SOCIAL SUSTAINABILITY INDICATORS OF GROUNDWATER RESOURCES IN HANOI, VIETNAM

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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 situation occurred in most of the river-streams system. Considering the social dimension in context of sustainable development is a key issue in groundwater resources management. The main object of this study is to develop the sustainability aspects and indicators from social point of view for the valuable groundwater resources in Hanoi by applying the indicator-based approach, AHP. In this study, we successfully not only select the appropriate list of three main social sustainability aspects including the quantity, quality and management dimensions but also the thirteen core social sustainability indicators, appropriately presenting for groundwater situation in the monsoonal area, Hanoi. The much more complex system can be developed if the more actual data are available and the specifically different point of view. Our findings are fundamental for further social sustainability assessments as well as the integrated sustainability assessment of the resources in Hanoi.

Keywords*: Social sustainability, indicators, groundwater resources, AHP, Hanoi*

INTRODUCTION

Groundwater sustainability issues in Hanoi, Vietnam

Water resources play a key role in any development process of human kinds. In terms of water resources management, ACSE (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, *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). 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.That is why groundwater resources are the main water supply sources for the local residents. Recently, up to 93% of the

water supply 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., 2012) and level trends in Hanoi (Bui et al., 2012); presented the current situation of groundwater abstraction from sustainability point of view (Bui et al.2015).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. 2012). 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. (2016)) focusing on environmental sustainability assessment is one of the very few examples newly investigated in this area. However, to cope with the limited data availability, we mainly discussed about the environmental problems, there was no integrated considerations of human well beings, human health adverse effects and the management even though the public supports are essential for successful implementations of any water-related projects and policies.

Social sustainability indicators of groundwater resources in Hanoi

Sustainable development is a concept composing of the environmental, economic and social dimensions; however, it is acknowledge that social dimension has received less consideration in comparison to the other aspects (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 definitely 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 dimension in 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, N. and Edmonds, A., 2013). So what are the main components presenting for social sustainability achievements since the 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 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 of groundwater resources should reflex 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.

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;Bui et al., 2007;Berg et al.,2008; Bui et al., 2010; Nguyen et al., 2012; Nguyen et al.,2015), etc., there have been a few studies regarding how these changes adversely affecting on the human safety and health, and almost no studies mentioned the relative measurement of the social sustainability. For instance, Berg et al.(2001, 2008) 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 other evidences 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 well beings and management in terms of sustainability.

In order to cope with these abovementioned problems, this paper aims to develop a list of social sustainability indicators as an initial step to assess social sustainability for Hanoi's groundwater resources. The sustainability indicators are created based on the UNESCO's guidelines of groundwater sustainability indicators and the actual problems in Hanoi from social point of view. Analytical Hierarchy Process (AHP) is utilized since it is one of the most powerful methods dealing with multifaceted and unstructured problems; and its main advantage is to categorize and identify the foremost components (aspects and indicators) that better reflect the significant performances. The results are fundamental for further sustainability assessment studies for groundwater resources in Hanoi.

STUDY AREA

Fig.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 million(in 2014) accounts for 7.5 % of Vietnam in total (General Statistic Office of Vietnam). 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^oC. Evaporation is quite high with an annual average of 933 mm[10)]. 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 rapidly economic development and fast socialization and urbanization have put pretty much pressure on the river basin environment. This surface water system is recently polluted by organic compounds, in which, the lakes especially in this study area are significantly polluted (Tong, 2008). That is the main reason why the groundwater resources have become the most important water supply for the local inhabitants.

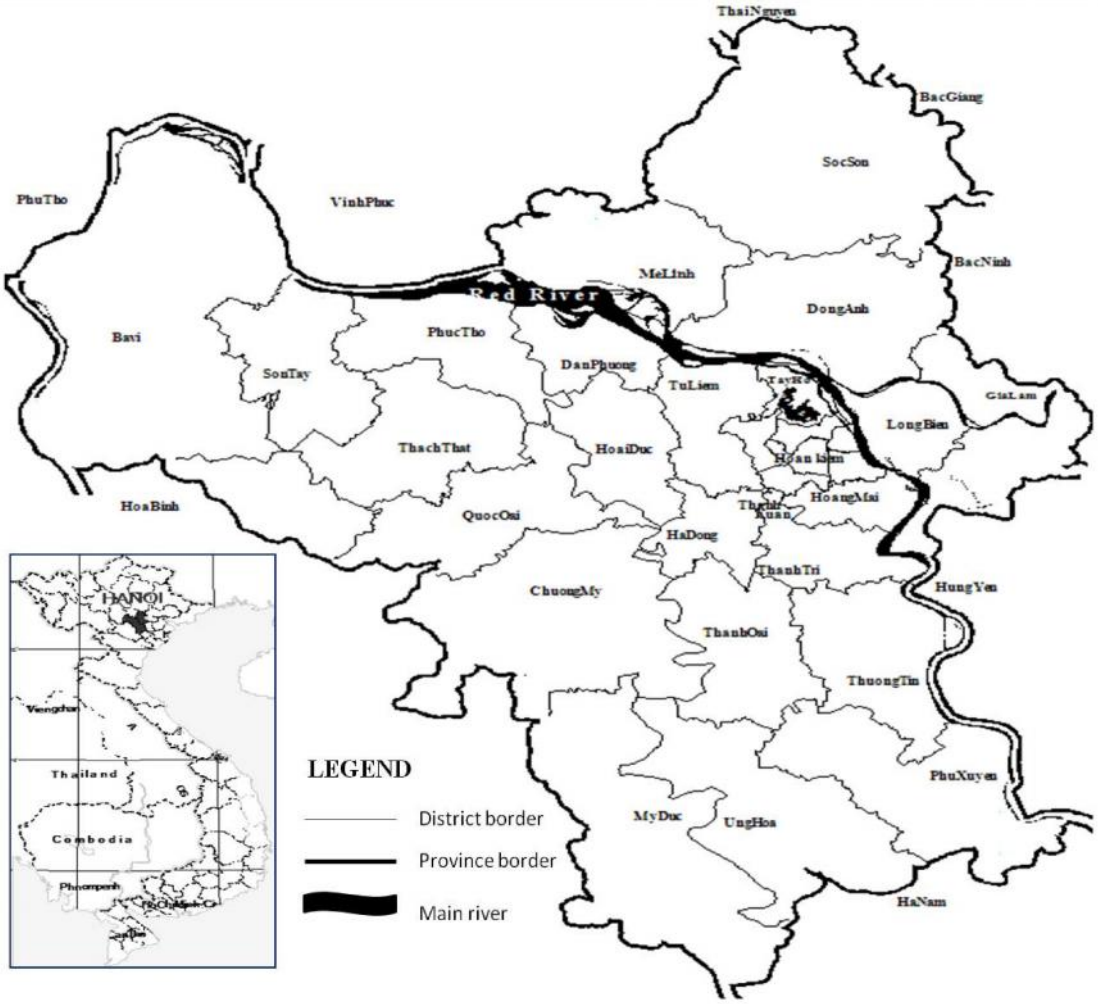

Fig. 1.Study area and main rivers and lakes

METHODOLOGY

Established in 1970s by Saaty, Analytical Hierarchy Process (AHP) is one of the most powerful and popular multi-criteria decision making methods dealing with multifaceted and unstructured problems in social sciences. To apply AHP, at first step, decision makers need to study about 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. This study applies AHP to develop a list of the main indicators and aspects appropriately covering the social situation of groundwater resources in Hanoi.

RESULTS AND DISCUSSION

In the AHP approach, generally, the most important step is to identify the main components in the sustainability hierarchy. In this study, we carefully selected the social indicators and aspects for groundwater sustainability assessment based on the consideration of the current situation actual problems occurred and expected goal (Chen et al., 2015). The more complex indicators system can be developed if the more actual data are available.

Table 1 shows the main social sustainability aspects and indicators for groundwater resources in Hanoi. In this study area, even the excessive groundwater abstraction has caused serious groundwater-level declines in the central and south parts, 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 obviously adversely affects to the daily life routines of the local residents, especially in the summer season when the temperature even reaches 45^0C 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 bottle 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 manage for driving Hanoi towards sustainable development from 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.

Regarding the quantity aspect, we focus on how much social satisfaction of water usage in terms of the quantity since groundwater are the main water supply sources. 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 number of residents having 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 hours of 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 ones if anyone have sufficient water use.

Regarding the quality aspect, we focus on the risk of water consumption for the residents as the answer for 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 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 are divided to two specific indicators, SI_{21} and SI_{22}, by the contamination from treated water supply and the untreated groundwater resources. Similarly, the SI_{23} and SI_{24} 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_{25}, furthermore, considers to the water related diseases of the residents due to the contaminated groundwater consumption. By these definitions, the socially sustainability contributions of the indicators are maximized at ones if there is no one using the polluted water resources and minimized at zeros if all the water supply sources are polluted.

Regarding the management aspect, this paper considers how the local government manages and improve 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 maintain 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. So that the big question for the government is how to raise the very poor understandings 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 responds 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 thirteen social sustainability indicators and three aspects shown in **Table 1** are considered as the core components presenting the actual social scenarios of groundwater resources in Hanoi. The much more complex system can be developed if the more actual data are available and the specifically different point of view.

Table 1. Social Sustainability indicators and aspects of Groundwater Resources

Aspect	Indicator	Definitions
Quantity Aspect	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 Aspect	SI_{21}	Ratio of number of residents who use the treated water supply with no arsenic contamination to the total population
	SI_{22}	Ratio of number of residents who use the untreated groundwater resources with no arsenic contamination to the

		total population
	SI_{23}	Ratio of number of residents who use the untreated groundwater resources with no nitrogen contamination to the total population
	SI_{24}	Ratio of number of residents who use the untreated groundwater resources with no coliform contamination to the total population
	SI_{25}	Ratio of number of residents who have no water related diseases to the total population
Management Aspect	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 positive 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 in any water conservation and protection activities to the total population
	SI_{35}	Ratio of number of respondents who are willing to pay for improve the water supply system for wellbeing to the total population

CONCLUSIONS

The main object of this study is to develop the sustainability aspects and indicators from social point of view for the valuable groundwater resources in Hanoi by applying the indicator-based approach, AHP. In this study, we successfully not only select the appropriate list of three main social sustainability aspects including the quantity, quality and management dimensions but also the thirteen core social sustainability indicators, appropriately presenting for groundwater situation in the monsoonal area, Hanoi. The much more complex system can be developed if the more actual data are available and the specifically different point of view. Our findings are fundamental for further social sustainability assessments as well as the integrated sustainability assessment of the resources in Hanoi.

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