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# Sustainability Assessment of Groundwater Resources in Hanoi, Vietnam from a Social Perspective

Nuong Thi BUI[1*], Akira KAWAMURA[2], Hideo AMAGUCHI[3], Duong Du BUI[4], Ngoc Tu TRUONG[5] and Kei NAKAGAWA[6]

[1]Member of JSCE, Ph.D. Student, Dept. of Civil and Environmental Eng., Tokyo Metropolitan University (1-1, Minami-Ohsawa, Hachioji, Tokyo 192-0397, Japan)

[2]Member of JSCE, Professor, Dept. of Civil and Environmental Eng., Tokyo Metropolitan University

[3]Member of JSCE, Assistant Professor, Dept. of Civil and Environmental Eng., Tokyo Metropolitan University

[4]National Center for Water Resources Planning and Investigation, Ministry of Natural Resources and Environment (93/95, Vu Xuan Thieu – Sai Dong, Long Bien, Hanoi, Vietnam)

[5]Shanghai Collaborative Innovation Center for Biomanufacturing Technology, East China University of Science and Technology. (Meilong 130, Shanghai 200237, China)

[6]Member of JSCE, Professor, Graduate School of Fisheries and Environmental Sciences, Nagasaki University (1-14, Bunkyomachi, Nagasaki 852-8521, Japan)

*Email: *buithinuong@gmail.com*

Groundwater plays a key role in public water supplies around the world. A consideration of social dimension is a key issue in the sustainable groundwater management, and making sure a safe and affordable drinking water for all is one of the main targets of 17 United Nations Development Goals. Recently in Hanoi, Vietnam, the groundwater overexploitation and contamination have been reported, which are life-threatening to the sustainable development of the community. This study is an attempt to assess the sustainability of groundwater from a social perspective. An outstanding multi-criteria decision-making approach, Analytical Hierarchy Process (AHP) is utilized here because it is suitable for sustainability assessment. In the AHP application for sustainability assessment, defining appropriate aspects and their indicators in each aspect is one of the most difficult tasks. This study proposes for the first time three main aspects including quantity, quality and management and their twelve sustainability indicators from a social point of view, based on the specific consideration of groundwater current problems in Hanoi. Hence, this study defines the index-based definitions of those sustainability indicators to clarify the way of their sustainability evaluations. Results show that the aspects and indicators are appropriate to cover Hanoi groundwater situation from a social point of view. The sustainability indices of Hanoi groundwater quantity and quality are assessed as socially good and acceptable, respectively. The sustainability index of the management aspect is assessed as socially acceptable. So that generally, Hanoi groundwater is assessed as socially acceptable.

***Key Words:*** *Hanoi Groundwater, Analytical Hierarchy Process, Index-based Definition, Social Perspective, Sustainability Assessment*

## 1. INTRODUCTION

Making sure a safe and affordable drinking water for all is one of the universal targets of 17 United Nations Development Goals[1)]. Groundwater plays a key role in public water supplies around the world. Worldwide, more than two billion people depend on groundwater for their daily supplies and over half of the population depends on it for drinking[2)]. Groundwater sustainability refers to the way of development and use of groundwater resource (GWR), in which the resource can be preserved for an indefinite time without causing any adverse eco-environmental and social consequences[3)]. Put simply, sufficient quantity and quality groundwater at an acceptable price should be available to meet social demand 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, groundwater contamination, and so on[4)]. Since the amount of groundwater abstraction has been rapidly and continuously increasing worldwide, achieving sustainable management of GWR is one of the essential objectives for the future of many countries[5]. The proper management of water resources is very important to ensure a sustainable socio-economic development of every country all over the world[6].

In Vietnam, GWR has become the most important water supply source for the communities, especially, in the urbanizing capital, Hanoi, where most of the rivers and lakes are seriously polluted due to the discharge of industrial, agricultural, aquacultural and domestic waste to the water bodies without treatment[7]. The rapid exploitation without an appropriate management system has caused a series of adverse impacts including drying up of shallow wells, level decline, and land subsidence[8), 9)]. The groundwater decline can be disastrous to those communities who tap their water from wells or shallow boreholes. This resource has been also locally contaminated by arsenic, coliform, and nitrogen[9),10),11)]. In Red River Delta where Hanoi is located, approximately several million people consuming such untreated groundwater might be at a considerable risk of health[9]. Both these quantity and quality degradations are life-threatening to the community for ensuring sustainability goals of the development process.

Multi-Criteria Decision Making approach is considered to be the best method for sustainability assessment[12]. As an outstanding multi-criteria decision-making approach, Analytical Hierarchy Process (AHP) is normally utilized for sustainability assessment[13),14)] because AHP can help decision makers to cope with multifaceted and unstructured problems such as sustainability[15]. In these AHP 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 indicators provide measures of change in the criteria over time. The purpose of sustainability indicators for industry is to provide information on how it contributes to sustainable development[16]. An indicator's significance can be extended beyond what is actually measured to larger phenomena of interest. Indicators should be easy to measure, cost effective, accommodate changing conditions, scientifically sound, and based on functional ecological relationships[17]. In this way, indicators can provide information for policy makers and aid in decision making[18].

While sustainable development is a concept composing of the environmental, economic and social criteria; it is acknowledged that social dimension has received less consideration in comparison to the other criteria[19] because this concept is hard to define and quantify. There is no specific definition for social sustainability and each research defines the concept based on the specific dimensions. For example, Chiu[20] and Vallance *et. al*[19] agree that the social sustainability is referred as the improvement and maintenance of the well-being of both current and future generations. They emphasize that the concept refers to the social necessary conditions to support ecological sustainability and the equality requirement of rights in access to resources and social services. On the other hand, as another example, Palich and Edmonds[21] defines that the concept is to "ensure the sustenance of the diverse social relations that exist in healthy communities" and "create the physical, cultural and social places that support well-being". The meaning of the concept still remains unclear and needs more investigations[22]. Especially, there are no studies dealing with AHP application on sustainability assessment of GWR from a social point of view even though having a better understanding of the social dimension is crucial for a sustainable GWR management.

Dealing with the above-mentioned problems, in this study, social sustainability assessment (SSA) of GWR in Hanoi is carried out by AHP for the first time. In the AHP application for sustainability assessment, defining appropriate aspects and their indicators in each aspect is one of the most difficult tasks. This study proposes three main aspects including quantity, quality and management and their twelve sustainability indicators from a social point of view based on a specific consideration of groundwater current problems in Hanoi. Hence, this study defines the index-based definitions of those sustainability indicators to clarify the way of their sustainability evaluations. Finally, SSA for Hanoi GWR is investigated.

## 2. 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 7.2 million (as of 2015) accounts for almost 10% of Vietnam in total with the highest density of more than two thousands people/$km^2$ [23]. Hanoi belongs to the tropical monsoonal area with two distinctive seasons in the year, the rainy and dry seasons. The annual average rainfall is about 1,600 mm, the average humidity is about 80%, and the average temperature


**Fig. 1** Study area and main rivers and lakes.

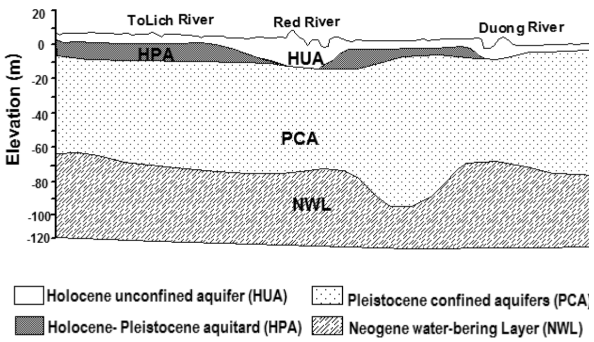


**Fig. 2** Hydrogeological cross section along A-A' line as shown in **Fig. 1**. (Source: adapted from Bui *et. al*[24])

is about 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 with the basin areas of approximately 155,000 km$^2$. However, the fast urbanization has put pretty much pressure on the river basin environment. This surface water system is seriously polluted. Thus, GWR become the most important water supply for the local inhabitants[7].

In a previous study, Bui *et. al*[24], we comprehensively analyzed the aquifer system for potential groundwater resources in Hanoi and described their geological characteristics and hydrological processes. **Fig. 2** shows that Hanoi's groundwater resources mainly exist in the topmost Holocene unconfined aquifer (HUA) and the shallow Pleistocene confined aquifer (PCA). The HUA is distributed at a rate of about 55% in the south of the city area, and has a relatively high potential of groundwater resources, sufficient for the small to medium scale domestic water supply. PCA is the highest potential of groundwater resources and widely distributed at a rate of about 80% in the south of the city, serving the most important aquifer for the area water supply.

## 3. METHODOLOGY

Established in the 1970s by Saaty[25], 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[25]. In AHP application for sustainability assessment, there is a need to define the appropriate components including aspects and the indicators in each aspect. This study utilizes this big advantage of AHP to establish the sustainability hierarchy for sustainability assessment of GWR. In these applications, the sustainability index is a common concept and normally used to assess the sustainability levels; the index value is various from 0 (the poorest level) to 1 (the excellent level)[13),14]. Following this common concept, in this paper, the sustainability index is denoted as **Ω***;* the aspect sustainability index is denoted as $\Omega_A$*;* and the indicator sustainability index is denoted as $\Omega_I$. The following part shows the basic steps in sustainability evaluation based on AHP approach.

*Step 1: Intensive review*

Decision makers need to intensively review and study the current situation and the complex multiple criteria decision problems (social sustainability).

*Step 2*: *Build up a sustainability hierarchy*

- Based on the results of *Step 1*, creating the appropriate hierarchy by breaking down it into its sustainability aspects (SA) and their sustainability indicators (SI) in each aspect.

*Step 3*: *Deciding the index-based definitions,* $\Omega_I$

$\Omega_I(i, j)$ , the sustainability index of the $j^{th}$ indicator in the $i^{th}$ aspect, is evaluated based on specific considerations of the aspects, indicators and the sustainability goal.

*Step 4: Data collection*

Collect the actual data for the indicators

*Step 5*: *Sustainability assessment*:

Once all the components of the sustainability hierarchy and $\Omega_I(i, j)$ are defined, $\Omega_I(i, j)$ can be simply calculated according to the actual data. The aspect sustainability indices ( $\Omega_A$ ) and the sustainability index ( $\Omega$ ) are simply evaluated by the following equations (1) and (2), respectively:

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

$$\Omega = \sum_{i=1}^{N} W_A(i) * \Omega_A(i) \qquad (2)$$

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

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

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

So that naturally, those sustainability indices are in a range of (0-1). The following paragraph describes how to decide the weights of aspects and indicators in each aspect.

Generally, in AHP applications, the weights refer to the relative contributions of the components to the final goal of sustainability. In order to find these relative contributions, questionnaires are made to consult expert's opinions by making a series of pair-wise comparison judgments. The expert's judgments are then checked whether they are acceptably consistent or not. The judgments will be making again and again until they are acceptably consistent. However, there is no such survey regarding Hanoi groundwater existed. Therefore, this study utilizes the simple AHP[26)] to simply evaluate the weights. The simple AHP is an approach in which the weighting process by functions of a number of the aspects ($N$) and functions of a number of the indicators ($N_i$) are used to replace the ones by the expert's comparison judgments in the standard AHP. For the simplest weight case, particularly, in this study, the aspect and indicator weights are equally evaluated by the following equations (5) and (6):

$$W_A(i) = \frac{1}{N} \qquad (5)$$

$$W_I(i, j) = \frac{1}{N_i} \qquad (6)$$

*Sustainability scale:* the sustainability can be classified into five classes on a scale of 0–1: Very poor: from 0 to 0.2; poor: from 0.2 to 0.4; acceptable: from 0.4 to 0.6; good: from 0.6 to 0.8 and excellent: from 0.8 to 1.0.

## 4. SSA FRAMEWORK

UNESCO/IAEA/IAH Working Group is the group first trying to define the sustainability indicators of groundwater resources which follow the DPSIR (Driving forces, Pressures, State, Impacts and societal Response) framework[27)]. Those indicators are related to usually groundwater situation and can be used as the general guideline to establish the sustainability indicators for any region in the world. However, those indicators are independent to contribute to the sustainability from different points of view. For example, one indicator is defined as the ratio between groundwater abstraction and groundwater recharge. Physically, this ratio can be used as a sign of over-exploitation of GWR. In terms of benefits for society and economic development, the increasing of groundwater abstraction is good to meet the cumulative demand, however, it is not good in terms of increasing environmental and social impacts. It is apparently difficult for specific applications of those indicators from one specific economic, social and/or environmental point of view. There is a need to develop a list of appropriate sustainability indicators from a particular perspective.

### (1) Social sustainability aspects

The components (aspects and indicators) for the groundwater sustainability hierarchy should be created with the foundation knowledge of the current situations, actual problems occurred and the expected goal[28)]. The aspects should cover all the dimensions of the final goal concept; the corresponding indicators are the smallest units in the hierarchy and physically measurable. The more complex indicators system can be developed if the more actual data are available.

In terms of social benefits from using GWR as a primary water supply source, it is important to care about the social demands and satisfaction of the quantity, the quality and the price of groundwater. These three significant things are controlled and driven by government management and regulations. In the fact that 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

**Table 1** SSA Framework for Groundwater Resources in Hanoi, Vietnam.

| Aspect | Indicator | Indicator description | Index-based definition of the indicators |
|---|---|---|---|
| Quantity ($SA_1$) | $SI_{11}$ | Water accessibility | Ratio of the number of residents who can access water for living to the total population in the study area. |
| | $SI_{12}$ | Daily sufficient water use | Ratio of the number of days per month, local residents having sufficient water use in the urban area |
| | $SI_{13}$ | Hourly sufficient water use | Ratio of the number of hours per day, local residents having sufficient water use in the urban area |
| Quality ($SA_2$) | $SI_{21}$ | Arsenic contamination groundwater use | Ratio of number of residents who use the groundwater with no arsenic contamination to the total population |
| | $SI_{22}$ | Nitrogen contamination groundwater use | Ratio of number of residents who use the groundwater resources with no nitrogen contamination to the total population |
| | $SI_{23}$ | Coliform contamination groundwater use | Ratio of number of residents who use the groundwater resources with no coliform contamination to the total population |
| | $SI_{24}$ | Water related diseases | Ratio of number of residents who have no water related diseases to the total population |
| Management ($SA_3$) | $SI_{31}$ | Water accessed capability from to the public water supply system | Ratio of the number of people who can access to the public water supply system to the total population |
| | $SI_{32}$ | Budget allocated | Ratio of the government budget allocated in integrated water resources management to the budget need for maintaining the water supply system |
| | $SI_{33}$ | Good responses from community | Ratio of the number of good responses from local residents to the water supply management of the local government |
| | $SI_{34}$ | Willingness to participate | Ratio of number of respondents who are willing to participate in any water conservation and protection activities to the total population |
| | $SI_{35}$ | Willingness to pay | Ratio of number of respondents who are willing to pay for improve the water supply system for wellbeing to the total population |

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[29]. 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 $45^0$C in the central areas. Moreover, 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[30]. It is not surprising that these problems adversely impact on the community in both short and long-term exposures. To face to these problems, how the local government manages to drive Hanoi towards sustainable development. There is a need to better understand public attitudes toward water resource management[31] and the human wellbeing and the public supports are essential for successful implementations of any water-related projects and policies. Therefore, in this study, the considerations of the groundwater quantity, quality, and management are considered as three main social sustainability aspects shown in **Table 1**.

**(2) Social sustainability indicators and their index based definitions**

The social sustainability indicators are context dependent and need to reflect the nature and requirements of the local community[31]. So that the indicators should be generated according to the current social problems of Hanoi groundwater usage.

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. So that 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 the no-water-provided day, the residents can have the access water use from the public water supply system. By these index-based definitions, the social 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 the 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[32]. 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. As these index-based 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 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, 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, there are up to 85% of the respondents are not actively participated in any water conservation and protection groups and 56% of local residents who are willing to contribute financial supports to improve water quality in general, as shown in the results of our previous pilot study in Hanoi City regarding to the public awareness, attitudes and behavior towards water management issues[33]. 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.

Finally, this study proposes the main social sustainability aspects and twelve social sustainability indicators in these aspects to build up the hierarchy for GWR in Hanoi with the consideration of the data availability. All the components, their descriptions and index-based definitions of the indicators are shown in **Table 1**.

## 5. RESULTS & DISCUSSION

This study calculates the values of $\Omega_I$ based on the actual data of the aforementioned social sustainability indicators 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 results of sustainability indices for the indicators, aspects and the sustainability assessment of GWR in Hanoi, Vietnam.

From **Table 3,** the quantity sustainability index, $\Omega_A(1)$, 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 sustainability index ($\Omega_A(2)$) of 0.59 indicates that the community also moderately satisfies with the quality of the GWR. The management sustainability index ($\Omega_A(3)$) of 0.46 implies that the community somewhat accepts the current policies and regulation of the government management. Consequently, the composite social sustainability index ($\Omega$) of 0.57 shows that the groundwater use and condition in Hanoi are socially acceptable. **Fig.3** shows the sustainability shape of GWR in Hanoi. The shape indicates that Hanoi community moderately satisfies and accepts the current conditions of the groundwater usage.

Among these evaluated sustainability indices, it is effortless to see that the quality index is somehow inappropriately assessed from the social point of view. Because, since there have been a series of reports regarding the serious pollution problems in the literature, this is a not easy-to-believe assessment from the quality point of view. For example, the index-based definition of $SI_{21}$ shows that almost 90% of local residents in Red River Delta are at risk of health problems due to the arsenic contaminated GW consumption; and $SI_{24}$ shows that approximately 7%

**Table 2** Social sustainability assessment.

| SA | SI | $\Omega_I$ | $W_I$ | $\Omega_A$ | $\Omega$ |
|---|---|---|---|---|---|
| Quantity ($SA_1$) | $SI_{11}$ | 0.52 | 0.33 | 0.65 (good level) | 0.57 (acceptable level) |
| | $SI_{12}$ | 0.93 | 0.33 | | |
| | $SI_{13}$ | 0.50 | 0.33 | | |
| Quality ($SA_2$) | $SI_{21}$ | 0.09 | 0.25 | 0.59 (acceptable level) | |
| | $SI_{22}$ | 0.57 | 0.25 | | |
| | $SI_{23}$ | 0.78 | 0.25 | | |
| | $SI_{24}$ | 0.93 | 0.25 | | |
| Management ($SA_3$) | $SI_{31}$ | 0.37 | 0.20 | 0.46 (acceptable level) | |
| | $SI_{32}$ | 0.63 | 0.20 | | |
| | $SI_{33}$ | 0.57 | 0.20 | | |
| | $SI_{34}$ | 0.15 | 0.20 | | |
| | $SI_{35}$ | 0.56 | 0.20 | | |

population have contracted one of six water-related diseases over the four-year period. For another example, the indicators $SI_{22}$ shows that there are about 43% areas with nitrogen contamination of the total and the sustainability level is acceptable at the value of 0.57. This sustainability scale is somehow not suitable due to the severely adverse impact of the nitrogen exposure from drinking water in general. Therefore, in terms of human health and safety, the index-based definitions of these indicators should be changed into more realistic ways to better reflect the actual situation and problems of the local GWR.

In order to generally improve the sensitivity of SSA performance, not only improving data availability but also developing the more practically suitable index-based definition of the sustainability indicators. By these improvements, the indicators will reflect the actual groundwater situation and could be more helpful to the decision makers.

From the simple AHP 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.

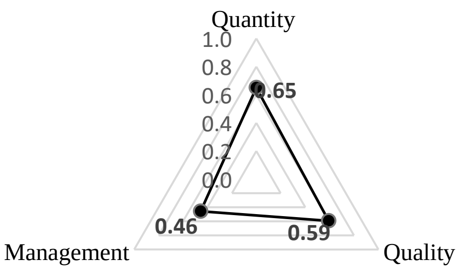


**Fig. 3** Social sustainability assessment.

## 6. CONCLUSION

The main object of this study is to assess the social sustainability of the groundwater resources by applying an outstanding multi-criteria decision-making approach, AHP. In the AHP application for sustainability assessment, defining appropriate aspects and their indicators in each aspect is one of the most difficult tasks. In this study, we successfully not only (1) appropriately generate three main aspects and the twelve core social sustainability indicators in these aspects, presenting for groundwater situation in Hanoi properly; but also (2) define the index-based definitions of those sustainability indicators to clarify the way of their sustainability evaluations and (3) gather the available data for the preliminary sustainability assessment of GWR in Hanoi. This study proposes three main aspects including quantity, quality and management and their twelve sustainability indicators from a social point of view, based on a specific consideration of groundwater current problems in Hanoi. The quantity and quality sustainability indices are assessed as good and acceptable, respectively, indicating that the community rather satisfies with the water accessibility and the daily water use and moderately satisfies with the quality. The sustainability index of the management aspect is assessed at the acceptable level, inferring that the community somewhat accepts the current policies and regulation of the integrated water management. So that generally, Hanoi groundwater is socially acceptable. The performance of SSA is sensitive to data availability in the target area and the index-based definitions of the sustainability indicators.

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