So that for quantity aspect (AS_1), the indicator SI_{11} shows the proportion of groundwater contributed to domestic water use purpose; SI_{12} demonstrates the proportion of groundwater contributed to industrial and service purposes. For the third indicator, SI_{13}, we focus on how much water is efficient for use. The reason is that even the excessive groundwater abstraction has caused serious groundwater-level declines, the public water utilities failed to supply urban districts approximately every two days per month (HAWACO, 2016). The water loss is reported at the high rate of 38% in Hanoi due to the inappropriate pipe system (ADB, 2010). By these index-based definitions, the MESI values are in the range of zero to one. Those indicators of the first aspect (SA_1) and their index-based definitions are shown in Tab. 2

4.2. Quality aspect and its index-based MESIs

From a quality point of view, as mentioned in Hanoi groundwater situation literature review, the resource is seriously polluted. Thus we firstly focus on how much monetary need is looked-for groundwater remediation (SI_{21}). SI_{21} in this case is defined as one minus the ratio of the remediation cost for GW contamination to Hanoi GDP on average.

Table 2. Economic sustainability assessment Framework for groundwater in Hanoi

Aspect	Indicator	Consideration	Index-based definition	Benefit/ Cost
Quantity (SA_1)	SI_{11}	Domestic water use contribution	Groundwater as a percentage of the Hanoi total water use for domestic purpose	Benefit
	SI_{12}	Industrial and service water use contribution	Groundwater as a percentage of the Hanoi total water use for industrial purpose	Benefit
	SI_{13}	Effective water use	Effective water as percentage of the total water supply	Benefit
Quality (SA_2)	SI_{21}	Groundwater remediation cost	One minus the ratio of the remediation cost for GW contamination to Hanoi GDP on average	Cost
	SI_{22}	Water-related disease cost	One minus the ratio of the estimated loss from water-related diseases to Hanoi GDP on average	Cost

Management (SA_3)	SI_{31}	Public water coverage	Ratio of the coverage from the public water distribution network	Benefit
	SI_{32}	Annual investment	Ratio of the annual investment in water supply per capita to the estimated unit costs for water supply facilities	Benefit
	SI_{33}	Affordable water	One minus the ratio of the maximum water prices to the average capital income	Benefit
	SI_{34}	Willing payability	Ratio of residents' willingness to pay for improving the water supply system to their average income	Benefit

For the second indicator of quality aspect, according to Economics of Sanitation Initiative of Water and Sanitation Program of World Bank (2012), 260 million USD is estimated for Vietnam economic loss because the communities' health problems are closely related to the low-quality water use. So here we consider how much the communities need to pay for their water–related disease treatment (SI_{22}). SI_{22} is defined as one minus the ratio of the estimated loss from water-related diseases to Hanoi GDP in a target year. These indicators are important in terms of groundwater quality because the demand for clean and safe water has become urgent not only in Vietnam but also in all developing countries (JICA, 2016). By these index-based definitions, the economic sustainability values of the MESIs in the SA_2 aspect are also in the range of zero to one (Tab. 2).

4.3. Management aspect and its index-based MESIs

Water resources development is derived and controlled by two main management powers, the local government and communities. Regarding government side, we here consider how the local government manages and improves the public water supply as the stable quantity and controlled quality sources for the community. Based on the current eco-social situation, the first indicator (SI_{31}) refers to public water coverage. This indicator reflects how much the distribution network can reach the community. The second indicator (SI_{32}) in this aspect is related to the annual investment per capita compared to the required unit cost for water supply facilities. This indicator shows how much the government cares about water resources development sector in terms of budget allocation. Regarding the community side, we here also consider how the community responds to the management and water-related policies, and how ready the community is for better water use. So that the third indicator (SI_{33}) of this aspect, we consider whether the current water is affordable or cheap enough compared to the average household income of the communities. The maximum water prices is somehow reaching 28% of the average income of Hanoi's population, considering 104.00 USD per month (UNDP, 2010). This water price-income relation apparently causes pretty much difficulty for the households whether they want to use the better quality water sources. For the last indicator in the community side, we define the SI_{34} as the ratio of residents' willingness to pay for improving the water supply system to their average income. SI_{34} thus shows not only the degree of public awareness but also how ready the communities are for a better quality water use. By these index-based definitions, the economic sustainability values of the MESIs are also in the range of zero to one (Tab.2).

Finally, three main sustainability aspects (quantity, quality, and management) and their respectively three, two, and four corresponding MESIs are proposed and defined to build up the economic sustainability hierarchy for Hanoi groundwater mainly based on the current problem consideration (Tab. 2).

5. Results and discussion

The primary data sets come from various sources, such as the Vietnamese government database, local and national environmental agencies, public and private research institutions, and our questionnaire survey investigations. After the weights for the aspects and indicators are obtained from Eqs. (1) and (2), the sustainability indices for Ω_A and the final economic sustainability index Ω are calculated by Eqs. (5) and (6), respectively. Those resulting sustainability indices are shown in Tab. 3 and their visualization is shown in Fig.2. In terms of quantity aspect (SA_1), the indicator SI_{11} is assessed at the excellent sustainability level of 0.93 according to the sustainability scale shown in Tab. 1, indicating that the majority of Hanoi domestic water use is abstracted from groundwater resources. The groundwater also significantly contribute to the water consumption of industrial and service activities with the good sustainability index of 0.77. These evaluations reveal the vital role of groundwater resources in Hanoi economic development. The indicator SI_{13} is assessed at the good sustainability level of 0.62, suggesting that the main part of water is effectively used. So that the good sustainability level is economically assessed for the quantity aspect with the index $\Omega_A(1)$ of 0.77 (Tab. 3 and Fig.2).

Similarly, in terms of quality, SI_{21} and SI_{22} indicators regarding groundwater remediation and water–related disease costs are assessed at the good and even excellent economic sustainability levels of 0.74 and 0.99, respectively. These economic sustainability indices show that the economic loss due to the adverse impacts of contaminated groundwater to human health are negligible for a short term consideration (in this case, a year as the index-based definitions of SI_{21} and SI_{22}). However, the groundwater is seriously polluted in the literature and it was estimated that 10 million people in the Red River Delta where Hanoi is located are affected due to arsenic exposure (Berg et al., 2011) for instance. Therefore, these economic sustainability assessments suggest that the MESIs of SA_2 should be considered in a long term period to see clearly how significantly the economic loss will be due to the currently severe groundwater contamination in Hanoi. The quality aspect is economically assessed at the excellent level (Tab.3 and Fig.2).

In terms of management aspect (SA_3), two of four indicators, $SI_{31}$and SI_{33} are assessed at the more than acceptable sustainability level, showing that the public water system cover about two-thirds of Hanoi communities and in a number of households, up to one-thirds (30%) as the maximum of their monthly incomes are spent for water consumption. In comparison with the "water bill-average household income" percentages in Japan of 0.15% (2016), and in United Kingdom and Wales of 1.50% (2016) (City-Cost, 2017; Water UK, 2018), we could see how extremely hard Hanoi communities need to afford for their monthly water bills based on their own monthly incomes at the present water prices. Two other indicators (SI_{32} and SI_{34}), however, are economically assessed at almost the poorest sustainability level, correspondingly reveal that the current investment for the public water system improvement is almost nothing compared to the current needs, and the willing contribution from the communities for a better water use is also too small based on their own incomes. Because in the fact that Vietnam's annual investment in water supply and sanitation is less than \$2 per capita per year, which is almost nothing compared to the required unit cost for water supply facilities of \$113 per capita (World Bank, 2006; 2010). The sustainability index of SI_{32} evidently shows a significant deficit in investment for water supply facilities in Hanoi and Vietnam also. As a result, the economic sustainability index of the management aspect is assessed at the poor level of 0.36.

Table 3. Economic sustainability assessment for Hanoi groundwater resources.

Aspect	Indicator	Indicator value	Economic sustainability assessment		
			Ω_I	Ω_A	Ω
Quantity (SA_1)	SI_{11}	0.93	0.93	0.77 (Good)	0.66 (Good)
	SI_{12}	0.77	0.77		
	SI_{13}	0.62	0.62		
Quality (SA_2)	SI_{21}	0.74	0.74	0.87 (Excellent)	
	SI_{22}	0.99	0.99		
Management (SA_3)	SI_{31}	0.68	0.68	0.36 (Poor)	
	SI_{32}	0.02	0.02		
	SI_{33}	0.72	0.72		
	SI_{34}	0.001	0.001		

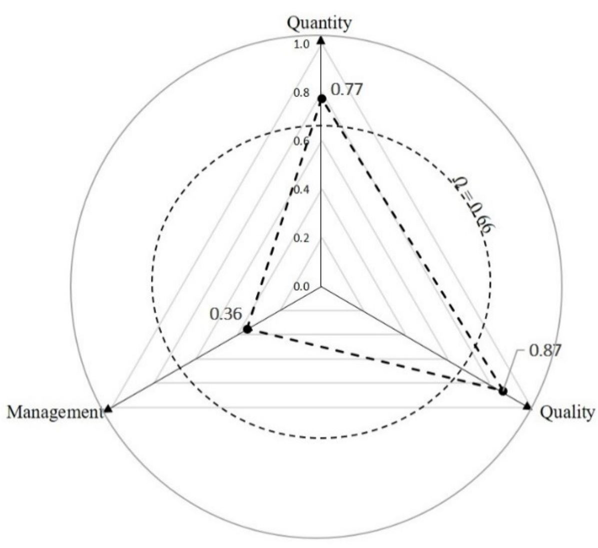

Figure 2. Visualization of economic sustainability assessment.

Consequently, the economic sustainability index Ω of Hanoi groundwater is assessed at a good sustainability level of 0.66 (Tab. 3). In Fig.2, the economic sustainability indices for the three aspects are shown as a dashed line triangle in the radar chart. The final economic sustainability index Ω is also shown as the dashed line circle with the radius equal to Ω value.

6. Conclusions

In this study, we carried out sustainability assessment of groundwater resources in Hanoi from an economic perspective. To do that, we modified the most tedious weighting process in the conventional AHP approach to cope with the limited data availability in Hanoi. We here practically proposed the three main aspects (quantity, quality, and management) and their corresponding three, two, and four MESIs, which appropriately represent the current economic situation of Hanoi groundwater. We have successfully assessed the sustainability of groundwater in Hanoi from an economic point of view.

As for the results, the quantity, quality and management aspects are economically assessed at good, excellent and poor sustainability levels, respectively, resulting a good assessment for the final economic sustainability index. The results not only (i) confirm the vital role of the groundwater resource in Hanoi economic development; (ii) reveal the significant investment deficit for water supply facilities; but also (iii) suggest that MESIs of the quality aspect should be considered in a long term period to show more accurately significant loss due to the currently serious situation of Hanoi groundwater problems. These findings are indispensable for any further sustainability assessment of groundwater resources.

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