Social Sustainability Assessment of Groundwater Resources in Hanoi, Vietnam by a Simple AHP Approach

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Abstract. In Hanoi, Vietnam, the people heavily depend on groundwater resources for both domestic and industrial uses due to the seriously polluted problems occurred in most of the river streams system. Considering the social dimension in the context of sustainable development is a key issue in groundwater resources management. The main object of this study is to assess the social sustainability of groundwater resources in Hanoi by applying a simple Analytical Hierarchy Process (AHP) approach. By applying the simple AHP, the most important task is to comprehensively study the current social situation and actual problems to define the appropriate foremost components contributing to the sustainability goal. In this study, we successfully not only select the appropriate list of three main social sustainability aspects including the quantity, quality and management aspects and the twelve core social sustainability indicators but also appropriately assessing the sustainability of the groundwater resources from the social point of view. By gathering the data from trusted sources, the groundwater quantity, quality, and management aspects are socially assessed at a good level of 0.65, a good level of 0.61 and a slightly acceptable level of 0.46, respectively. The composite social sustainability index, *S*, is assessed at a strongly acceptable level of 0.57, indicating that Hanoi's groundwater resource is socially acceptable. The results of SSA are not only sensitive to data availability but also the definition of the indicators. The linear relationships do not reflect the actual situation well and the non-linear ones could be used to replace these sustainability scales of the actual values. The social sustainability indices are evaluated at the moderately high values, improbably reflecting the current problems in the target area. The study then points out the main research gaps and suggests the ways to improving social sustainability assessment for the better groundwater resource development.

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1 Introduction

1.1 Groundwater Sustainability Issues in Hanoi, Vietnam

Sustainable development has been defined as a process that "meets the needs of the present without compromising the ability of future generations to meet their own needs" (Brundtland 1987). This concept has nowadays become one of the critical global issues for humankind and all application fields. In terms of water resources management, ASCE (1998) defined that "s*ustainable water resource systems are those designed and managed fully contribute to the objectives of society, now and in the future, maintaining their ecological, environmental, and hydrological integrity*". The proper management of water resources is very important to ensure a sustainable socioeconomic development of every country all over the world (Hutton and Bartram 2008; UNESCO 2009). Specifically, in terms of groundwater resources management, 'groundwater *sustainability*' may refer to the way of development and use of groundwater resource, in which the resource can be preserved for an indefinite time without causing any adverse eco-environmental and social consequences (Alley *et al.* 1999). Put simply, sufficient quantity and quality groundwater at acceptable prices should be available to meet social demands for domestic, industrial, agricultural, environmental purposes of the region now and in the future without causing the environment degradations such as land subsidence, saltwater intrusion, and so on (Plate 1993). Since groundwater resources play a key role in public water supplies around the world and the amount of groundwater abstraction has been rapidly and continuously increasing, achieving sustainable management of groundwater resources is one of the essential objectives for the future of countries (Mende *et al.* 2007).

In Hanoi, Vietnam, the river-streams system is pretty dense, but most of the main rivers and lakes are seriously polluted (Tong 2008) due to the discharge of industrial, agricultural, aqua-cultural and domestic waste to the water bodies without treatment. As described by United Nations University (2015), the water quality in the rivers inner city Hanoi is organic pollution, eutrophication, microbial contamination at a high level and signs of heavy metal pollution including Fe and Cr^{6+}. Specifically, regarding the surface water quality in the rivers, dissolved oxygen concentration (DO) is low, below the level of development of some species (> 4); BOD5 and COD contents beyond the allowable limit of National Technical Regulation (NTR) from 1.1 to 20 and from 1.1–10 times, respectively, indicating that the organic pollution level is high; and about the heavy metal pollution, there are a considerable percentage of the samplings including Fe and Cr^{6+} concentrations exceeding NTR from 1.1 to 20 and from 1.3 to 4 times, respectively. That is why groundwater resources are the main water supply sources for the local residents. Recently, up to 93% of the public water supply (not private) is provided by 13 main treatment water plants which are extracting groundwater as their main sources and the Song Da water plant, which obtains its water from the Da River, contributes about 7%, equivalent to 43,000 m^3/day only (Hanoi Water Company 2013). The resource is the target area addressing the sustainability issues because the use and development of the main water supply systems obviously have a big effect on economic development, environmental protection, and social needs. In terms of quantity, there have been a number of our previous Hanoi-targeted studies comprehensively investigated groundwater potential resources (Bui *et al.* 2012a) and level trends in Hanoi (Bui *et al.* 2012b); presented the current situation of groundwater abstraction from sustainability point of view (Bui *et al.* 2016a). The rapid exploitation of the groundwater without an appropriate management system has caused a series of adverse impacts such as drying up of shallow wells, decline of groundwater level and land subsidence (Tong 2008; Bui *et al.* 2012a). In terms of quality, furthermore, we have studied about hydrogeochemical assessment of groundwater quality during dry and rainy seasons for the two main aquifers (Nguyen *et al.* 2015a); clustered hydrogeochemical groundwater data comprising major ions to investigate the seasonal and spatial hydrogeochemical characteristics of groundwater in the Pleistocene confined aquifer of the Red River Delta where Hanoi is located (Nguyen *et al.* 2015b). However, there have been very few such studies dealing with the integrated sustainability assessment of the groundwater resources, in which we (Bui *et al.* 2016b) mainly focused on sustainability assessment from the environmental point of view as one of the very few examples newly investigated in this area. To date, the integrated social sustainability assessment has not been carried out yet even though the human wellbeing and the public supports are essential for successful implementations of any water-related projects and policies.

1.2 Social Sustainability Assessment of Groundwater Resources

In order to meet their ever increasing needs, humankind continuously and progressively extracts and exploits natural resources. In terms of groundwater resources, people withdraw the natural resources for their daily life activities, develop the advanced techniques to more efficiently abstracting the resources and discharge the wastewater sources after use to make the groundwater quality anthropogenically degradable beside the natural causes. One day, the resources are over-exploited because of the continuously increasing social needs; drying up of shallow wells, a decline of groundwater level and even land subsidence have probably occurred; the resource becomes polluted and adversely affects to the human well beings. To adapt these situations, protecting the natural groundwater resources and using the various treatment methods to make it cleaner appropriately are used. While sustainable development is a concept composing of the environmental, economic and social criteria; it is acknowledge that social dimension has received less consideration in comparison to the other criteria (Vallance *et al.* 2011). The other important thing is that public supports are essential for successful implementations of any water-related projects and policies; and there has been a need to better understand public attitudes toward water resource management (Randolph and Troy 2008; Dolnicar and Hurlimann *et al.* 2011). Therefore, considering the social criteria in the context of sustainable development is a key issue in the groundwater resources development.

Social sustainability is defined as "*ensuring the sustenance of the diverse social relations that exist in healthy communities, creating the physical, cultural and social places that support wellbeing and a sense of community involves a process of engagement with the people who inhabit those places.*"(Palich, and Edmonds 2013). So that which methods are used to measure the social sustainability appropriately. To this end, Multi-Criteria Decision Making (MCDM) methods have been considered proper for sustainability assessment (Boggia and Cortina 2010). In such MCDM applications, principles are general conditions for achieving sustainability, which may be seen as the ultimate goal. Hence, sustainability should be formulated as a general objective to be achieved. The goal may be reviewed as the three fundamental pillars of sustainability including environmental, social, and economic criteria while sustainability indicators provide measures of change in the criteria over time. The purpose of sustainability indicators for an industry is to provide information on how it contributes to sustainable development (Azapagic 2004). The indicators should be easy to measure, cost effective, accommodate changing conditions, scientifically sound, and based on functional ecological relationships (Worrall *et al.* 2009). In this way, indicators can provide information for policy makers and aid in decision making (Niemeijer and de Groot 2008). Therefore, finding out the important social sustainability indicators is one of the main tasks for social sustainability assessment. What are the main components presenting for social sustainability achievements since the social sustainability indicators are context dependent and need to reflect the nature and requirements of the local community (McKenzie 2004)? Chan *et al.* (2008) found out the six critical factors for improving the social sustainability of the urban renewal project by collecting the results from a questionnaire given to planners, property development managers, and local citizens in Hong Kong. The six factors are listed up as "*satisfaction of welfare requirements*", "*conservation of resources and the surroundings*", "*creation of harmonious living environment*", "*provisions facilitating daily life operations*", "*form of development*" and "*availability of open spaces*". Interpretations of those factors for groundwater resources development, the social sustainability indicators should reflect the facilities of the water supply system for the local residents, the social satisfactions of groundwater quantity and quality as well, and the effects of the quantity and quality on human safety and health. More importantly, in terms of water supply system management, the local government have a vital role in driving the society toward sustainable development. They should manage the appropriate national/provincial/local budget to maintain the system, raise public awareness of water resources conservation and security and also understand the needs of local residents to make sure their policies and strategies effective.

Similarly in Hanoi, while there have been a series of our previous Hanoi-targeted studies and others focusing on the groundwater quantity (Bui *et al.* 2012a; Bui *et al.* 2016a, b), decline of groundwater level (Bui *et al.* 2012b), groundwater quality such as groundwater arsenic, coliform, and nitrogen contaminated situations (Berg *et al.* 2001; 2007; Bui *et al.* 2007; Bui *et al.* 2010; Nguyen *et al.* 2012; Nguyen *et al.* 2015a, b), etc., there have been a few studies regarding how these changes adversely affecting the human safety and health, and almost no studies mentioned the relative measurement of the social sustainability. For instance, Berg *et al.* (2001; 2007) presented a threat of arsenic contamination of the Red River alluvial tract in the city of Hanoi. The research indicated that several million people consuming untreated groundwater sources might be at a considerable risk of chronic arsenic poisoning. We (Bui *et al.* (2007; 2010)) presented the prevalence of arsenic contamination in both two main aquifers in Hatay province (now is combined into Hanoi) and its health effects on the community with the supports of GIS and Mathematical model. Recently, Agusa *et al.* (2014) shows the another evidence of human exposure to arsenic from drinking water in three rural districts of Hanoi via investigating and analyzing the human hair and urine samples as the bio-indicators for arsenic exposure. However, these limited number of papers mainly focus on the warnings of health and safety risks caused by the arsenic contamination while the effects of the water resources on society broadly consist of not only that but also other contamination agents such as coliform and nitrogen; the social satisfactions of groundwater quantity, quality, facilities, the effects on human wellbeing and management in terms of sustainability.

1.3 Analytical Hierarchy Process (AHP) Approach

The MCDM methods have been considered as a proper approach for sustainability assessment (Boggia and Cortina 2010). AHP is one of the most popular and powerful MCDM methods (Saaty 2000) because it can help decision makers to cope with multifaceted and unstructured problems such as environment, economic and social. The AHP has been used as a widespread decision-making analysis tool for modeling unstructured problems in areas such as political, economic, social, and management sciences (Yu 2002). AHP has been utilized in a variety of sustainability assessment for a number of application fields including regional water resource (Sun *et al.* 2016). The main advantage of those applications is to categorize and identify the foremost components (aspects and indicators) that better reflect the significant performances. The indicators have been considered as an important communication tool for policy-makers, managers and the public (Chen *et al.* 2015). However, there have been very few such studies dealing with sustainability assessment of groundwater resources, in which Chen *et al. (*2015) focusing on Hohhot Plain in China as one of the very few examples investigated in the semiarid regions where the annual precipitation is about 408 mm only. There have been no social sustainability assessment (SSA) studies carried out by this outstanding MCDM method for groundwater resources so far.

Dealing with these above-mentioned problems and in order to assess the social sustainability degree for Hanoi's groundwater resources, this paper utilizes the simple AHP to properly weighting the sustainability contribution of the components. This study develops the SSA framework in checking with the actual data's availability and assesses the sustainability from the social point of view. Based on the discussion in the social sustainability assessment (SSA), the paper provides the useful recommendations to improve SSA's performance. The results are fundamental for further integrated sustainability assessment for groundwater resources in Hanoi.

2 Study Area

Figure 1 shows the geographical location and the main rivers and lakes of Hanoi. Hanoi is located in the north-eastern part of Vietnam with the area of 3324.5 km^2. The population of more than 7.2 million (as of 2015) accounts for almost 10% of Vietnam in total with the highest density of more than 2 thousands people/km^2 (General Statistic Office of Vietnam 2015). Hanoi belongs to the tropical monsoonal area with two distinctive seasons in the year, the rainy season from May to October and the dry season from November to April of the following year. The annual average rainfall is about 1,600 mm, the average humidity is about 80%, and the average temperature is around 24.3°C. Evaporation is quite high with an annual average of 933 mm. Hanoi also has a dense river network (density of 0.7 km/km^2) and is mainly supported by Red River, one of two biggest river systems, with the basin areas of approximately 155,000 km^2. However, the fast economic development and socialization and urbanization have put pretty much pressure on the river basin environment. This surface water system is recently seriously polluted due to a large amount discharge of untreated sewage, industrial waste, and garbage, in which, the lakes are significantly polluted (Tong 2008). The water quality in the rivers is organic pollution, eutrophication, microbial contamination at a high level and signs of heavy metal pollution including Fe and Cr6+ (United Nations University 2015). That is the main reason why the groundwater resources have become the most important water supply for the local inhabitants.

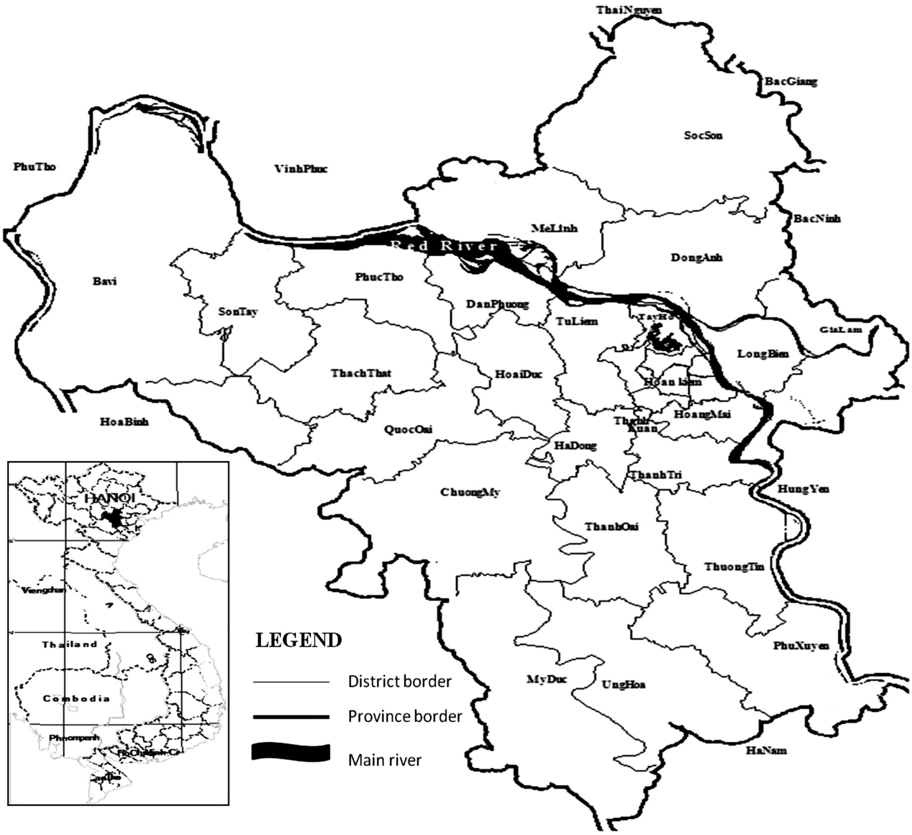

Fig. 1. Study area and main rivers

3 Methodology

Established in the 1970s by Saaty, AHP is one of the most powerful and popular multi-criteria decision-making methods dealing with multifaceted and unstructured problems such as political, economic, social, and management sciences (Yu 2002). To apply AHP, at first step, decision makers need to study the current situation of the complex multiple criteria decision problems (for example, social sustainability) to create the appropriate hierarchy by breaking down it into its aspects and the corresponding indicators in each aspect. Secondly, the relative contribution of the indicator and aspect to the final goals are defined by series of the consistent judgments from the experts. Based on the results of AHP, decision makers could see which aspects and indicators should/shouldn't be improved to enhance the sustainability performance.

3.1 SSA for Groundwater Resources by the Simple AHP

Figure 2 shows the basic evaluation steps in SSA evaluation based on the simple AHP proposed by Bui *et al.* (2016b).

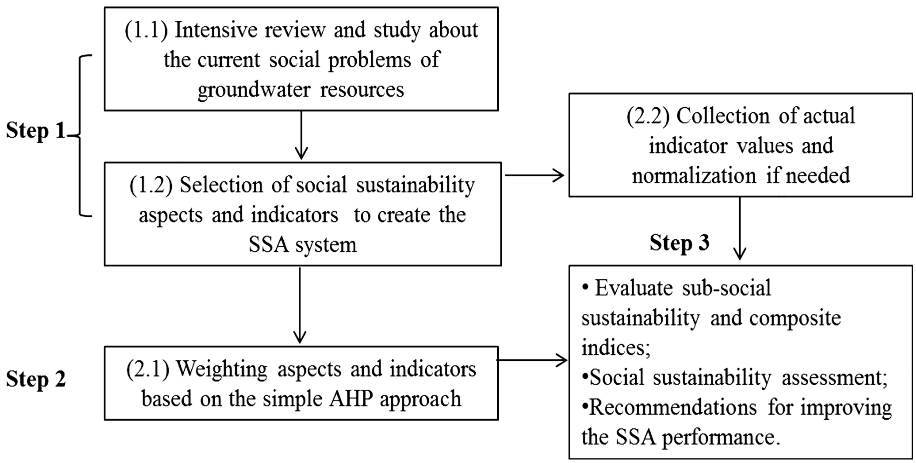

Fig. 2. Social sustainability assessment (SSA) based on the simple AHP approach.

Step1: *Establishing the multiple-level hierarchy*

Decision makers need to study the current situation of the complex multiple criteria decision problems (social sustainability) to create the appropriate hierarchy by breaking down it into its sustainability aspects and the corresponding sustainability indicators in each sustainability aspect.

Step 2:

– The relative contribution of each aspect and indicator to the corresponding goals are defined by the expert's comparison judgments in the standard AHP. In the standard

AHP, the performance ratings and the weights of the attributes result from series of pairwise comparison judgments between two attributes at the same level of the hierarchy, which are given in crisp numbers from 1 to 9. Practically, it is difficult to extract precise data pertaining to measurement factors because human preferences normally include a degree of uncertainty and it is unrealistic to expect that decision-makers have either complete information or a full understanding of all aspects of the problem (Boender *et al.* 1989). Therefore, these judgments are the 'unconfident pair-wise comparison judgment. The second step is considered as the most practically time-consuming and complicated due to several reasons such as: finding the appropriate experts; waiting for their big efforts to make the large series of the unconfident pair-wise comparison judgments; making these judgments again and again until they become acceptably consistent (Saaty 2000). In Hanoi, however, there are no such complicated surveys carried out to consult the expert's opinions regarding groundwater sustainability assessment. In order to cope with above-mentioned problems, we aimed to modify the standard AHP to make it simple in the way of properly weighting the contribution of each sustainability component to the final goal.
– A collection of actual data values for all the indicators.

Step 3: The social sustainability index (SA_i) of the i^{th} aspect is evaluated by the Eq. (1) and the composite index for social sustainability assessment, S, is assessed by the Eq. (2).

$$SA_i = \sum_{j=1}^{N_i} W_{ij} * SI_{ij} \tag{1}$$

$$S = \sum_{i=1}^{N} WA_i * SA_i \tag{2}$$

where N: number of the aspects; $i = 1 \ldots N;$ N_i: number of the indicators in the i^{th} aspect; $j = 1 \ldots N_i$; WA_i: the weight of the i^{th} aspect; W_{ij}: the weight of the j^{th} indicator in the i^{th} aspect; SI_{ij} is the social sustainability index for the j^{th} indicator in the i^{th} aspect, with the constrains:

$$0 \leq WA_i, W_{ij} \leq 1; \tag{3}$$

$$\sum_{i=1}^{N} WA_i = 1; \sum_{j=1}^{N_i} W_{ij} = 1; \tag{4}$$

So that naturally, those indices are in a range of (0–1).

– In this research, the relative contribution of each aspect and indicator to the corresponding goals are defined by the simple AHP. The simple AHP is an approach in which the weighting process by the function of a number of the sustainability aspects and the indicators is used to replace the ones by the expert's comparison judgments in the standard AHP. In the simple AHP, particularly, once these foremost components are decided, their weights can be made automatically by the following Eqs. (5) and (6):

$$W_{ij} = \frac{1}{N_i} \quad (5)$$

$$WA_i = \frac{1}{N} \quad (6)$$

Sustainability Scale: the groundwater sustainability can be classified into five classes on a scale of 0–1:

Very poor level: from 0 to 0.2; poor level: from 0.2 to 0.4; slightly acceptable level: from 0.4 to 0.45; acceptable level: from 0.45 to 0.55; strongly acceptable level: from 0.55 to 0.6; good level: from 0.6 to 0.8 and excellent level: from 0.8 to 1.0. The highest scores for sustainability is 1, and the lowest one is 0.

4 SSA Application to Hanoi Groundwater Resources

UNESCO/IAEA/IAH Working Group is the group first trying to define the sustainability of groundwater resources which follows the DPSIR (Driving forces, Pressures, State, Impacts and societal Response) framework (Vrba and Lipponen 2007). Those indicators are related to generally groundwater situations and can be used as the broad guideline to establish the indicators. However, those indicators are the independent contributions to the sustainability from different points of view; in other words, these indicators assess the sustainability not in a common system. Therefore, from a specific point of view, it is obviously difficult for specific applications of those indicators into other areas. Since AHP has been considered as one of the powerful indicator-based approaches in the literature review, this paper is the first effort in building up the list of sustainability aspects and the corresponding indicators in each aspect for groundwater resources in a common system based on the AHP concept. By using the AHP approach, the components (aspects and indicators) for groundwater sustainability should be created with the foundation knowledge of the current situations, actual problems occurred and the expected goal (Chen *et al.* 2015), the aspects need to covered all the dimensions of the final goal concept and the corresponding indicators are the smallest units in the system and physically measurable. The more complex indicators system can be developed if the more actual data are available.

Table 1 shows the main sustainability aspects and indicators built up for the first time for the valuable groundwater resources from the social point of view and Hanoi situation is a case study. Three proposed aspects are quantity, quality, and management with the following basic reasons in this study area. Even the excessive groundwater abstraction has caused serious groundwater-level declines in the central and south parts of Hanoi, there is still some information of insufficient water use reported in Vietnam's newspapers. In 2016, approximately two days per month the urban districts having no water supplied from the public water supply companies (Hanoi Water Limited

Company 2016). This insufficient water use apparently adversely affects to the daily life routines of the local residents, especially in the summer season when the temperature even reaches 45°C in some central areas. About the quality, the untreated groundwater resources are reported as arsenic, nitrogen, and coliform contaminated by both natural and anthropogenic causes in the literature review. More dangerously, the contamination is still existed in the bottled water and treated water supply (Craig *et al.* 2013). It is not surprising that these problems adversely impact on local community in both short and long-term exposures. To face to these problems, how the local government manages for driving Hanoi towards sustainable development from the social point of view. Therefore, in this study, from the social sustainability point of view, the social considerations of the groundwater quantity, quality and management are considered as three main social sustainability aspects.

Table 1. SSA framework for groundwater resources in Hanoi, Vietnam

Aspect	Indicator	Definitions
Quantity (SA_1)	SI_{11}	Ratio of the number of residents who can access water for living to the total population in the study area
	SI_{12}	Ratio of the number of days per month, local residents having sufficient water use in the urban area
	SI_{13}	Ratio of the number of hours per day, local residents having sufficient water use in the urban area
Quality (SA_2)	SI_{21}	Ratio of number of residents who use the groundwater with no arsenic contamination to the total population
	SI_{22}	Ratio of number of residents who use the groundwater resources with no nitrogen contamination to the total population
	SI_{23}	Ratio of number of residents who use the groundwater resources with no coliform contamination to the total population
	SI_{24}	Ratio of number of residents who have no water related diseases to the total population
Management (SA_3)	SI_{31}	Ratio of the number of people who can access to the public water supply system to the total population
	SI_{32}	Ratio of the government budget allocated in integrated water resources management (IWRM) to the budget need for maintaining the water supply system
	SI_{33}	Ratio of the number of good responds from local residents to the water supply management of the local government
	SI_{34}	Ratio of number of respondents who are willing to participate (WTPa) in any water conservation and protection activities to the total population
	SI_{35}	Ratio of number of respondents who are willing to pay (WTP) for improve the water supply system for wellbeing to the total population

Regarding the quantity aspect, we focus on how much social satisfaction of water usage in terms of the quantity since groundwater is the main water supply. The terms of "satisfaction" and/or "sufficient water use" are difficult to define. Depending on social needs and situation, the amount considered as "enough" is totally different. As one of the developing countries, we define that "sufficient water use" means people can access and have water for the basic daily activities. As guided by the UNESCO/IAEA/IAH Working Group, the indicators are defined as the ratios between numbers of residents who have insufficient water use to the population in a quantitative aspect. However, in this study, the sustainability indicators indicate that the bigger values of the indicators are, the better contribution can be made to the final social sustainability goal. That is the reason why we define as ratios of the number of residents having sufficient water use to the total population. More specifically, our indicators can relatively measure how many days per month and how much time in 24 h of the no-water-provided day, the residents can have the access water use from the public water supply system. By these definitions, the socially sustainability contributions of the indicators are maximized at one if anyone has sufficient water use.

Regarding the quality aspect, we focus on the risk of water consumption for the residents as the answer to the "how many people who are using the contaminated groundwater resources for living?" question and the water-related-diseases situation in Hanoi. In Vietnam, up to 80% of diseases in Vietnam are caused by polluted water resources, said the Ministry of Natural Resources and Environment, and about six million Vietnamese people have contracted one of six water-related diseases (such as bacterial diarrhea, hepatitis A, typhoid fever, dengue fever, malaria, and Japanese encephalitis) over the four-year period. In this study area, there are three main pollution concerns such as the arsenic, nitrogen and coliform contaminated groundwater, thus the indicators are defined as the ratios between the numbers of residents who are probably not affected due to living in the no-contaminated areas to the total population. The indicators regarding arsenic risk, SI_{21}, by the contaminated groundwater resources. Similarly, the SI_{22} and SI_{23} are defined as the ratios between the numbers of residents who are probably not affected due to living in the no-nitrogen/coliform contaminated areas to the total population. The indicator SI_{24}, furthermore, considers to the water-related diseases of the residents due to the contaminated groundwater consumption. By these definitions, the social sustainability contributions of the indicators are maximized at one if there is no one using the polluted water resources and minimized at zero if all the water supply sources are polluted.

Regarding the management aspect, this paper considers how the local government manages and improves the water supply system for better use and how the residents respond to the management by their willingness to pay (WTP) for improving the public system. The indicator SI_{31} mainly considers the sufficient water supply facilities and how much percentage of the residents who can access the water supply system piles. The indicator SI_{32} presents the sufficient budget allocation in integrated water resources management (IWRM), compared to the expected budget needed for maintaining the system. These two important indicators show how much the government cares about the water supply system in their development strategy. However, it is obviously missing if we do not care about what and how the local residents say about the management. In fact, as resulted in our previous pilot study in Hanoi City about public awareness, attitudes and behaviour towards water management issues, there are up to 85% of the respondents are not actively participated in any water conservation and protection groups (Bui *et al.* 2014) even though there are about 56% of local residents who are willing to contribute financial supports to improve water quality in general. So that the big question for the government is how to raise the very poor understanding of water use and water resources for the local residents. This thing could help the decision makers evaluate their performance and improve it to make it much more closed to the actual social needs. The indicator SI_{33}, SI_{34} and SI_{35} are mainly about the response from local residents, how much interest on the water related programs and how much their willingness to pay for improving the water supply system.

In this study, the three social sustainability aspects and twelve indicators in Table 1, are considered as the core components presenting the actual social scenarios of groundwater resources in Hanoi. The more complex system can be developed if the more actual data are available and the specifically different point of view.

5 Results

This study calculates the actual values of the aforementioned social sustainability indicators (SI_{ij}) by gathering the necessary data from the government database, Ministry of Health Portal and Ministry of Natural Resources and Environment, Vietnam.

Table 2 shows the twelve indicators in three sustainability aspects with their formula, variables used and the explanations. Table 3 shows the results with weights defined by the simple AHP approach. The groundwater quantity index (SA_1) is assessed at a socially good level of 0.65; the quality index (SA_2) is relatively assessed at a

Table 2. Groundwater social sustainability indicators, formula, variables used and value

Indicator	Formula	Variables used/Explanation	Value
SI_{11}	(the number of residents can access clean water for living)/(the total population)	About 70% local residents can access clean water for living in the special-level city (Ministry of Health Portal 2009). About 36.68% local residents in the rural areas of Hanoi can access clean water for living in 2014, said Tran Xuan Viet, the Vice Chairman of Hanoi City Committee. Hanoi is currently extended and includes more than 3.2 million and 3.9 million residents living in the urban districts and sub-urban districts, respectively. We take the calculation for SI_{11}: (0.7*3.2 + 0.37*3.9) million/7.1 million = 0.52	0.52
SI_{12}	(the number of days, local residents having sufficient water use)/(30 days)	Approximately two days per month in 2016, the urban districts having no water supplied from the public water supply companies (Hanoi Water Limited Company 2016)	0.93
SI_{13}	(the number of hours in the no-water-supplied day, local residents having sufficient water use)/(24 h)	In 2016, approximately 12 daily hours per 24 h in the no-water-supplied day, the urban districts having no water supplied from the public water supply companies (Hanoi Water Limited Company 2016)	0.50

(*continued*)

Table 2. (*continued*)

Indicator	Formula	Variables used/Explanation	Value
SI_{21}	(the number of residents who use the groundwater water with no arsenic contamination)/(the total population)	Estimated that 10 millionpeople in the Red River delta are at risk of chronic arsenicpoisoning (Berg *et al.* 2007). Total population in Red River Delta is about 11 million people inhabited. We simply take this roughly estimation presenting for Hanoi.	0.09
SI_{22}	(the number of residents who use the groundwater resources with no nitrogen contamination)/(the total population)	About 43% ammonium, 15% nitrate dioxide and 12% nitrate of the water samples in Hanoi are not permissible for drinking water (Nguyen *et al.* 2012); the maximum percentage is about 43%, thus the possible largest area with no ammonium, nitrate dioxide and nitrate-contaminated groundwater could be 57%	0.57
SI_{23}	(the number of residents who use the groundwater resources with no coliform)/(the total population)	About 22% of samples in both the Hanoi aquifers have coliform values higher than the standard limit in Hanoi (Nguyen *et al.* 2012)	0.78
SI_{24}	(the number of residents who number of residents who have no water related diseases)/(the total population)	Around six million Vietnamese people have contracted one of six water-related diseases over the past four years. (http://www.ngocentre.org.vn/content/80-diseases-vietnam-caused-polluted-water-resources)	0.98
SI_{31}	(the number of people who can access to the public water supply system)/(the total population)	About 70% local residents can access clean water for living from the public water supply system in the special-level city and in the rural areas (Ministry of Health Portal 2009). About 10% local residents can access clean water from the public water supply system in the rural areas. Hanoi is currently extended and includes more than 3.2 million and 3.9 million residents living in the urban districts and sub-urban districts, respectively. We take the calculation for SI_{31}: (0.7*3.2 + 0.1*3.9) million/7.2 million = 0.36	0.37
SI_{32}	(the government budget allocated in integrated water resources management (IWRM))/(the budget need for maintaining the water supply system)	In 2006, the total budget of MARD was US$200 million of which US$1r26 million was allocated to investment for development. (Molle and Hoanh 2011)	0.63
SI_{33}	(number of good responds from local residents)/(the total population)	There are about only 6% of respondents commented that the management and propaganda methods of government departments are good, while most citizens (43%) rated as poorly managing and protecting water quality. (Bui *et al.* 2014)	0.57
SI_{34}	(number of residents who are willing to participate in any water conservation and protection activities)/(the total population)	There are about 85% of the public is not actively participated in any water conservation and protection groups. (Bui *et al.* 2014)	0.15
SI_{35}	(number of residents who are willing to pay for improve the water supply system)/(the total population)	There are about 56% of local residents who are willing to contribute financial supports to improve water quality. (Bui *et al.* 2014)	0.56

socially good level of 0.61 and the management index (SA_3) is assessed at a slightly socially acceptable level of 0.46. The composite social sustainability index, S, is about 0.57, socially assessed at strongly acceptable level.

6 Discussion

From Table 3, the groundwater quantity index (SA_1), which is assessed at a socially good level of 0.65, indicates that the community rather satisfies with the water accessibility and the amount of daily water use. The quality index (SA_2) of 0.61 indicates that the community also moderately satisfies with the quality of the groundwater resources. The management index (SA_3) of 0.46 implies that the community somewhat accepts the current policies and regulation of the government management. Consequently, the composite social sustainability index of 0.57 shows that the groundwater use and condition in Hanoi is socially strongly acceptable. Among these indices, it is effortless to see that the quality index is somehow inappropriately assessed from the sustainability point of view. The following paragraph explains the reasons why and also points out how to improve the assessment properly.

Table 3. Social sustainability assessment for Hanoi groundwater resources

Sustainability aspect	W_i	Sustainability indicator	W_{ij}	Values of SI_{ij}	SA_i	S
Quantity (SA_1)	0.333	SI_{11}	0.33	0.52	0.65	0.57
		SI_{12}	0.33	0.93		
		SI_{13}	0.33	0.50		
Quality (SA_2)	0.333	SI_{21}	0.25	0.09	0.61	
		SI_{22}	0.25	0.57		
		SI_{23}	0.25	0.78		
		SI_{24}	0.25	0.98		
Management (SA_3)	0.333	SI_{31}	0.20	0.37	0.46	
		SI_{32}	0.20	0.63		
		SI_{33}	0.20	0.57		
		SI_{34}	0.20	0.15		
		SI_{35}	0.20	0.56		

From Table 2 and Fig. 3, the quality aspect (SA_2) is assessed at the socially good level. Since there have been a series of reports regarding the serious pollution problems published, this is a not easy-to-believe assessment from the quality point of view. Because we could see that, the indicator SI_{21} in Table 2 shows that almost 90% of local residents in Red River Delta are at risk of arsenic poisoning due to the arsenic contaminated groundwater resource consumption; and the indicator SI_{24} shows that approximately 2% population have contracted one of six water-related diseases over the four-year period. Therefore, in terms of human health and safety, the sustainability scales should be appropriately changed in a more realistic way. In addition, due to the

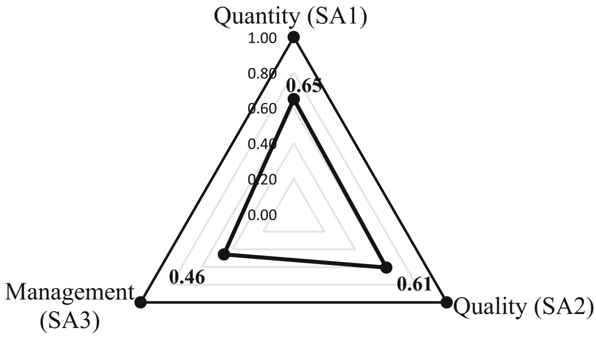

Fig. 3. Social sustainability assessment of Hanoi groundwater resources

limitations of the data availability, the indicators (SI_{22} and SI_{23}) in this study are evaluated as the same as the area ratios. These area ratio estimations do not locally reflect the actual problems appropriately due to the moderately small proportion between the contaminated areas and the total study area. Previously, Hanoi was small and the abstraction wells are mainly located in the central area which becomes the most vulnerable areas regarding groundwater over-exploitation due to the fast population growth and the rapid urbanization. Recently, since 2008, Hanoi has been largely extended; the previous area is about 15% of the current. The sustainability indicators show the general sustainability assessment in the total extended area. Therefore, the values of these indicators do not locally reflect the actual problems appropriately. Another thing, in Table 2, is that the measurement values in the description for the indicators of the second aspect were at different scattered sites in Hanoi. The way to convert the point-based measurements into the area absolutely encompasses the uncertainty and error in the calculations. However, all the groundwater samples were broadly collected over the study area. That is why to cope with the data availability; we use the assumption in which the point-based measurements are the representatives for the area. Therefore, not only the sustainability scales should be changed from social point of view but also these values of the actual data (SI_{ij}) should be validated to make the evaluation much more closely to the reality.

The results of SSA are not only sensitive with data availability but also the definition of the indicators. Regarding to quality aspect (SA_2), the indicator formulas are defined by ratios of the number of residents who use the groundwater with no contamination to the total population, inspired from the way to define the indicators of UNESCO/IAEA/IAH Working Group. For example, in the indicators SI_{22}, there are about 43% areas with nitrogen contamination of the total; the sustainability level is strongly acceptable at the value of 0.57. This sustainability scale is apparently not suitable due to the severely adverse impact of the nitrogen exposure from drinking water in general. For instance, excess the WHO standard of nitrates (50 mg L−1 (WHO 2011)) in the drinking water cause human health risks of depleting blood oxygen levels; the additional consequences are enlargement of the thyroid gland, increased incidence of cancer and birth defects, and hypertension (Forman *et al.* 1985). Such these linear relationships, therefore, do not reflect the actual situation well. In order to avoid this inappropriate scale, we could use a non-linear relationship to define the SI_{22}, and we need to make another detailed sustainability scales for this quality indicator. The sustainability could be suitably scaled in a manner, in which, (i) if the proportion of the nitrogen contaminated area to the total area is 0% and 100%, the sustainability scale converted should be 1 and 0, respectively; and (ii) if this proportion is 50%, the sustainability scale should be converted into 0.1, for instance. In general, in order to improve the sensitivity of SSA performance, the more suitable definition of the sustainability indicators is indispensable to be improved to make it closed to the actual groundwater situation and the indicators could be more helpful to the decision makers.

Regarding to the modification of the methodology, in order to cope with the limited data availability, the purpose of this study is to economically reduce the most practically time-consuming and complicated step in the standard AHP due to several reasons such as: finding the appropriate experts; waiting for their big efforts to make the large series of unconfident pair-wise comparison judgments again and again until they become acceptably consistent. To do that, we carefully build up the main sustainability aspects and indicators covering the actual situation of groundwater resources in Hanoi from the social point of view. From the simple method, once the sustainability criteria and indicators are proposed, the social sustainability of the groundwater resources can be relatively assessed when the data are available. This simple sustainability assessment thus provides a quick view of the current groundwater use status and can be applied to other areas with the similar interests. Moreover, using this simple assessment, we can relatively make the comparisons among the quantity, quality, and management aspects; as well as make the comparisons among the sustainability indicators. The purpose of these comparisons is to fairly point out the most important aspects and indicators which are needed to be highly invested in order to effectively improve social sustainability. Therefore, the simple AHP could be considered as the first test of an economically substituted approach for the standard AHP; the validation should be carried out as the future work.

7 Conclusions

The main object of this study is to assess social sustainability level for the valuable groundwater resources by applying the indicator-based approach, the simple AHP. In this study, we successfully not only create the appropriate list of three main aspects and the twelve core social sustainability indicators, appropriately presenting for groundwater situation in Hanoi, but also test the simple AHP approach in handling the limitation of data availability. The results of SSA are not only sensitive to data availability but also the definition of the indicators. The linear relationships do not reflect the actual situation well and the non-linear ones could be used to replace these sustainability scales of the actual values. The social sustainability indices are evaluated at the moderately high values, improbably reflecting the current problems in the target area. The study then points out the main research gaps and how to improve social sustainability assessment for the better groundwater resource development.

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