ENVIRONMENTAL SUSTAINABILITY ASSESSMENT OF GROUNDWATER RESOURCES IN HANOI, VIETNAM BY A SIMPLE AHP APPROACH

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In order to assess the sustainability for groundwater resources, this study applies Analytical Hierarchy Process (AHP) approach to establish an environmental sustainability assessment (ESA) framework. The study modifies the standard AHP to make it simple in the way of weighting the component contribution properly and applies for Hanoi as the first tropical monsoonal case study. Groundwater abstraction, pollution and environment situations are selected as the three main aspects. The ten core indicators are adopted from the groundwater sustainability indicators, suggested by the UNESCO/IAEA/IAH Working Group, to indicate that the bigger values of the indicators provide the better contribution into sustainability from environmental point of view. As the result, the composite sustainability index, *S*, is assessed at a good level, resulting from the contributions of the acceptable abstraction, good pollution and excellent environment situations. The sustainability indices are evaluated at the moderately high values, improbably reflecting the current problems. The study explores reasons for this gap and finds out suitable solutions to enhance ESA's performance. In order to improve the sensitivity of ESA, it is necessary to not only improve the indicator definition, validate the data used, but also carry out in smaller scales, to have a better view of resources.

Key Words: *Environment, groundwater resources, sustainability assessment, AHP, Hanoi*

1. INTRODUCTION

(1) Groundwater sustainability

The appropriate term of sustainability has been considered as a process that "*meets the needs of the present without compromising the ability of future generations to meet their own needs*"[1]. This concept has nowadays become one of the global critical issues for all application fields. 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[2]. In other words, 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 corrosions such as land subsidence, saltwater intrusion, and so on[3].

Groundwater plays a key role in public water supplies around the world. Worldwide, more than two billion people depend on groundwater for their daily supply and over half of the world's population depends on groundwater for drinking water[4]. Since 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[5]. The excessive groundwater abstraction has caused serious groundwater-level declines in a number of areas[6]. Declining groundwater levels have caused a number of adverse impacts on the environment condition such as groundwater depletion, which practically threatens sustainable aquifers[7], land subsidence resulting from compaction of aquifer materials[8] and groundwater pollution due to additional recharge from wastewater sources[9].

(2) Groundwater sustainability issues in Hanoi

In Hanoi, Vietnam, the river-streams system is pretty dense, but most of the main rivers and lakes are seriously polluted[10] due to the discharge of industrial, agricultural, aqua-cultural and domestic waste to the water bodies without treatment. Hanoi is the target area addressing the environmental sustainability issues of groundwater resources because 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[10],[11]. There have been a number of Hanoi-targeted studies regarding each aspect individually such as quantity, quality and environmental impacts. In terms of quantity, a number of our previous studies has comprehensively investigated groundwater potential resources[12] and level trends in Hanoi[11],[13]; presented the current situation of groundwater abstraction from sustainability point of view[14]. In terms of quality, furthermore, we have studied about hydrogeochemical assessment of groundwater quality during dry and rainy seasons for the two main aquifers[15]; 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[16]; presented the prevalence of arsenic contamination in both two main aquifers[13] and its health effects on the community in this study area[17]. In terms of environmental impacts, Phi and Strokova have studied about land subsidence from over-exploitation[18], and Nguyen and Nguyen[19] also found that the land surface in Hanoi had subsided with an average rate of about 0.02 m/year focusing on Hanoi central and south parts. However, there have been no existed studies dealing with the integrated assessment of environmental sustainability for the valuable resource in Hanoi.

(3) AHP approach for environmental sustainability assessment

The Multi-Criteria Decision Making (MCDM) methods have been considered as a proper approach for sustainability assessment[20]. Analytical Hierarchy Process (AHP) is one of the most popular and powerful MCDM methods[21] because it can help decision makers to cope with multifaceted and unstructured problems such as environment, economic and social. AHP has been utilized in a variety of sustainability assessment for a number of application fields including mining sector[22], environmental sustainable evaluation[23] and regional water resource[24]. 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[25]. However, there have been very few such studies dealing with sustainability assessment of groundwater resources, in which Chen et al. 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[25]. There have been no such studies carried out in Vietnam's groundwater resources as a representative of tropical monsoonal areas so far.

For these reasons, this paper, for the first time, assesses groundwater sustainability of Hanoi by applying AHP approach. In order to apply the standard AHP approach for sustainability assessment, the scientists need to (i) comprehensively study about the current situation and actual problems in the target area to define the appropriate list of the foremost components contributing to the sustainability goal; (ii) consult the expert's opinions to weight those components and (iii) find out the actual data for the lowest-level components. Among these three main steps, the second one 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 unconfident pair-wise comparison judgments; making these judgments again and again until they become acceptably consistent[21]. In Hanoi, however, there are no such complicated surveys carried out to consult the expert's opinions regarding to groundwater sustainability assessment. In order to cope with abovementioned problems, in this paper, we aim to modify the standard AHP to make it simple in the way of properly weighting the contribution of each sustainability component to final goal. In terms of sustainability, three bottom line concepts including economic, environmental and social aspects are normally used[1]. This study assesses the sustainability from the environmental point of view at the initial step due to the limited data availability. Based on the discussion in the environmental sustainability assessment (ESA), the paper provides the useful recommendations to improve ESA's performance. The results are fundamental for further sustainability studies for groundwater resources in Hanoi.

2. STUDY AREA

Fig.1 shows the geographical location and the main river and lake 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^{o}C. 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[10]. That is the main reason why the groundwater resources have become the most important water supply for the local inhabitants.

Our previous study, we comprehensively analyzed the aquifer system for potential groundwater resources in Hanoi[12]. Hanoi's groundwater resources mainly exist in the topmost Holocene unconfined aquifer (HUA) and the shallow Pleistocene confined aquifer (PCA). In HUA layer, silty clay and various kinds of sands

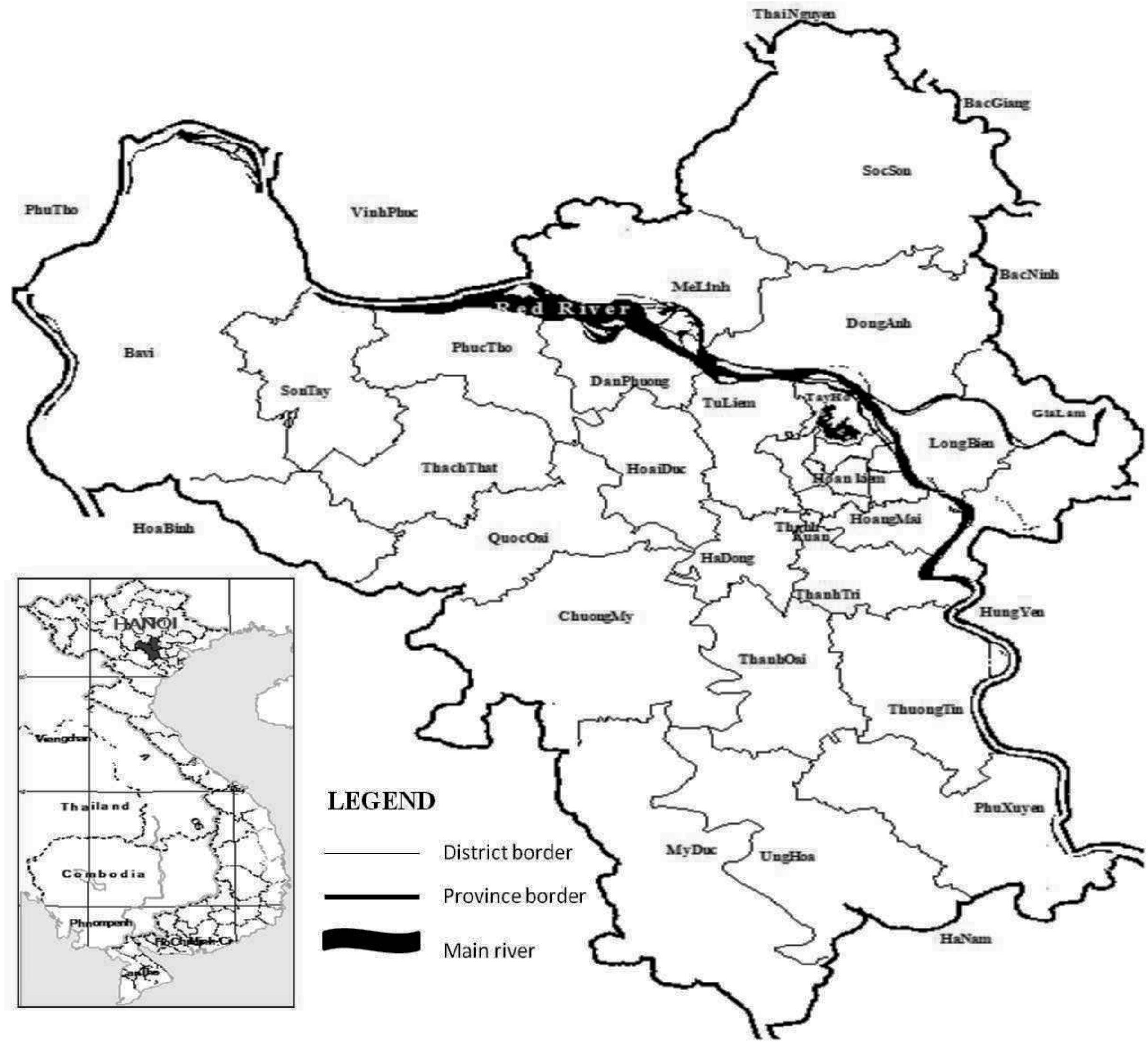

Fig. 1 Study area and main rivers and lakes.

mixed with gravels are the main components. The HUA thickness is variously distributed, more than 35 m with an average of 15 m, approximately. The transmissivity and the specific yield of this layer ranges from 20 to 1,788 m^2/day and from 0.01 to 0.17, respectively. The HUA, thus, 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. The shallow Pleistocene confined aquifer (PCA) depth is also widely distributed, less than 10m in the North of the Soc Son District, around 20m in Dong Anh District, and up to 40 m in the South of the Red River. The PCA layers have a complex components of sand mixed with cobbles and pebbles. The PCA thickness is variously changed, with the highest value of up to 50m and the average of 35 m approximately and trend increasing from the North to the South. With a large range of transmissivity from 700 to 2,900 m^2/day, and the specific storativity from 0.00004 to 0.066, 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

(1) ESA for groundwater resources by AHP

The main advantage of AHP is to decompose a decision problem into a hierarchy of more easily comprehended sub-problems, each of which can be analyzed independently. This study utilizes this big advantage of AHP to establish the indicators and aspects for sustainability assessment of groundwater resources.

Fig.2 shows the basic evaluation steps in ESA evaluation based on the conventional AHP.

Step 1: Establishing the multiple-level hierarchy:

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

Step 2: In order to find the relative contribution of each indicator to the final goal, questionnaires are made to consult expert's opinions by making a series of pair-wise comparison judgments. The sound-number ratios are used to present the judgments (2.1). The expert's judgments are then checked whether they are acceptably consistent or not (2.2). The judgments will be making again and again, until they are acceptably consistent.

Step 3: Collection of actual data values for all the indicators.

Step 4: Sub-environmental sustainability indices (SA_i) are evaluated by the equation (1) and the composite environmental sustainability index, *S*, is assessed by the equation (2).

$$SA_i = \sum_{j=1}^{N_i} W_{ij} * SI_{ij} \quad (1)$$

$$S = \sum_{i=1}^{N} WA_i * SA_i \quad (2)$$

where *N*: number of the aspects; $i = 1 \ldots N$;
N_i: number of the indicators in the aspect i^{th}; $j = 1 \ldots N_i$;
WA_i: the weight of the the aspect i^{th};

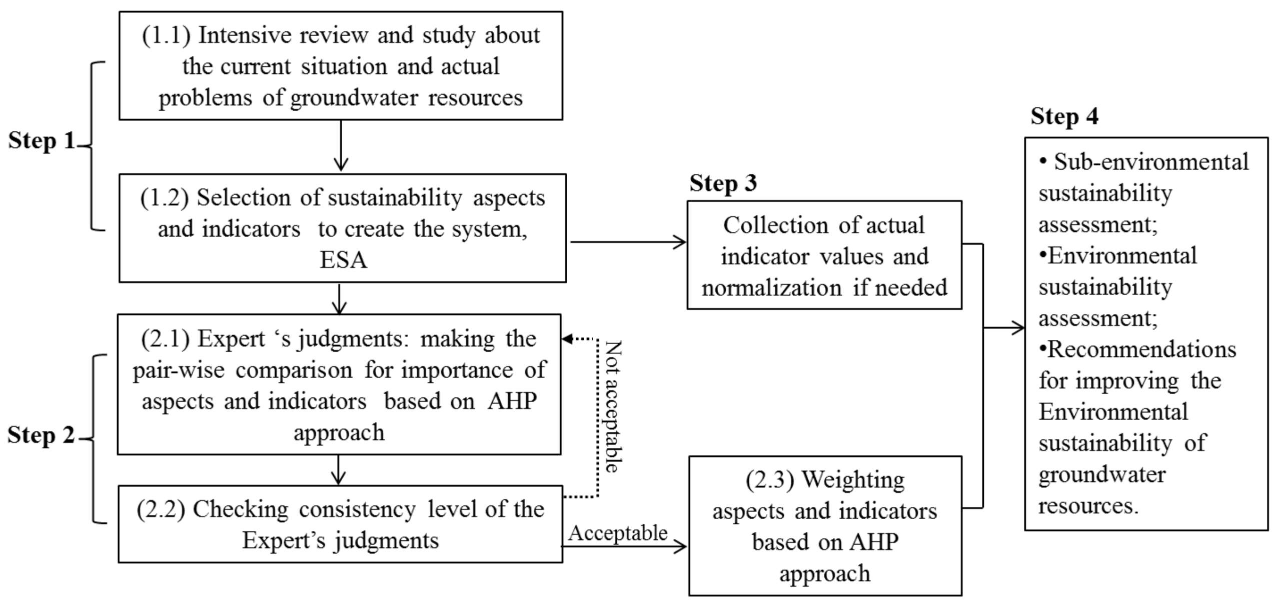

Fig. 2 Environmental sustainability assessment (ESA) based on the standard AHP approach.

W_{ij}: the weight of the indicator j^{th} in the aspect i^{th};
SI_{ij}: the actual values of the indicator j^{th} in the aspect i^{th};
SA_i: Sub-environmental sustainability index for the aspect i^{th};
S: the composite environmental sustainability index;
with the constrains:

$$0 \le WA_i, W_{ij} \le 1; \quad (3)$$

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

$$0 \le SI_{ij}, SA_i, S \le 1; \quad (5)$$

Sustainability Scale: This study proposes a suitable sustainability scale in which the situation of each indicator in terms of achievement of groundwater sustainability can be classified into five classes in a scale of 0–1: very poor (0 - 0.2), poor (higher or equal to 0.2 - 0.4), acceptable (higher or equal to 0.4 - 0.6), good (higher or equal to 0.6 - 0.8) and excellent (higher or equal to 0.8 - 1.0). The highest scores for sustainability is 1, meaning as 100%; and lowest one is 0, as zero percentage.

(2) The simple AHP

The numbers of main steps in the simple AHP are the same with the standard AHP. The simple AHP is an approach in which the weighting process by the function of number of the sustainability aspects (N) and the indicators (N_i) is used to replace the ones by the expert's comparison judgments in the standard AHP. The reasons for this replacing: the weighting process based on the standard AHP has drawn much criticism[26] because it is as an arbitrary process based on sound-number ratio and human preferences; while the equally theoretical weights can help to avoid bias in the results caused by unequal weights[27]; and there is no such uncertainty judgment survey done in the study area. To cope with these problems, in the simple AHP, particularly, once these foremost components are decided, their weights can be made automatically by the following equations (6) and (7):

$$W_{ij} = \frac{1}{N_i} \quad (6)$$

$$WA_i = \frac{1}{N} \quad (7)$$

4. ESA APPLICATION TO HANOI GROUNDWATER RESOURCES

In the AHP approach, generally, the most important step is to identify the main components in the sustainability hierarchy (step 1). In this study, we carefully selected the indicators and aspects for groundwater sustainability assessment based on the consideration of the current situation actual problems occurred and expected goal[25]. The more complex indicators system can be developed if the more actual data are available.

Table 1 shows the main aspects and sustainability indicators for ESA framework. In Hanoi, the excessive groundwater abstraction has caused serious groundwater-level declines in the central and south parts, in turn; declining groundwater levels have caused a number of adverse impacts on the environment condition such as groundwater depletion, land subsidence and groundwater pollution. Therefore, in this study, in order to evaluate the environmental sustainability, the situation of groundwater regarding abstraction, pollution and environment are considered as three main aspects in ESA framework.

Regarding groundwater abstraction situation (SA_1), ESA focuses on the situation of groundwater abstraction, recharge and exploitable. As guided by the UNESCO/IAEA/IAH Working Group[28], the indicators regarding to these ratios between abstraction to recharge and exploitable groundwater resources, are mainly used to assess groundwater sustainability 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 sustainability goal. That is the reason why we define SI_{11} and SI_{12} as following. By these definitions, the environmentally sustainability contributions of the indicators are maximized at ones if there is no groundwater abstraction, and minimized at zeros if over-exploitation.

$$SI_{11} = \begin{cases} 1 - \dfrac{\text{Total abstraction}}{\text{Total recharge}} & \text{if the abstraction} \le \text{the recharge} \\ 0 & \text{if the abstraction} > \text{the recharge} \end{cases} \quad (8)$$

$$SI_{12} = \begin{cases} 1 - \dfrac{\text{Total abstraction}}{\text{Exploitable groundwater}} & \text{if the abstraction} \le \text{the exploitable} \\ 0 & \text{if the abstraction} > \text{the exploitable} \end{cases} \quad (9)$$

Regarding groundwater pollution situation (SA_2), the indicators are defined as the ratios between the contaminated areas due to natural and anthropogenic causes to total areas[28]. ESA adopts four indicators based on the current situation of groundwater pollution, which recently has been reported in the number of publications in literature review. In this study, there are three sustainability indicators regarding the three main pollution concerns such as the arsenic, nitrogen and coliform contaminated groundwater[29] and the fourth referring to treatment requirement. The ESA's indicators in aspect SA_2 are defined as the total areas with no contaminated issues to total study area to indicate that the bigger these values are, the better contribution to the environmental sustainability goal the indicators can make. Similarly with the indicators regarding environmental situation (SA_3), ESA focuses on four indicators based on the environmental impacts reported as the adverse consequences from over-exploitation, groundwater table decline and salinization. In this study, the ten indicators shown in **Table 1** are considered as the main components presenting the actual scenarios of groundwater resources in Hanoi.

5. RESULTS

This study calculates the actual values of the aforementioned sustainability indicators by gathering the necessary data from the government database and Ministry of Natural Resources and Environment, Vietnam.

Table 2 shows the ten indicators in three main sustainability aspects with their formula, variables used and the explanations. We use the assumption in which the point-based measurements are the representatives for the area by converting the point-based measurements into the area because all the groundwater samples were broadly collected[29].

Table 3 shows the results with weights proposed by the simple AHP approach. The composite environmental sustainability index, S, is about 0.688 assessed at good level, resulting from the contributions of the acceptable abstraction (SA_1) of 0.5, the good pollution (SA_2) of 0.628 and the excellent environment (SA_3) of 0.938. Further, the **Fig.3** shows the environmental sustainability triangle for Hanoi's groundwater resources. The sustainability triangle area (SA_1, SA_2, SA_3) almost covers 75% of the perfect sustainability triangle (1, 1, 1), indicating that Hanoi is environmentally good in groundwater use and development.

6. DISCUSSION

From **Table 2**, the proportional of groundwater abstraction is small, compared to groundwater recharge (about 71%) and groundwater exploitable resources (about 29%); thus the groundwater in Hanoi can be considered as "low development" and the abstraction amount could be tentatively increase to meet the current needs. From **Table 3** and **Fig.3**, the resource is assessed at good sustainability with the excellent environmental situation. These assessments are hard to believe because as reported in our previous studies, groundwater over-exploitation and water table decline are seriously occurred in the central area (about 7% of the study area)[11),13)]. So what are the main reasons for this gap and how to improve the performance of ESA framework to have a better view on the resources?

Table 1 ESA Framework for Groundwater Resources in Hanoi, Vietnam.

Sustainability Aspect	Sustainability Indicator	Definitions
Groundwater Abstraction Situation (SA_1)	SI_{11}	One minus the ratio of groundwater abstraction to groundwater recharge if this ratio is less than 1, otherwise 0
	SI_{12}	One minus the ratio of groundwater abstraction to exploitable groundwater resources if this ratio is less than 1, otherwise 0
Groundwater Pollution Situation (SA_2)	SI_{21}	Proportion of area with no arsenic-contaminated groundwater to study area
	SI_{22}	Proportion of area with no ammonium, nitrate dioxide and nitrate -contaminated groundwater to study area
	SI_{23}	Proportion of area with no coliform-contaminated groundwater to study area
	SI_{24}	Proportion of area with no groundwater treatment requirements to study area
Environment Situation (SA_3)	SI_{31}	Proportion of area with no occurrence of overexploitation to study area
	SI_{32}	Proportion of area with no decline of groundwater level caused by groundwater over-exploitation to study area
	SI_{33}	Proportion of area with no occurrence or potential of land subsidence caused by groundwater over-exploitation to study area
	SI_{34}	Proportion of area with no groundwater salinization problems caused by groundwater over-exploitation to study area

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

Indicator	Formula	Variables used/ Explanation	Value
SI_{11}	1- (Total groundwater abstraction)/(Total groundwater recharge)	• Total groundwater abstraction: 1,799,562 m^3/day[14]. • Recharge estimation: 276 mm/year (equal to 917,562,000 m^3/year)[14]	0.29
SI_{12}	1- (Total groundwater abstraction)/(Exploitable groundwater resources)	• Total groundwater abstraction: 1,799,562 m^3/day[14]. • Groundwater exploitable resources: 6,199,140 m^3/day[14]	0.71
SI_{21}	(The areas with no arsenic-contaminated groundwater)/(Study area)	About 43% samples in the major aquifer are exceeded the Vietnam guideline of arsenic concentration of 0.01 mg/l[29]. Because these all groundwater samples were broadly collected over the study area, to cope with the data availability, we simply use the assumption in which the point-based measurements are the representatives for the area for the indicators in this second aspect, SI_{21}, SI_{22}, SI_{23}, SI_{24}.	0.57
SI_{22}	(The areas with no ammonium, nitrate dioxide and nitrate-contaminated groundwater)/(Study area)	About 43% ammonium, 15% nitrate dioxide and 12% nitrate of the water samples are not permissible for drinking water [29]; 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 areas with no coliform-contaminated groundwater)/(Study area)	About 22% of samples in both the aquifers have coliform values higher than the standard limit in Hanoi [29]	0.78
SI_{24}	(The areas with no groundwater treatment requirements)/(Study area)	Approximately, 41%, 33% and 22% of groundwater needed to be treated because of exceeding the standard limits of arsenic, nitrogen and coliform values, respectively[29]; the maximum percentage is about 41% thus the possible largest area with no groundwater treatment requirements could be 59%	0.59
SI_{31}	(The areas with no occurrence of overexploitation)/(Study area)	See the explanations for SI_{32}	0.91
SI_{32}	(The area with no decline of groundwater level caused by groundwater over-exploitation)/(Study area)	• Study area: 3324.5 (km^2) • Groundwater level is mainly declined in the central and south parts of Hanoi including Tuliem, Tayho, Caugiay, Longbien, Hoangmai, Hoankiem, Badinh, Haibatrung Dongda[18] and Hadong [13]	0.91
SI_{33}	(The areas with no occurrence or potential of land subsidence caused by groundwater over-exploitation)/(Study area)	• Study area: 3324.5 (km^2) • Land subsidence is occurred and/or predicted to be occurred in Hanoi metropolitan areas including Badinh, Tuliem, Caugiay, Dongda, Haibatrung, Hoankiem, Hoangmai, Thanhxuan and Thanhtri[18]	0.93
SI_{34}	The areas with no groundwater salinization problems caused by groundwater over-exploitation)/(Study area)	• Study area: 3324.5 (km^2) • Groundwater salinization problems have been predicted in coastal areas in Vietnam[30], but there is no evidence of groundwater salinization problems reported in Hanoi.	1.00

From **Fig.3**, the environment situation aspect (SA_3) is assessed at the excellent sustainability scale. The reason for this hard-to-believe assessment is about the moderately small proportion between the areas with the environmental impacts to 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 indicators do not locally reflect the actual problems appropriately. Moreover, in **Table 2**, 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, in our previous study, Nguyen et al.[29], 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. In addition, the unlisted groundwater abstraction in the documents can make the errors in total reported abstraction amount compared to the actual one, thus the general abstraction situation may be not appropriately assessed. The values of the abstraction and exploitable resources should be validated to make the evaluation much more closely to the reality.

The results of ESA are not only sensitive with data availability but also the definition of the indicators. Regarding to groundwater pollution situation aspect (SA_2), the indicator formulas are defined by ratios of the non-contaminated areas to the total area. For example, the indicator SI_{21}, the area with no arsenic contaminated groundwater is about 50% of the total area, the sustainability level is acceptable. Such these linear relationships do not reflect the actual situation well. Moreover, the sustainability indicators regarding groundwater pollution situation are sensitive with the different aquifers. Because the pollution situations in the two main unconfined and confined aquifers are different in both chemical compositions and concentrations[12), 13)]. Therefore, in order to improve the sensitivity of ESA performance, the more suitable definition of the sustainability indicators is indispensable to be improved and the indicators could be investigated at the smaller scales such as aquifers and districts to make it closed to the actual groundwater situation and the indicators and aspects 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[21)]. To do that, we carefully select the main sustainability aspects and indicators covering the actual situation of groundwater resources in Hanoi. Those aspects and indicators are considered as equally and importantly contributing to the sustainability goal and the corresponding sustainability aspects, respectively, from the environmental point of view. 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.

Table 3 Environmental sustainability assessment for Hanoi groundwater resources.

SA_i	WA_i	SI_{ij}	W_{ij}	SI_{ij}	SA_i	S
SA_1	0.333	SI_{11}	0.50	0.29	0.500	0.688
		SI_{12}	0.50	0.71		
SA_2	0.333	SI_{21}	0.25	0.57	0.628	
		SI_{22}	0.25	0.57		
		SI_{23}	0.25	0.78		
		SI_{24}	0.25	0.59		
SA_3	0.333	SI_{31}	0.25	0.91	0.938	
		SI_{32}	0.25	0.91		
		SI_{33}	0.25	0.93		
		SI_{34}	0.25	1.00		

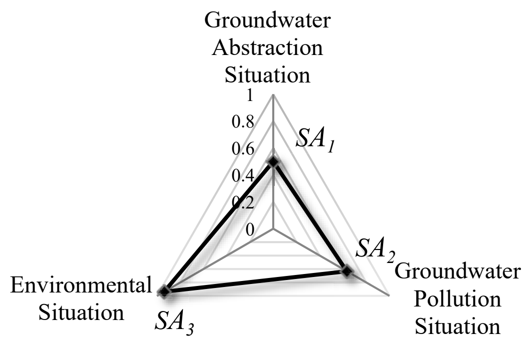

Fig. 3 Environmental sustainability assessment for Hanoi.

7. CONCLUSION

The main object of this study is to assess environmental sustainability level for valuable groundwater resources by applying the indicator-based approach, AHP. In this study, we successfully not only select the appropriate list of three main aspects and the ten core sustainability indicators, appropriately presenting for groundwater situation in the monsoonal area, Hanoi, but also propose the simple AHP approach in handling the limitation of data availability for the first time. The sustainability indices are evaluated at the moderately high values, improbably reflecting the current problems in the target area. The study then explores the main reasons for this gap and finds out the suitable solutions to enhance ESA's performance. In order to improve the sensitivity of ESA, it is necessary to not only improve the definition of the sustainability indicators, validate the data used, but also carry out studies in the smaller scales such as district and aquifer, to have the better views of groundwater resources.

ACKNOWLEDGEMENT: This study was carried out as a part of the research project "Study on guerrilla rainstorms, flood inundation and water pollution in metropolitan watersheds" supported by the Tokyo Metropolitan Government, Japan (represented by A.Kawamura). We would like to thank Ministry of Natural Resources and Environment (MONRE) of Vietnam for supplying the necessary field data from the earlier feasibility studies.

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(Received April 7, 2016)