論文の内容の要旨
Abstract of Dissertation

論文題目　MULTI-CRITERIA ASSESSMENT ON SANITATION SYSTEMS FOR SMALL TOWNS IN VIETNAM

（ ベトナムの小都市における衛生施設の多側面評価 ）

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ABSTRACT

World communities are now focusing attention on sustainability as a defined goal. However, the road toward sustainability poses many challenges with many areas of human needs to be dealt. One of the most important areas of daily human needs is appropriate and adequate sanitation. There is no doubt that sanitation is vital for human health, especially for people living in poor and developing countries. It could generate economic benefits, contribute to dignity and social development, as well as help to improve the environmental quality. That was the reason why on 20th December 2006, the UN General Assembly decided to declare 2008 as the International Year of Sanitation (IYS). This is an opportunity for global community to raise awareness and accelerate actions for the achievement of the sanitation Millennium Development Goal (MDG) through a variety of proposed actions and interventions. However, for the transition to sustainability, those actions and interventions must be assessed. This has posed important challenges in providing efficient but reliable tools and assessment frameworks.

In the efforts to provide communities with technically well-functioning systems for sanitation, we might ignore the broader issues of sanitation, including environmental protection and human health, the important social and aspects of sanitation. Therefore, an integrated view in sanitation planning where planners move beyond technical aspects is required to supply sustainable sanitation. There is one of possible ways of reaching beyond the provision of merely technical solutions to sanitation is to focus on what assessment criteria which future sanitation systems should comply with to be sustainable in given settings. By focusing on the functions of sanitation systems rather than technology itself, more rooms will be available for innovative solution.

In sanitation planning process, attention must also be given to pro-active involvement and participation as well as contributions of both governmental and non-governmental stakeholders. The different points of views from these various stakeholder groups should be considered in the decision making process.

Consequently, there is a need to develop a framework that integrates these preferences and multi-criteria analysis towards a series of wastewater treatment scenarios as decision support tools for sanitation planning process.

Based on this goal, this dissertation aimed to:

- Develop a methodological framework for multi-criteria assessment of wastewater treatment scenarios, which was based on various analytical methods covering both qualitative and quantitative aspects such as Life Cycle Assessment (LCA), health risk analysis, cost analysis and stakeholders' preferences assessment through Analytic Hierarchical Process (AHP) technique, which was chosen as mean of analysis and incorporation of stakeholders' preferences into the sanitation planning process.
- Application of the developed methodological framework to evaluate a series of treatment scenarios for wastewater system in Vietnam, with a case study in one of small towns in Vietnam called Toan Thang town.
- Investigate which assessment criteria or impact categories were the most relevant on the selection of the most promising and sustainable wastewater treatment scenarios from the different stakeholders' perspective under a given context.

The first part of the assessment was referred as systems analysis and scenarios development, started with defining the problem and objectives to subsequently determine the consequences of various alternatives, often through the helps of different tools and models, and then evaluate and select the best alternative, which will be implemented and possibly monitored. As a result, a detailed investigation of the current situation on wastewater treatment system in the study town was carried out in order to identify the problems and objectives to be considered during the planning process. Once the problems, characteristics of the current system as well as the objectives have been decided, various potential scenarios were developed based on the diverse factors considered.

These potential scenarios would then go through a developed 3-Step screening approach for comprehensive and multi-criteria assessment, which taking into accounts both qualitative and

quantitative aspects in the overall screening process. A set of 12 potential scenarios was identified for the coarse screening in the Step 1. In this step, the evaluation was based on a proposed set of multidimensional criteria. After this coarse screening step, a short-listed 3 scenarios, which was explained in detail on chapter 5, out of 12 potential scenarios was proposed for further, fine screening process using quantitative analysis tools. Several scientific analytical and assessment tools, such as LCA, risk analysis, cost analysis were utilized in this quantitative screening process (Step 2). Results from this step would give stakeholders a deep and valuable insight of different proposed scenarios. Based on this valuable information, stakeholder groups would give their judgments and preferences toward impact categories as well as scenarios in the stakeholders' preferences analysis in the Step 3.

From the detailed analysis conducted in Toan Thang town as a case study, three treatment scenarios for wastewater treatment system in Toan Thang were proposed from the coarse screening process using qualitative and multi-criteria evaluation technique. Each scenario presents a certain degree of trade-offs between benefits and its associated impacts that provided the basis for the decision problem among stakeholder groups. Scenario 1 represents "Business as usual", where residents will continue with the existing wastewater system, no collection and central treatment facility. The only household wastewater treatment facility is on-site sanitation system using septic tanks as a common trend during the urbanization process in Vietnam nowadays. Effluent from household septic tank, which does not satisfy National Effluent Discharge Standard TCVN 5945-2005 (column B), will still be discharged directly into water bodies in the surrounding areas. Meanwhile, Scenario 2 represents a combination between decentralised and centralized sanitation solution. It's an environmentally sound solution where wastewater will be treated on-site using household septic tanks, and then will be collected by a newly constructed wastewater collection system and further treated using a series of waste stabilization ponds including anaerobic ponds, facultative ponds and maturation ponds to reduce the organic and microbial pollutants to an acceptable level before discharging to environment. Scenario 3 represents a decentralised sanitation solution where a group of 25 households or more will be equipped with one communal baffle septic tank. Wastewater from each household will be collected by PVC pipe system and then leaded to this common baffle septic tank for treatment before discharging into the water bodies. The baffled septic tank is suitable for all kind of wastewaters, including domestic. It has been proven that baffled septic tank with or without anaerobic filter (BAST or BASTAF) seems to be one of the most feasible and promising decentralized sanitation options for wastewater treatment in residential areas of Vietnam.

These three scenarios were then compared quantitatively according to a series of assessment criteria (also referred as impact categories). These criteria were broken into: *Organic emission loading* (in term of BOD/COD) (A), *Human health impacts due to global warming potential* (B), *Potential of nutrient recovery and safe reuse of treated wastewater* (C), *Local health impacts due to water pollution and microbial infection* (D), and *Costs of construction, operation and maintenance of the system* (E).

The ranking and weighting of these selected scenarios as well as the proposed impact categories were carried out by three different stakeholder groups with a total number of 109 stakeholders involved into interviewing process for preferences assessment. These stakeholder groups have been identified based on the characteristics and institutional framework under the local context of Toan Thang town. They were included sanitation scientists who work at Universities, research institutes in Vietnam, engineers and consultants who work at environmental consulting companies and involved directly or indirectly into ongoing water and sanitation projects in small towns of Vietnam (group 1). Group 2 consists of sanitation planners and policy decision makers who are representatives of governmental side to formulate decisions regarding sanitation planning in small towns. Local resident, farmers and interest groups, who currently residing in the study town, represent for group 3. The group 3 was further divided into three sub-groups including rich, poor and middle-income group. Each group has its own way of viewing the world, its own method of envisioning solutions, and its own societal responsibility.

These groups were interviewed to determine how they perceived the relative importance of scenarios with respect to assessment criteria/ impact categories, relative importance among these criteria as well as stakeholder groups. A questionnaire was developed based on the AHP approach. Each question consisted of a pairwise comparison of two scenarios, two assessment criteria/impact categories and two stakeholder groups with respect to the overall goal. Finally, the analysis results were synthesized and compared among three scenarios with respect to each assessment criteria, relative importance among criteria and stakeholder groups' priorities in a consensus fashion.

Results from the stakeholders' preferences assessment revealed that, in case of group 1, the possible *local health risk* associated with wastewater treatment scenarios due to water pollution and microbial infection has a greatest important if compared to the other impact categories, with weighting factor of 0.333. This impact category was followed by potential of nutrient recovery and safe reuse of treated wastewater and costs, which have almost the same weighting factor of

0.225 and 0.224, respectively. Health impact due to Global Warming Potential (GWP) has received the lowest importance or in another word, lowest weighting factor of 0.049, which is 6.8 times less important than the *local health risk* impact. The weighting trend given to impact categories of group 2 was almost similar to group 1. However, a different distribution was applied for the case of group 3 for local residents, business and interest groups, where local health risk impact plays the most important role with weighting factor of 0.375, but followed by potential of nutrient recovery and safe reuse of treated wastewater of 0.231, global health impact due to GWP of 0.169, the associated costs of 0.131 and organic emission loads impact of 0.095, respectively. There is no significant difference regarding preferences among three sub-groups within group 3.

There are several reasons for such ranking results. One of the possible reasons is due to the reason that sanitation issue in general and wastewater treatment in particular is becoming a very urgent issue at the study town; therefore, according to the local residents' opinions, they are very much concerned not only on their health but also the health of their future generations, such as their children or grandchildren, are much more important than ever; thus local health risk, nutrient recovery and safe reuse of treated wastewater and global health risk are rated and given more priority than the other impact categories like organic emission loads and costs. As a result, they tended to choose the option, which produces the lowest health risks to both their lives as well as their future generations. According to the questionnaire survey, the local residents seem to be fully convinced of the reality, global health impacts and seriousness of global warming. This can be the results from effective information communication on televisions and media means for global warming phenomena. However, it is critical to highlight that those people are widely different in terms of backgrounds, experiences and knowledge. Thus, there is a wide range from those respondents who know a lot about global warming or climate change, to those who never heard of it.

Regarding stakeholders' preferences toward treatment scenarios, the aggregation of weighting results and synthesis analysis have revealed that the total weights assigned, from both three stakeholder groups, Scenario 2 was rated as the highest priority or the most preferred option with around 64% of preferences over Scenario 3 with 23% and Scenario 1 with 13 %. Sensibility analysis of weighting scheme for treatment scenarios showed that the preference for scenarios would not change across the stakeholder groups if the weighting factors assigned to different groups change; although the weight values assigned for each scenario are varied among different groups.

In summary, the overall results from this case study have indicated clearly that Scenario 2 will remain the most promising and sustainable solution for Toan Thang town as well as for other similar small towns in Vietnam, where land space is available, due to cost effectiveness, ease of maintenance, and low use of expensive aeration devices. Although it's expected that if this scenario is to implemented, greenhouse gases (GHGs) emissions from this scenario will continue to rise in those areas until economic and technical means are more available to adopt advanced (and costly) compacted treatment processes.

This case study has proved that multi-criteria approach based on AHP, which was supported by several other analytical tools like LCA and health risk analysis, is a powerful approach supporting to the decision-making process, allowing stakeholders to grasp technical insights and other aspects of sustainability for proposed scenarios in searching for acceptable compromise solutions for a sustainable wastewater treatment system. In addition, it is often seen that decision makers who involved in sanitation planning issues usually agree on the necessity of interventions. However, conflicts occur when interventions are specified and touch upon citizens' personal interest and responsibilities in their local societies. In this case, a rationalization of the decision making process is clearly needed in order to deal with conflicting objectives and divergent interests. AHP has been proven in this case study as a powerful process for tacking this kind of complex problem. It provides a framework, which facilitates understanding and discussion on the different solutions towards finding the most promising, acceptable and compromise solution during a process in which stakeholders which diverse background, point of views can participate in. Moreover, it is a flexible model that allows stakeholders to make decisions by combining judgments and personal values in a logical way. Furthermore, it can be integrated with other techniques such as LCA, health risk and cost analysis in order to assist for the integrated and comprehensive assessment process of sanitation solutions. Its application in the real world has also been discussed in this dissertation.

Such scientifically sound decision support framework should be adopted by sanitation planners, decision makers and approval authorities, not only at the small town scale in Vietnam but also at a larger scale in other developing countries, to ensure specific sustainable solutions are selected under a given local context.