Practical Paper

Household survey of installation and treatment efficiency of point-of-use water treatment systems in Hanoi, Vietnam

An Thuan Do, Keisuke Kuroda, Takeshi Hayashi, Tran Thi Viet Nga, Kumiko Oguma and Satoshi Takizawa

ABSTRACT

Since urban water supply is not yet available for every inhabitant in Hanoi City, numerous residents look for alternative sources such as groundwater and rainwater to compensate the supply shortage. However, in parts of Hanoi, it was reported that groundwater is polluted by various contaminants including arsenic (As) and ammonia (NH_4-N). Therefore, numerous types of point-of-use (POU) water treatment systems have been used in households, but treatment efficiency has not been well documented. Hence, this study aims to investigate the proliferation and efficiency of household treatment systems. One hundred and seventy households from three communes were selected for a survey of questionnaires and face-to-face interviews. Twenty-four household water treatment systems from six communes were monitored for water sample collection and analysis. The results indicate that sand filter (SF), ceramic filter (CF), microfiltration (MF), anion exchange (AX) and reverse osmosis (RO) were popular POU water treatment systems, but removal efficiency varied among different treatment processes. Groundwater quality shows an average As concentration of 71 µg/L (max. 305 µg/L) and 81% of these samples had As concentration higher than the World Health Organization guideline value of 10 µg/L. An integration of SF and RO can guarantee water with As concentration below 10 µg/L, whereas AX, MF and CF did not remove As at all.

Key words | arsenic, groundwater, Hanoi, point-of-use (POU) water treatment systems

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INTRODUCTION

Access to safe drinking water is essential to human health, a basic human right and a component of an effective policy for health protection (WHO 2008). UNICEF & WHO (2012) estimated that over 780 million people in the world still lack access to safe drinking water. In Hanoi City, rapid urbanization and high population growth require greater effort for the development of water supply systems to fill the gap between water demand and provision. In reality, not every inhabitant has access to a public water system, especially in rural and suburban areas. The result is that many inhabitants use alternative sources such as groundwater and rainwater to compensate the supply shortage. In addition, the groundwater in some parts of Hanoi is reportedly polluted by various contaminants including arsenic (As) and ammonia (NH_4-N) (Berg *et al.* 2001, 2006; Dan & Dung 2002; Nga *et al.* 2003; Winkel *et al.* 2011). A number of different types of point-of-use (POU) water treatment systems (hereafter called POU treatment systems) therefore have been exploited in households to filter locally obtained groundwater, rainwater and even piped water from central treatment plants. Although many POU technologies have been used in Hanoi and also in Vietnam, their treatment efficiency is not well documented. This study aims to survey the water practices, the proliferation and treatment efficiency of

POU treatment systems in Hanoi such as sand filter (SF), ceramic filter (CF), microfiltration (MF), anion exchange (AX) and reverse osmosis filter (RO) by questionnaires, face-to-face interviews and water quality analyses.

MATERIALS AND METHODS

Urban water supply and groundwater quality

In 2008, the boundary of Hanoi sprawled towards the west and covered a total area of 3,345 km^2 and the population was higher than 6.56 million in 2010. Forty-one per cent of this population (2.71 million) live in urban areas and 59% (3.85 million) in rural areas (Statistical Public House 2011). In the next 20 years, the total population is estimated to grow from 6.56 million to 10.73 million, of which 58% (6.22 million) will settle in urban areas (PPJ-VIAP-HUPI 2011). These data indicate that the urban population will increase by 2.3 times. Water consumption in 2011 was estimated at about 700,000 m^3/day plus 150,000–200,000 m^3/day used in rural and suburban areas. The total production capacity of the water treatment plants is about 920,000 m^3/day, nevertheless, the supply network has not yet been expanded outside of the urbanized areas. In 2030 the total urban water demand is estimated to be 2,359,000 m^3/day, approximately 2.6 times higher than current water production capacity (VIWASE-HPC 2012). The common water treatment technologies in Hanoi consist of conventional processes such as coagulation, flocculation, sedimentation, sand filtration and disinfection. These processes are expected to remove iron (Fe), manganese (Mn) and bacteria.

With regards to groundwater quality, Berg et al. (2001) reported that the average As concentration in Hanoi was 159 µg/L and the concentrations varied greatly within the study areas. In a study carried out by UNICEF (2001), about 73% of groundwater samples contained As with a concentration lower than 50 µg/L, and the distribution of As coincided with the distribution area of high ammonia (NH$_4$-N). However, the maximum As concentration in groundwater varied widely from 216 to 331 µg/L in the area south of the Hong River, which runs through the centre of Hanoi. In the downstream of the Nhue River,

which flows through the western suburbs of Hanoi, As concentration greater than 300 µg/L was also recorded (Berg et al. 2008). Nga et al. (2003) indicated that groundwater in the northwest of Hanoi was similar to the Hong River water and of a good quality whereas in the south concentrations of iron (Fe), As, NH$_4$-N and organic matter exceeded the World Health Organization (WHO) guideline values.

Groundwater contamination by NH$_4$-N in the south of Hanoi has been studied by Northern Hydro-geological Engineering since the early 1990s. The average NH$_4$-N concentration has increased over the years, from 4.3 mgN/L (in 1992) to 18.7 mgN/L (in 2002). The average NH$_4$-N concentration in the Pleistocene aquifer (lower aquifer) was lower than that in the upper aquifer and varied from 3.7 to 11.1 mgN/L (Dan & Dung 2002).

Study area

The study was conducted in three communes in Hanoi with diverse urbanization levels to compare different water practices and different types of usage of POU treatment systems (Figure 1). An urban commune Tan Mai (TA), a rapidly urbanizing suburban commune Ngoc Hoi (NH) and a rural commune Tien Yen (TY) were surveyed by two monitoring methods: questionnaires and face-to-face interviews, and water quality surveys. These communes were selected according to urbanizing features and water consumption behaviours. TA and NH are located in the south and TY is in the northwest area. Three additional communes, Ngoc Thuy (NT), Tay Mo (TM) and Van Phuc (VP), where high As levels have been reported, were also visited for water quality measurements.

Household survey

A household survey campaign was conducted at 170 randomly selected households in the first three first mentioned above by questionnaires and face-to-face interviews in March 2012. The survey consisted of five sections: (1) household information, (2) current practice of water use, (3) POU treatment systems, (4) comments of interviewees and (5) site inspection. The interviewees were the representatives of households, such as wives or
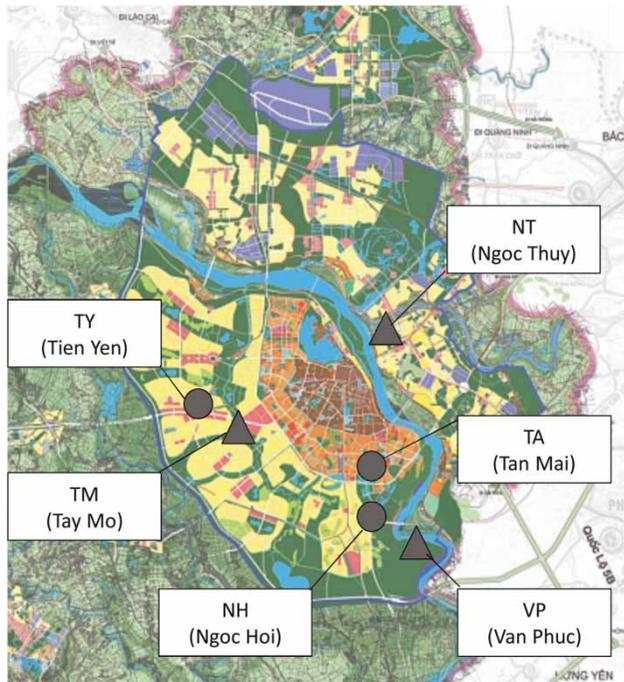
(The base map is from PPJ-VIAP-HUPI 2011)

● Questionnaire interviews + water quality survey

▲ Water quality survey

Figure 1 │ Location map of surveyed communes (PPJ-VIAP-HUPI 2011).

husbands who manage the water supply system at their homes. We also selected interviewees based on gender and age; inhabitants were almost equally divided between males (45%) and females (55%). Numerous residents (72%) were in the age range of 30–60 years old while percentages of residents >60 years old and <30 years old were 16 and 12%, respectively. In TA, households with three to four people were dominant (61%), but households with more than five people were the majority in both NH and TY (54 and 53%, respectively). In NH and TY, the majority of the residents were farmers (>70%); the ratios of farmer tends to be higher in the rural area than in the urban area. We also compared households with or without children under 10 years old. These households might pay more attention to water issues to ensure that their children are living in safe health conditions. The ratios of households having children of <10 years old were 55, 44 and 49% in TA, NH and TY, respectively.

Water sampling and analysis

The sampling campaign was conducted in the three aforementioned communes (TA, NH and TY) and also in the additional three other communes of NT, TM and VP in November 2011 and January 2012 to investigate water quality. The water samples ($n = 52$) included ground-, piped and rain water, and water samples collected before and after POU treatment systems. These samples were taken after running water for 10 minutes. NH_4-N was analysed using DR890 (Hach) by the salicylate method in the laboratory of the National University of Civil Engineering within 12 h after collection. All the water samples were filtered through a 0.45 μm PTFE membrane on-site, stored in plastic containers and kept in the dark at 4 °C. Samples for the analysis of As, Fe and Mn were acidified with nitric acid (HNO_3) 1% (v/v) in the laboratory in Hanoi, brought to Tokyo and refrigerated until analysis. Phosphate concentration was analysed by ion chromatography (861 Advanced Compact IC, Metrohm; Shodex SI-90 4E column). Concentrations of As, Fe and Mn were analysed by inductively coupled plasma-mass spectrometry (ICP-MS, 7500cx: Agilent Technologies) in the laboratory of the University of Tokyo.

RESULTS AND DISCUSSION

Water use practices

Figure 2(a) shows the number of water sources in households and Figure 2(b) the depths of tubewells. The supply systems in the study area had various water sources such as piped, ground- and rain water. The piped water supply systems come from two types of plants: central treatments (>1,000 m³/day) and community treatment plants (<1,000 m³/day) (QCVN 01 2009; QCVN 02 2009). In the urban commune TA, every household ($n = 64$) had access to a piped water system from the central treatment plants and 61% of households consumed 10–16 m³/day. In the rapidly urbanizing commune NH, not every household had access to piped water from community treatment plants. Merely 39% ($n = 22$) of households used only one water source, 47% ($n = 27$) used two and 14% ($n = 8$) used three water sources (piped, ground- and rain water).
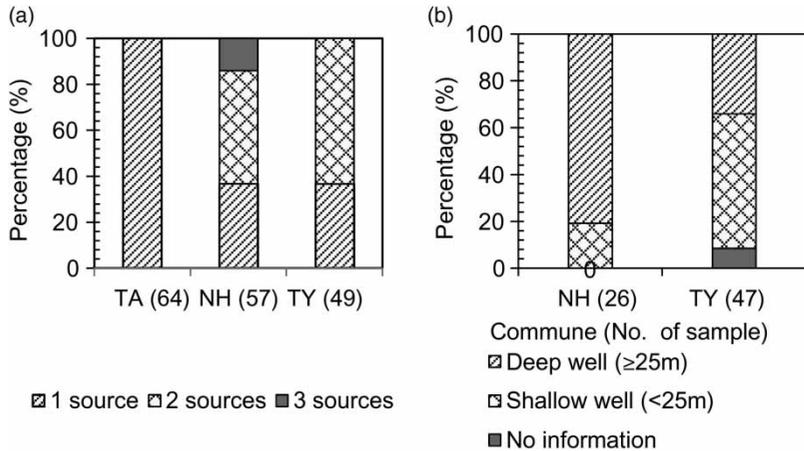
Figure 2 │ (a) Number of water sources in households and (b) depths of tubewells.

Fifty-five per cent of households consumed groundwater from private wells and the number of deep wells (81%, $n = 21$, depth ≥ 25 m) was higher than the number of shallow wells (19%, $n = 5$, depth < 25 m). Seventy-three per cent of the households used SFs. Because NH commune is located in the lowland area in the south, the groundwater has been contaminated by organic matter and As (Berg et al. 2001, 2006; Dan & Dung 2002; Nga et al. 2003; Winkel et al. 2011). Thus, residents in NH preferred to use groundwater from deep wells rather than that from shallow wells. In the rural commune TY, 100% ($n = 49$) of households used groundwater from private wells and 67% ($n = 33$) of them used more than one water source, such as ground- and rain water. Households in TY tended to use groundwater from shallow wells (57%, $n = 27$) rather than deep wells (34%, $n = 17$) and 9% ($n = 4$) of the households did not remember the depth of well at the time of the survey.

Figure 3(a) shows the installation of wells and POU water treatment systems and Figure 3(b) shows storage facilities of household water in the communes TA, NH and TY. In the urban commune TA, residents had access to a piped water system. On the whole, piped water was stored in a brick tank installed underground and then pumped up to a tank on the roof of the house. However, in the suburban commune NH and in the rural commune TY, residents had to make more effort to obtain and treat water by installing a series of facilities such as tubewells, pumping systems, water filters and storage tanks. Approximately 40% of households in NH needed these systems, whereas it was more than 90% in TY. This was because a limited number of households in NH had access to a piped water supply whereas piped water in TY was not available at all.

In TA, 58% of households used POU devices of CF and RO. In NH, 37% of households had CF, MF and RO to treat
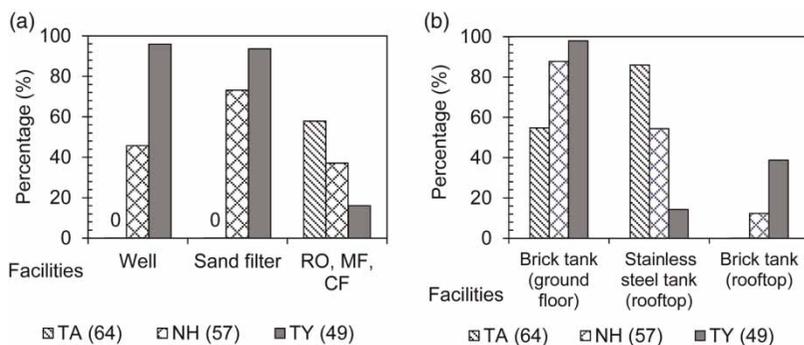

Figure 3 │ (a) Installation of wells and POU water treatment systems and (b) storage facilities of household water.

piped water or filtered groundwater for cooking and drinking. In TY, 94% of households built SFs and only 16% of households used CF and RO for advanced water treatments. There was a lower usage rate of POU devices CF and RO in TY than in TA and in NH, perhaps because the majority of the inhabitants worked in the agricultural sector (70% of interviewees) with lower incomes, but with better groundwater quality (Figure 3), and with a higher usage of rainwater (67% in TY, 42% in NH and 0% in TA). In the three surveyed communes, RO was the rather dominant POU device (>57%) although it was more expensive. Interestingly, the dissatisfaction rates with water quality and quantity turned out to be higher in urban areas than they were in rural areas. The results showed that 73, 68 and 53% of households in TA, NH and TY, respectively, would like the water quality to be improved. The higher dissatisfaction rate of the water supply for residents in the urban commune TA might explain the higher ratio of households using POU devices in TA than in NH and in TY. The results also indicated that the urban residents in TA demanded that the piped water quality and quantity should be improved, whereas the residents in TY and in NH had a high expectation that the urban sprawl could provide them better access to the public water supply system and that water quality would become better than that of their current water sources.

Water pumps were largely exploited in the three investigated communes. Over 80% of households used pumps to extract groundwater, or to maintain required pressure by pumping water up to a higher elevation. In TA, residents chose water storage facilities such as underground brick tanks (55%) and stainless steel tanks on the rooftops (86%) of their dwellings. Underground tanks aim to reserve water in case of a water shortage or of low pressure from the piped water system. As well as that, some residents used underground tanks working as a clarifier to remove suspended solids from piped water. The high installation rate of stainless rooftop tanks in TA was because residents there wanted to have pressurized water for their water devices, and the level of water devices' usage in TA was also higher than in NH and TY. In the commune NH, the ratios of households that had underground brick tanks, rooftop stainless steel tanks or rooftop brick tanks were 88, 54 and 12%, respectively. In addition, 81% of households in

NH depended upon individual pumps for household water supply purpose. These pumps were used to suck water from service water pipe, tubewells, or to transfer water from ground floor tanks to rooftop tanks. The brick tanks were commonly used in the rural commune TY, where 98% of households built them on the ground floor and 39% of households on the rooftop. Stainless steel tanks were rarely used in TY (only 14% of households), and pumps, which were used in 100% of the households, were indispensable in household water supply systems. The survey showed that urban residents selected stainless steel tanks because of their light material and easy installation, whereas rural residents utilized local materials available with lower construction costs. Groundwater usage in rural areas required a water supply system including a tubewell, a pump, a SF and a storage tank.

Groundwater quality assessment

The concentrations of As, Fe, Mn, NH_4-N in groundwater are presented in Figure 4. In total, 21 groundwater samples from the households in NH, TY, NT, TM and VP were analysed with an average As concentration of 71 μg/L (max.: 305 μg/L), where 81% ($n = 17$) of these samples exceeded As concentrations higher than the WHO guideline and Vietnamese standard value of 10 μg/L (Figure 4(a)). Fe concentration was very high (max.: 40 mg/L), and 76% of samples exceeded the Vietnamese standard of 0.3 mg/L (QCVN 01 2009) (Figure 4(b)). Manganese (Mn) concentration was in the range of 0.1–3.0 mg/L; in 57% of samples Mn concentration was higher than the Vietnamese standard of 0.3 mg/L (QCVN 01 2009) (Figure 4(c)). NH_4-N levels were also very high in the study areas (max.: 26 mgN/L), where 67% of samples exceeded the Vietnamese standard of 3.0 mgN/L (QCVN 01 2009) (Figure 4(d)). However, the ratio of Fe/As (mg/mg) was moderately high which was favourable for As removal by SFs (Berg et al. 2006). Seventy-one per cent of samples had an Fe/As ratio of 50 or higher; and 24% of samples demonstrated an Fe/As ratio higher than 250. The highest concentration of As, Fe and NH_4-N was often observed in NH and VP located in the south of Hanoi City. This finding had similar results when compared with previous studies. The maximum concentration of Mn was found in NT (3.0 mg/L) but As, Fe
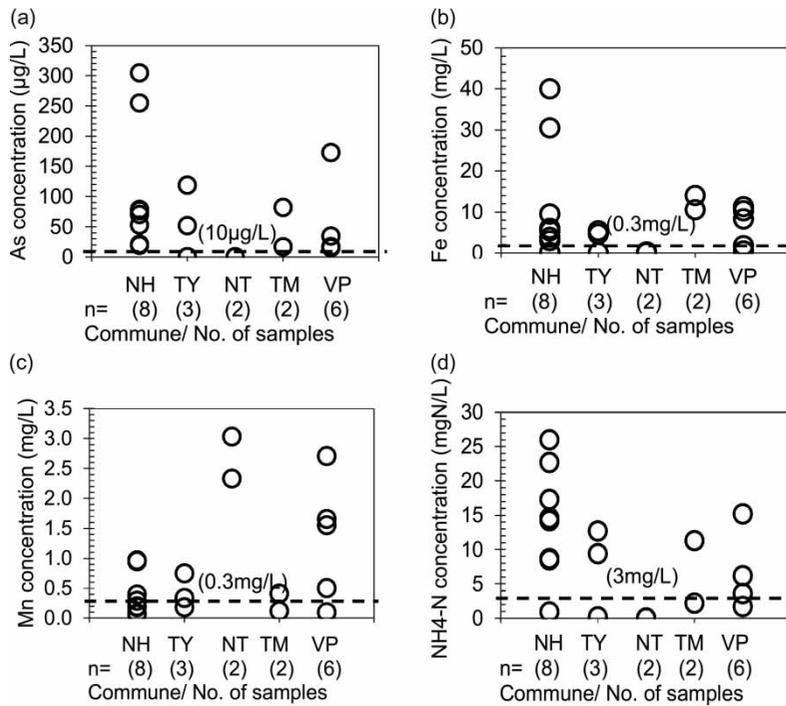
Figure 4 | Concentration of (a) As, (b) Fe, (c) Mn, (d) NH₄-N in groundwater. (National technical regulation on drinking water quality values (QCVN 01 2009).)

and NH$_4$-N concentrations were the lowest in this area. Regarding the contaminant distribution with depth of tube-wells, the concentrations of As, Fe, Mn, NH$_4$-N often showed elevated values at 40–50 m depth.

Removal efficiency of As by POU treatment systems

Table 1 shows As removal by different POU treatment systems. The removal efficiency of As by POU treatment systems varied not only among different treatment processes but also among the same processes. The average As removal efficiency by SF was 63% ($n = 7$). Fifty-seven per cent of SF ($n = 4/7$) demonstrated high As removal efficiency (>85%), whereas 33% of SF had less than 60% of As removal efficiency. The trend of As removal from groundwater by SF was correlated with the previous study in Hanoi in 2006, when Berg et al. demonstrated that Fe/As ratios of >250 are required for household SFs to reduce As concentration to the WHO drinking water guideline level of 10 μg/L. It is known that low phosphate concentration in groundwater might not interfere with As removal by SF (Berg et al. 2006;

Table 1 | Arsenic removal by different POU treatment systems

Commune	Sample ID	Influent (µg/L)	SF (µg/L)	CF (µg/L)	MF (µg/L)	AX (µg/L)	RO (µg/L)
				Treated by			
Groundwater							
NH	NH20G	79	51				
	NH24G	305	142		144		
	NH25G	255	27				0.6
TY	TY01G	52	7.7				0.1
	TY02G	0.6	0.6				
	TY03G	119	14				
TM	TM21G	17	0.9				0.0
Piped water							
TA[a]	TAM01T	6.3					0.2
	TAM03T	5.8		5.6			
	TAM02T	5.5					0.2
NH[b]	NH15T	17					0.0
	NH21T	40	33				0.1
	NH22T	37		37			
NT[a]	NT2T	22				22	
VP[b]	VP7T	7.0					0.0

[a]Piped water from central treatment plant.
[b]Piped water from community treatment plant.

Hug et al. 2008). In the present study, phosphate concentration in groundwater was very low (0–0.78 mg/L) in all the communes. Hence, phosphate did not influence the efficiency of SF in As removal. With regard to RO filter ($n = 8$), 100% of this equipment removed more than 94% of As, with As concentration in the permeate water of less than 10 μg/L. Their mean As removal efficiency was 98%, which was the highest among all the POU treatment systems investigated. The As removal efficiency of RO filters was higher than that documented in the USA (mean: 86% from Slotnick et al. (2006); 79% from George et al. (2007)). As anticipated, AX ($n = 1$), MF ($n = 1$) and CF ($n = 2$) did not remove As at all. For the other contaminants, NH_4-N was effectively removed by RO purifiers and CF filters (>85%), while Fe removal was lower (45%). The results indicated that an integration of SF and RO can guarantee water with an As concentration below 10 μg/L.

CONCLUSIONS

The usage of POU treatment systems was very popular in all the three communes of TA, NH and TY, in Hanoi. In these communes, piped, ground- and rain water were the main water sources. In a suburban commune NH and a rural commune TY, where piped water was available only for a limited number of residents, these residents had to use groundwater and rainwater to compensate for water shortage. SFs were commonly used to treat groundwater and rainwater. On the other hand, the POU devices of CF and RO at households were more popular in the urban commune TA than in communes NH and TY. Although groundwater was contaminated by As, some of the POU water treatment systems are competitive options for the removal of As from contaminated groundwater. This study provided evidence that whereas CF, MF and AX might not remove As content, SF and RO can eliminate As effectively from groundwater. Because of varied removal efficiency of As by these different processes, a safe water supply can be achieved by expansion of public water supply systems and/ or by installation of reliable and efficient household treatment processes, which are crucial to safeguard the public's health. In the urban commune TA, the need to meet customer satisfaction with the public water supply is an urgent priority which can be dealt with by improving water quality and providing sufficient amounts of water.

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