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【論文の内容の要旨】

Groundwater plays a key role in public water supplies around the world. In Hanoi, Vietnam, the communities mainly depend on the groundwater for domestic, industrial and commercial purposes. The rapid groundwater exploitation without an adequate institutionalized management system has caused a series of adverse impacts such as drying up of shallow wells, decline of groundwater level, land subsidence and groundwater pollution. There have been a number of Hanoi-targeted studies regarding groundwater potential investigation, groundwater level trends and groundwater quality with the prevalence of severe arsenic contamination. However, none of them have dealt with sustainability assessment of groundwater resources as a primary objective and how to translate this objective into a set of more specific actions, which could provide a sufficient information to assist decision-making effectively. To this end, sustainability assessment is considered as a useful technique in any application field specifically in sustainable water resources development. This technique can provide a certain level of awareness on the environmental, social and economic benefits, which is necessary to support the preservation of this resource for future generations.

Regarding sustainability assessment methodologies, Multi-Criteria Decision Making (MCDM) methods have been considered as a proper approach for sustainability

assessment. Analytical Hierarchy Process (AHP) is one of the most popular and powerful MCDM methods due to its ability to cope with multifaceted and unstructured problems such as environment, economic and social sustainability. The main advantage of AHP applications for sustainability assessment is their capability to categorize and identify the main components (criteria, aspects and indicators) that better reflect significant performances. An indicator-based AHP is common for sustainability assessment but it has been not intensively investigated for groundwater yet. Therefore, a study dealing with the indicator-based AHP sustainability assessment of groundwater is necessary to provide fundamental references for finding solutions towards sustainability of the resource.

Based on these above-mentioned reasons, this dissertation focuses on the following main objectives: (i) to develop an indicator-based AHP for Sustainability Assessment of Groundwater resources (AHP-SAG) to cope with the limited data availability and reliability, and insufficient financial supports in the developing countries like Vietnam; (ii) to develop a clearly defined sustainability assessment framework including the utmost sustainability goal, associated with its sustainability criteria, aspects and indicators for groundwater resources of Hanoi by using the proposed AHP-SAG; (iii) to apply the proposed AHP-SAG framework for a reasonable sustainability assessment of groundwater resources in Hanoi. In order to achieve these main objectives, this dissertation is composed of five chapters.

Chapter 1 was comprised of the background, motivation, and objectives of this study. A comprehensive review of literature and a description of the scopes and methods were presented.

Chapter 2 focused on current sustainability issues of groundwater resources in Hanoi, Vietnam. A brief description of the basic topographical conditions, current situation of domestic water uses, and groundwater conditions of Hanoi was provided. The environmental and socioeconomic sustainability issues of groundwater in Hanoi were comprehensively reviewed and presented.

Chapter 3 proposed a sustainability assessment framework for groundwater resources, which was mainly developed from the AHP. In the proposed AHP-SAG, weighting process, the most tedious step in the conventional AHP applications was modified to make it simple. A necessary concept of sustainability index function (SIF) was introduced to make a clear relationship between an indicator value and its sustainability index, which has remained unclear in the sustainability assessment literature. In sustainability assessment studies, a reasonable assessment is the one whose results could reflect appropriately the actual situation in reality. So in this

Chapter, not only the linear SIF, which was usually carried out in the conventional AHP application for sustainability assessment, but also the non-linear SIF cases were also investigated to find out a reasonable sustainability assessment for groundwater resources. The proposed AHP-SAG approach is described in detail in this Chapter.

Chapter 4 dealt with the applications of the proposed AHP-SAG technique in sustainability assessment of groundwater resources in Hanoi, in which all the three main pillars (environmental, social and economic) of sustainability concept were considered as the three important sustainability criteria in the framework. Based on the available and reliable data of the current groundwater situation in the target area, the sustainability aspects were proposed as quantity, quality, and management in each criterion. Furthermore, the sustainability indicators in each aspect were defined clearly, which could present the overall situation of groundwater resources development in Hanoi.

For sustainability assessment, the environmental, social and economic criteria were composed of their twelve, thirteen and nine (34 in total) core sustainability indicators, respectively. By gathering the necessary data, environmental, social and economic sustainability assessment of Hanoi was investigated by using the proposed AHP-SAG. It was found that the sustainability indices assessed by the combined linear and non-linear SIF case were more reasonable than the conventional linear SIF alone, because the sustainability indices properly reflected the current groundwater problems in Hanoi. The environmental, social and economic criteria were appropriately assessed at acceptable, acceptable, and good sustainability levels, respectively. Lastly, the final sustainability index was assessed at acceptable level. However, there was a big variation among the 34 sustainability index values of indicators. Some indicators were assessed closely to the poorest but the others were even reaching the most excellent sustainability levels. The variability of the environmental sustainability indices indicated that the current groundwater abstraction networks are heavily concentrated to some specific areas in Hanoi, which is not successful to utilize the rich recharge from nature. From the social viewpoint, the communities are satisfied with the quantity but dissatisfied with the current poor quality and the relative high water prices. Some economic indices revealed that there was a considerable economic loss due to the ineffective water supply in the target area. The proposed AHP-SAG method thus provided a clear panoramic view of the environmental, social and economic impacts on sustainability of groundwater resources in Hanoi.

Chapter 5 presented the overall conclusions and recommendations for sustainable groundwater resources management in Hanoi, including the future research works.