博士論文（要約）

Integrated Water Management in Hanoi for Adaptation to Urbanization and Climate Change

（ハノイの都市化と気候変動に適応するための総合的水管理）

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Between 2000 and 2025, the urban population in Vietnam is expected to double from 10 million to 20 million. Therefore, urbanization and increasing water demand is one of the most important challenges in Vietnam, especially in Hanoi. At present, Hanoi city relies on groundwater as a main source of water supply, but it is going to shift to the surface water as the demand increases in the near future. However, variation of rainfall, dam construction in the upstream of the Red River and climate change in the near future make the surface water unreliable water source for water supply in Hanoi City. As the extension of water supply coverage is slow, many households still rely on groundwater as their drinking water sources. However, groundwater is contaminated by ammonia, arsenic, iron, bacteria and others. In order to obtain clean drinking and cooking water many households use point-of-use (POU) treatment devices including Sand filter (SF), anion-exchange (IX), ceramic filter (CF), microfiltration (MF), and reverse osmosis (RO).

Hence, this is the first comprehensive research to assess water quality and the occurrence and level of microorganism in aquatic environments and drinking water in Hanoi City, to identify the water practices and the proliferation and treatment efficiency of point-of-use (POU) water treatment systems and to identify the solutions for urban water system to adapt with urbanization and climate change.

A survey of POU usage in 239 households by questionnaires and face-to-face interview in five sites in Hanoi was carried out in 2012 and 2013. Two-hundred ninety 294 water samples were taken to investigate the treatment efficiency of those POUs from 35 households in 9 sites. I also tested 110 water samples to investigate the occurrence of bacterial indicators *Escherichia coli* (*E. coli*) and total coliforms (TC) in wastewater, pond, rivers, wells, piped water in household and bottled water. In which, 38 samples were tested for adenovirus (AdV), aichivirus (AiV), norovirus genogroup I (NoV GI), norovirus genogroup II (NoV GII) and entrovirus (EV) by using reverse transcription quantitative PCR (RT-qPCR). Finally, I investigated available commercially POUs also in the market.

As a result, groundwater presented an average As concentration of 69 μg/L (maximum 305 μg/L) and 84% of these samples had As concentrations higher than 10 μg/L (the WHO guideline). Other contaminants such as iron, manganese, ammonia, dissolved organic carbon, dissolved organic nitrogen, microbial indicators were moderately high in water sources using at household.

Results showed that *E. coli* and total coliforms was found to be positive not only in environmental waters but also in piped- and bottled water samples. *E. coli* was detected in 6%, 21%, and 11% of ground-, piped-, and bottled water samples, respectively and total coliforms were detected in 35%, 79% and 89% of ground-, piped-, and bottled, respectively. Remarkably, all piped water samples contained free chlorine levels lower than 0.16 mg/L that did not comply with the Vietnamese drinking water standard value of 0.3-0.5 mg/L and the WHO guideline of 0.2 mg/L. AdV, AiV, and NoV GI, NoV GII and EV were positive in all influent wastewater samples. Human enteric viruses were also found to be positive in wastewater effluent, pond- and river water samples, where, AdV and NoV GII were the most abundant. Two out of eight groundwater samples were positive with AiV and NoV GI but the concentration was below the quantification limit. The levels of human enteric viruses were below the detection limit of all the piped water samples. Remarkably, however, one of the four bottled water samples was positive with *E. coli*, total coliforms and AdV, indicating poor handling or management of bottled water.

Regarding the household survey, most of residents in study areas requested an improvement of water quality, and the use of POU devices tended to increase significantly. The result also indicated that 90% of households in rural areas had sand filters and between 18% and 76% of the households in rural and urban areas used POU water treatment devices, of which RO devices accounted for 58%. In the market, there were 136 brands of commercially available POUs, but the removal efficiency varied among different treatment processes. POU water treatment systems were not only used to treated groundwater but also for piped water. Arsenic was moderately effective to remove As from groundwater (67% removal) by sand filter, and higher 90% with RO, but other POU systems could not remove As at all. Although most of the arsenic was As(III) form in groundwater, it was oxidized to As(V) in the sand filters. Thus, RO filtration was found quite effective in removal of arsenic from groundwater to obtain water with As concentration bellow 10 µg/L and were bacteria free.

On the other hand, under the urbanization process, widely proliferation of point-of-use (POU) water treatment systems, especially reverse osmosis (RO) may cause the increase in water consumption in a home. Additionally, water demand variability can be increased due to the impacts of climate change. The impacts of urbanization and climate change on water demand was investigated and evaluated the ability of water conservation and multiple water use in Hanoi City. Rapid urbanization leading urban population increase and water consumption per capita are the main impacts to increase future water consumption. Generally, the impacts of climate change and RO usage would be relatively small to urban water supply system, but the impacts of RO usage may be higher than the impacts of climate change does.