Characterization of Arsenic contaminated groundwater in Hanoi City and a treatment option by using recycled Autoclaved Aerated Concrete (AAC)

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ABSTRACT

Groundwater has been used as the main source of water supply in Hanoi City for more than a century. At present, 623,500 cubic meter of groundwater have been providing per day for urban districts. In recent years, groundwater pollution due to arsenic (As), iron (Fe), ammonia (NH₃), and organic matters (OM) has been reported. This paper presents a review of As contamination in groundwater in Hanoi City and investigates the adsorption capacity by autoclaved aerated concrete (AAC) as a possible adsorbent for treating As contaminated water. Results showed that a high concentration of As which was up to above 800 µg/L was found in groundwater from the Southern region of Hanoi City and was associated with high concentrations of Fe, NH₃, and OM. Based on the data of As and other water quality parameters, it was suggested that the degradation of OM and ferric (Fe(III)) oxyhydroxides played a role in the mobilization of As in groundwater under reductive condition. Batch and column filtration experiments using crushed grains of AAC were carried out to evaluate the treatment performance of heavy metals including As in contaminated groundwater. Especially, the column filtration experiments gave a high efficiency of metal removal (~100 %), implying that AAC could be a sustainable and low-cost media to treat heavy metals in wastewater.

Keywords: Adsorption, autoclaved aerated concrete (AAC), groundwater, heavy metals.

1 INTRODUCTION

Hanoi, the capital of Vietnam, covers a total area of 3,344.47 km² and comprises a population of over 8 million. Groundwater has been used as the primary source of water supply in the City for more than a century. At present, groundwater provides 623,500 m³/d of the water supply in urban districts (Decision no. 499/QĐ-TT., 2013).

Hanoi is located in the Red River Delta (RRD) where in recent years, groundwater contamination due to arsenic (As), iron (Fe), ammonia (NH₃), and organic matters (OM) has been reported. Arsenic is the element of greatest toxicological concern in well waters. Arsenic concentrations were found to vary greatly throughout the delta (<0.1 to 810 µg/L) and 27% of the wells exceeded the WHO guideline value of 10 µg/L. Conventional sand filter were very popular application for groundwater treatment at this delta, but it only got 70 -80% of As removal and the quality of treatment water could not get the standard of domestic water of Vietnam (QCVN 01:2018-BYT). There are variety technologies for arsenic or heavy metal removal such as

sand filtration, membrane filtration or using adsorbent materials. In recent years, low-cost adsorbents materials such as natural-available adsorbents, construction wastes, agricultural wastes, industrial wastes are studied for heavy metals removal due to the high efficiency, low cost, easy to access, and in many cases, no harmful to the environment (Khulbe et al., 2018).

Autoclaved aerated concrete (AAC) is a lightweight and highly porous building material that was invented in Sweden in 1923 and is now used worldwide (Walczak et al., 2015; Jerman et al., 2013). AAC comprises sand and fly ash and mineral binders including lime and cement, and is produced at high temperatures (typically 180 to 200°C) under saturated steam pressure. In Vietnam, AAC has been used for building purposes for more than 10 years. With the increase in AAC production, the amount of scrap waste has also been increasing in developing countries (Chen et al., 2016; Kumara et al., 2019). According to the state of environmental report of 2011 about solid waste management issued by Ministry of Natural Resources and Environment (MONRE, 2011), the total

municipal solid waste generation was about 60 thousand tons/d on average, in which the total construction and demolition waste (CDW) accounted for 10-12 % of total solid waste. In 2013, CDW accounted for around 1.9 million tons, and all of which was landfilled or incinerated (Kien et al., 2013).

Adsorption process has been known as a potential remediation process for wastewater laden with heavy metals. Wang et al. (2015) reported that adsorption resulted in high removal of copper, lead and cadmium from storm-water runoff. Kumara et al. (2017) indicated several studies that used CDW such as brick, concrete and cement for the removal of heavy metals in wastewater. Nonetheless, the use of AAC as a low-cost adsorbent for wastewater treatment process has been limited (Zhang et al., 2017). Hence, continued evaluation of the reuse of these waste materials as a cost-effective adsorbent in wastewater treatment is needed (Kumara et al., 2019).

Removal of metals and Arsenic in groundwater by using the material from CDW wastes such as AAC is a potential and sustainable solution to remove pollutants and promote reuse & recycle materials toward a circular economy. In this study, the potential use of AAC from CDW for the removal of metals and heavy metals in groundwater is investigated, in which the potential removal of iron, arsenic and heavy metals in contaminated groundwater by AAC was examined by series of batch absorption test, and the continuous filtration experiments was designed to evaluate the removal efficiency of filtration system in different operating parameters.

2. CHARACTERIZATION OF ARSENIC CONTAMINATED GROUNDWATER IN HANOI CITY

In the Red River Delta, high As levels were found in both the Holocene and Pleistocene aquifers (Berg et al., 2001, 2007; Winkel et al., 2011). Private wells predominantly extract water from the Holocene aquifers, whereas wells for urban treatment facilities tap Pleistocene aquifers (Berg et al., 2007). The mechanisms responsible for the high concentration of As in groundwater are microbial and/or chemical reductive dissolution of As-bearing iron minerals in the aquifer sediments (Nga et al., 2003; Berg et al., 2007; Winkel et al., 2011). Winkel et al. (2011) reported groundwater data from 512 private tube wells in the RRD indicating that large-scale groundwater abstraction from deep aquifers had actually impacted a much larger area of Pleistocene groundwater resources in the RRD to a greater extent than had been previously known. Consequently, elevated As concentrations in the Pleistocene aquifers in Hanoi and in the vicinity of Ninh Binh, Nam Dinh, and Thai Binh seriously threaten the quality of urban drinking water derived from these aquifers (Winkel et al., 2011). Berg et al. (2008)

reported that the area south of Hanoi contains elevated As concentrations (130 µg/L) in the Pleistocene aquifer due to groundwater abstraction by the Hanoi Water Works, resulting in the vertical downward migration of reducing conditions and/or downward transport of As tainted waters to the Pleistocene aquifers (Berg et al., 2008). The results from previous studies (Nga et al., 2003; Berg et al., 2007; Winkel et al., 2011) showed an interesting and important finding that the Southern groundwater of Hanoi which had large amounts of As, NH₃, Fe and OM but not Mn. A coexistence of both Fe and Mn (oxidized environment) occurred only in the Northern area of Hanoi.

Table 1 presents a summary of groundwater quality data in the study area (Nga et al., 2003). The water quality varied extensively among the well-fields which abstracted groundwater from the Pleistocene deep aquifer. A high concentration of As (up to 110 µg/L), Fe (up to 32 mg/L), DOC (up to 12.6 mg/L), and NH₄-N (up to 29 mg/L) were detected in samples from groundwater in the south region (Phap Van, Tuong Mai and Ha Dinh), whereas the levels of these contaminants were significantly lower in other regions (Mai Dich, Ngo Si Lien, Ngoc Ha, Yen Phu and Luong Yen). Samples having arsenic concentration ≥ 30 µg/L were selected for analysis of two arsenic species, namely arsenite As(III), arsenate As(V), and ferrous iron and ammonium. The results are summarized in Table 2.

Table 1. The average quality of groundwater in 8 well-fields in Hanoi City (Nga et al., 2003).

Well-fields	As (µg/L)	Fe (mg/L)	NH ₄ -N (mg/L)	DOC-C (mg/L)
Luong Yen	23.7	3.1	0.6	1.8
Yen Phu	40.4	3.5	1.5	2.1
Mai Dich	1.2	1.4	0.1	2.2
Ngoc Ha	1.8	2.3	1.7	2.2
Ngoc Si Lien	1.5	2.1	0.9	1.7
Phap Van	73.2	16.9	18.8	9.1
Tuong Mai	50.7	16.6	6.4	3.5
Ha Dinh	101.3	26.7	7.1	3.5

Arsenic levels in groundwater in Pleistocene aquifer ranged from less than the detection limit of 0.1 to 112 µg/L. Groundwater in the south region of Hanoi had high As concentrations of 43–112 µg/L which were greater than the WHO guideline of 10µg/L for drinking water. The concentration ranges of arsenic detected in this study were consistent with other studies (Nga et al. 2007; Kuroda et al., 2018) and about 1/3 of those reported elsewhere (Berg et al., 2001). According to Kuroda et al. (2018), elevated arsenic concentration in the Pleistocene deep groundwater was likely due to vertical infiltration through the arsenic-rich and organic matter-rich overlying Holocene estuarine sediments,

caused by massive groundwater abstraction from the Pleistocene deep aquifer.

Table 2. Chemical species in groundwater in Hanoi City (Nga et al., 2003).

Well field	Fe ²⁺ (mg/L)	NH ₄ ⁺ (mg/L)	As(III) (μg/L)	As(V) (μg/L)	T-As (μg/L)
YP	5.4±2.	3.4±0.	64.3±3.2	59.9±2.8	92.7±7
PV	7.9±0.	18.8±7	48.6±19	11.9±7.2	61.4±13
TM	7.0±0.	6.9±3.	30.7±6.2	22.3±13	44.2±11
HD	12.1±5	7.1±1.	60.3±10	26.7±6.3	83.9±7

Notes:

As(III) + As(V), analysis by LC-ICP-MS

T-As : mean analysis by ICP-MS

YP: Yen Phu WTP PV: Phap Van WTP

TM: Tuong Mai WTP HD: Ha Dinh WTP

The primary arsenic species detected in the groundwater were As(III) and As(V), with the ratio of As(III) to total arsenic varying from 0.5 to 1.0. Tran (2019) reported that the primary form of arsenic found in the groundwater was As(III) with some As(V). Arsenic levels were closely related to levels of ammonium, which was released by the breakdown of OM. As(III) concentration peaks in the middle part of the aquifer with distribution highly similar to that of ammonia (NH₃) and methane (CH₄). This result indicated that there may be a direct relationship between the release of As into the groundwater and the decomposition of organic matters. The high alkalinity (up to 810 mg/L) and high nitrogen (N) concentrations (10–48 mg/L) of the groundwater strongly supported this possibility (Tran, 2019).

Nga et al. (2007) reported that organic matters in these soils was an important solid phase source for arsenic and that high contents of organic-matter-bound arsenic were associated only with these samples. Furthermore, results from sequential extraction revealed that, in the peat cores, 70-100% of the total sedimentary arsenic was comprised of ironbound and organic-matter-bound arsenic. It suggested that peat could be the sink and source of sedimentary arsenic. That is, peat sequestered arsenic through two major solid phases, i.e., arsenic bound to organic matter and arsenic associated with iron oxyhydroxides. It indicated by the coincidence of the geographical distribution of arsenic rich-wells with the distribution of the peat layer (Nga et al., 2007).

3. MATERIALS AND METHODS

3.1 Adsorbent preparation and physicochemical characterization

Waste Autoclaved aerated concrete was collected from the Viglacera Yen Phong factory in the Yen

Phong industrial zone, Bac Ninh province, Vietnam. Materials were crushed and sieved into by 3–5 mm, 5–10 mm and 10–20 mm particle size ranges. In addition, to identify the chemical composition of the tested adsorbents, energy-dispersive X-ray spectroscopy (EDX; XMax Extreme, Oxford Instruments, UK) experiments were performed using adsorbent powder particles.

3.2. Batch adsorption experiments

A standard batch method (OECD, 2008) was used for all batch adsorption experiments in this study. The first experiment used synthetic, metal laden wastewater-prepared using H₃AsO₄, K₂Cr₂O₄, PbCl₂ and CdCl₂ (Wako Pure Chemical Industries, Ltd., Japan). The solid liquid ratio was maintained as 1:10 (by mass) to determine adsorption performance of As, Cd, Cr and Pb to the solid phase for each range in particle size. The second experiment used groundwater. The groundwater was recovered from a 60m-deep well located within the Pleistocene aquifer at the dormitory of Hanoi University of Civil Engineering (HUCE), Vietnam. Adsorbent and known concentration of ad-sorbates were filled into the 50ml centrifuge tubes (triplicate samples) and placed on a reciprocating shaker and shaken for 24 h at 100 rpm at 25°C. Then, the tubes were centrifuged at 8000 rpm for 15 min, and supernatants were filtered through membrane filter (Millipore 0.22 μm). The resulting supernatants were diluted to achieve measurable concentration ranges and measured by atomic adsorption spectrophotometry (AA-6200, Shimadzu, Japan) and the portable colorimeter (DR/890, HACH, USA). The pH and EC values for each experimental solution were measured before all experiments, and their changes were monitored during the experiments using a pH/EC meter (PC110, Horiba, Japan).

3.3. Calculation of removal percentage and adsorption capacity

The removal rate (E, %), the amount of heavy metal ions adsorbed per unit mass of adsorbent at time *t* (*Q_t*, mg/g), and the amount of metal ions adsorbed per unit mass of adsorbent at equilibrium (*Q_e*, mg/g), were calculated as follows:

$$E = \frac{C_o - C_e}{C_o} \times 100 \quad (1)$$

$$Q_t = \frac{C_o - C_t}{m_s} \times V \quad (2)$$

$$Q_e = \frac{C_o - C_e}{m_s} \times V \quad (3)$$

where *C_o* and *C_e* (mg/L) are the initial and the final (equilibrium) concentrations of heavy metal ions in solution respectively, *C_t* (mg/L) is the concentration at time *t*. *V* is the volume of the solution (L) and *m_s* is the mass of adsorbent powder (g).

3.4. Continuous filtration experiments

The filtration column was made of a PVC column with 110mm internal diameter and 2.0 m height (length) as shown in Figure 1.

Fig. 1. Schematic diagram of AAC filtration column.

A filter capture supported the media layer within the column and collected water from the bottom. The AAC (size 3-5mm) filter layer with a height of 1.2 m was used, and the weight of AAC was 4 kg. The distribution and collection networks were made of perforated PVC pipe. The groundwater flowed into the column from the top to bottom (rapid gravity filtration). The experiment was conducted at different linear flow velocities of $V = 10, 14$ and 20 m/h. For each velocity, the samples were taken at three locations: effluent (E0), 0.3 m height from bottom (E30) and 0.6 m height from bottom (E60). The concentrations of As, Fe and Mn were measured using the standard method and the Hach DR890 portable colorimeter. The pH and EC values for each experimental solution were measured before all experiments, and their changes were monitored during the experiments using the pH/EC meter.

4. RESULTS AND DISCUSSION

4.1 Physicochemical characterization of adsorbents

Adsorption of metals from the liquid phase to the solid phase is affected by the fundamental characteristics of the adsorbents. The chemical composition of the recycle concrete (AAC) is summarized in Table 3. As shown in the table, the results of EDX analysis before adsorption indicated a relatively higher SiO_2 content in AAC (>50%). A higher CaO content was observed, indicating the possibility for ion exchange (Ca^{2+}) with heavy metals (HMs), like calcium silicate materials. Interestingly the adsorbent comprised a sufficient amount of metal oxides such as Al_2O_3 and Fe_2O_3 , implying the possibility for ion exchange and surface complexation reactions with HMs. AAC had been reported that It exhibited a slightly alkaline pH. Negatively charged adsorbent surfaces had a potential to adsorb cations from wastewater and might be able to neutralize acidic wastewater during the adsorption process (Yuanming et al.,2015; Sabalala et al.,2017).

Table 3. The chemical composition of AAC.

Chemical compound	Current study (%) (Result of EDX – XRD)	Literature (%) (Result of XRF) (Joana et al.,2019)
SiO_2	55.2	44.8 – 57.0
CaO	28.9	24.9 – 27.6
Al_2O_3	2.8	2.0 – 16.1
Fe_2O_3	1.7	1.0 – 4.2
K_2O	0.9	0.7
MgO	0.6	0.5 – 0.7

4.2. Batch adsorption experiment

The concentration of As(V), Cr(III) and the proportion of As(V) and Cr(III) removal were as shown in Fig. 2 and Table 4. The concentration of As(V) in initial and final samples decreased slightly from 1093 ppm to 843, 933, and 947 ppm. Arsenic removal efficiency (E, %) ranged from 13.4% to 22.9 %. The highest efficiency of As removal of 22.9% was associated with the smallest of AAC particle size ranges (3–5 mm), whereas the lowest efficiency of 13.9% was associated with the largest particle size ranges (10–20 mm).

Fig. 2. Concentrations of As(V) and Cr(III) as a function of AAC Particles size (mm) from batch adsorption tests.

Table 4. Comparison of percentage of As(V) and Cr(III) removal with different AAC particle sizes.

Index	Sizes 3-5	Sizes 5-10	Sizes 10-20	Average
As (%)	22.9	14.6	13.4	17.0
Cr (%)	17.3	16.6	15.9	16.6

Figure 2 showed the concentration of Cr(III) in the initial and final solutions respectively. The amount of Cr(III) in the samples after the adsorption test decreased slightly from 1172 ppm (initial sample) to 970, 977, and 986 ppm (final samples). The efficiency of Cr(III) removal of all AAC sizes under 20% were shown in Table 4. There was not much different impact between the different particle sizes when the percentage Cr(III) removal changed only 1.4% (17.3% vs 15.9%) between the smallest size (3–5mm) and the biggest size (10–20mm). In comparison, the average proportion of As(V) and Cr(III) removal was closely around 17%.

The concentration of Pb(II) decreased strongly from 970 ppm (in the initial sample) to 5, 6, and 6 ppm (in the final samples) (Fig. 3). The results have reported more than 99% of Pb(II) was removed after the batch adsorbent test (Table 5). It was similar with the results from Kumara et al (2019), when the percentage of Pb(II) removal was nearly 100%. There was not much different impact between the different particle sizes when the percentage Pb(II) removal changed only 0.15% between the smallest size (3–5mm) and the biggest size (10–20mm).

The significant decreasing trend of the concentration of Cd(II) ion in the initial and final samples was shown at Fig 3. The concentration of Cd(II) jumped down from 1066 ppm in initial sample to 108, 172, and 116 ppm in final samples. The results showed that the average percentage of Cd(II) removal showed around 87.6 % (Table 5). The same efficiency of Cd(II) removal have been presented in some previous studies. Zeng et al (2017) reported the proportion removal of Cd ion using AAC particle under condition with initial

concentration of each ion = 10 mg/L, h 6.0, AAC 10.0 g/L, t = 90 min and T = 25°C with a solid to liquid ratio 1:100 around 90% (Zeng et al. 2017). Kumara et al (2019) also reported noticeably, the Cd(II) removal for AAC fines increased rapidly from > 90 % at pH ≥ 7 (the particle sizes 0.105–2 mm and a solid: liquid ratio 1:60).

Fig. 3. Concentrations of Cd(II) and Pb(II) as a function of AAC Particles size (mm) from batch adsorption tests.

Table 5. Comparison of percentage of Cd(II) and Pb(II) removal with different AAC particle sizes.

Index	Sizes 3-5	Sizes 5-10	Sizes 10-20	Average
Cd (%)	89.8	83.9	89.2	87.6
Pb (%)	99.5	99.4	99.3	99.4

Table 6. Comparison of adsorption capacities of heavy metals with different AAC particle sizes.

Index	Sizes 3-5	Sizes 5-10	Size 10-20	Average
Qe _As (mg/g)	2.50	1.60	1.46	1.85
Qe _Cr (mg/g)	2.02	1.95	1.86	1.95
Qe _Cd (mg/g)	9.57	8.94	9.50	9.34
Qe _Pb (mg/g)	9.65	9.64	9.64	9.64

The amounts of metal ions adsorbed per unit mass of adsorbent at equilibrium (Qe, mg/g) are shown in Table 6. The Qe (As) decreased from the AAC small size to the AAC bigger size from 2.5 to 1.6 and 1.46 mg/L. The comparatively higher BET surface area of AAC small size might have contributed to increase the chance of contact between AAC particles and metal ions and it facilitated higher adsorption. The amount of Cr(III) adsorbed per unit mass of adsorbent at equilibrium was also decreased from the AAC small size to the AAC bigger size from 2.02 to 1.95 and 1.86 mg/L. The difference between the highest and the lowest was only 0.16 mg/L. The amount of Cd(II) and Pb(II) ions adsorbed per unit mass of adsorbent at

equilibrium (Q_e , mg/g) were around 8.9–9.6 (mg Cd/ g AAC) and around 9.6–9.7 (mg Pb/ g AAC). They were 5 times higher compared to the Q_e of As (1.5–2.5 mg/g) and Q_e of Cr (1.9–2.0 mg/g).

Table 7. Comparison of pH of initial and final (Equilibrium).

Index	Initial	Final (Equilibrium)		
		Size 3-5	Size 5-10	Size 10-20
pH (As test)	2.4	8.5	8.5	8.6
pH (Cr test)	8.1	8.8	8.8	9.1
pH (Cd test)	5.8	7.5	7.0	7.5
pH (Pb test)	4.8	8.8	8.8	9.2

Table 7 showed the comparison of the pH in the initial and in the final samples. The pH of final solutions was higher than 7, especially the pH after As, Cr and Pb adsorbent test were higher than 8 and closed to 9.0. The final solution pH was close to 9.0 when 1 g of sample was placed in 100 mL deionized water. It indicated that the adsorbent showed strong acid neutralization capacity as used in wastewater, especially acid mine drainage. (Zeng et al., 2017). Kumara et al (2019) used ACC for removal Pb(II), Cd(II), Cu(II), Ni(II), Zn(II) by batch adsorption experiments. It reported that there were four ways to remove heavy metals:

1. Hydration of the adsorbent surface:
 $(X, Si - O)_2^- Ca^{2+} + 2H_2O \rightarrow 2(X, Si - O)^- H^+ + Ca^{2+} + 2OH^-$ (4)
2. Hydrolysis of metal ions:
 $M^{2+} + H_2O \rightarrow M(OH)^+ + H^+$ (5)
3. Ion exchange on the adsorbent surface:
 $(X, Si - O)_2^- Ca^{2+} + M^{2+} \rightarrow (X, Si - O)_2^- M^{2+} + Ca^{2+}$ (6)
 $(X, Si - O)_2^- Ca^{2+} + 2M(OH)^+ \rightarrow 2(X, Si - O)^- M(OH)^+ + Ca^{2+}$ (7)
4. Surface precipitation of metals:
 $M^{2+} + 2(OH)^- \rightarrow M(OH)_2$ (8)
(X = Al, Fe, K, and Mg, and M = Cd²⁺ or Pb²⁺)

According to Table 4, Table 5 and Table 6, the smallest particle size (3-5 mm) had a highest percentage of heavy metal removal. The selectivity sequence for the removal of Pb(II), Cd(II), Cr(III), As(V) ions in a single metal system became Pb(II) > Cd(II) > As(V) > Cr(III) for AAC. This implied strongly that Pb(II) possessed preferable bindings with tested adsorbents and occupied the potential sorption sites predominately. Srivastava et al. (2005) reported that the selectivity series for metal sorption followed the tendency of hydration and hydrolysis of metals. Pb ion hydrolyze more readily and quickly interact with a hydroxylated surface (Srivastava et al., 2005).

The results of adsorbent batch test with groundwater are shown in Table 8. The groundwater was taken from the tube well (60m deep–the Pleistocene aquifers) at the dormitory of HUCE. It carried all the features of

groundwater in Hanoi, with a high amount of Fe, Mn, and As. After the adsorbent test, the pH of final solutions was close to 9.0, it was a alkaline condition. According to Table 8, the smallest particle size (3–5 mm) had the highest percentage of heavy metal and metals removal. As the amount of Arsenic in raw sample was only around 15 µg/L, after the test the concentration of As was 0 µg/L, the As efficiency was 100%. The Fe ion removal was also around 100% because Fe (II) was easy aggregate and followed by the surface adsorption process with the AAC adsorbent. The efficiency of Mn was the lowest compare with As and Fe, however, the average was still higher than 90%.

Table 8. Comparison of metals removal with different adsorbent sizes.

Index	Initial (GW)	Final (Equilibrium)		
		Sizes 3-5	Sizes 5-10	Sizes 10-20
pH	6.8	8.9	9.0	8.9
Ec (ms/cm)	0.6	1.8	1.7	1.6
Fe (mg/L)	15.8	0.02	0.02	0.06
E % (Fe)		99.9	99.9	99.6
Mn (mg/L)	1.2	0.06	0.08	0.13
E % (Mn)		95.4	93.6	89.3
As (µg/L)	15.0	0.0	0.0	0.0
E % (As)		100	100	100

After the batch adsorbent experiments, the results showed that the small AAC particle size (3–5 mm) had the highest amount of heavy metal ions adsorbed per unit mass of adsorbent at equilibrium. It also had the highest efficiency of heavy metal removal.

4.3. Continuous filtration experiments

The experiment was at three filtration velocities (V) of 10, 14 and 20 m/h, respectively, and the samples were taken at 3 points: effluent (E0), 0.3 m height from the bottom (E30) and 0.6 m height from the bottom (E60) (Fig. 1). Concentration of Fe and Mn in groundwater before and after treatment by the AAC filtration column were shown in Fig. 4 and Fig. 5. The results showed that, the concentration of Fe and Mn at the point E0 were always the lowest. The concentration of Fe and Mn were higher than 6 mg/l and 0.6 mg/l, respectively, in all effluent samples. When the depth of AAC layer was increased from 0.6m to 1.2 m, the efficiency of Fe removal increased from 24.8 to 53.6 % and Mn removal increased from 26.4 to 44.1 % (Fig. 6). Because of the low concentration of As in groundwater (10-15 µg/L), the concentration of As at all effluent point (E0, E30, E60) were under 5 µg/L and met the standard of domestic water of Vietnam (QCVN 01:2018-BYT).

Fig. 4. Concentrations of Fe in raw and treated groundwater at different filtration velocities and different effluent points.

Fig. 5. Concentrations of Mn in raw and treated groundwater at different filtration velocities and different effluent points.

Fig. 6. Comparison of metals removal (%) at different filtration velocities and different effluent points.

The velocities of filtration were around 10, 14 and 20 m/h which were the normal filtration velocity of rapid sand filtration tank and pressure sand filtration tank. Nguyen et al. (2017) reported the same filtration velocity (17 m/h) with the Chemiles sand filtration which was developed by Nagaoka International Corporation, Japan, operated at Tuong Mai water treatment plant, Hanoi. Chemiles system was one of the most popular sand filtration system in Japan. It uses the ejector for making the maximum dissolved oxygen in groundwater which accelerates the oxidation of Iron

species to $\text{Fe}(\text{OH})_3$. At the last step, $\text{Fe}(\text{III})$ is then removed by the rapid sand filtration with two-meter thick of filter media. The removal efficiency of Iron, Manganese, Ammonia by Chemiles could reach more than 90% and treated water met the Vietnamese and Japanese standard for drinking water. According to the report from Nagaoka Company, Chemiles system could get the filtration velocity around 20 m/h (Nguyen et al., 2017). However, as the water have been keeping re-circulation, the electricity consumption is relative high. The result from the filtration column test showed that at the lowest filtration velocity (10 m/h), the percentage of Fe and Mn removal were the highest. With the slow velocity, higher retention time, metals had more time to contact with the surface of AAC. At the slower the filtration speed, the ion exchange reactions were become easily. At the highest filtration speed 20 m/h, at the E60 points, the percentage of Fe removal was only around 25 % compared with 33.7 % at the lowest filtration velocity. Also at the highest filtration velocity, the Fe removal rate at different points decreased significantly from 53 to 39 and 25% compared with the lowest filtration velocity from 54 to 47 and 38%, respectively. However, the Fe concentration in the effluent (E0) was not changing much when the velocity changing. When the filtration speed changed two times the Fe removal rate at E0 only changed around 1% (Mn removal rate changed 8%). The results show smaller removal efficiency compared to existing Chemiles, highlighting the need for improvement of system configuration and operation modes.

5. CONCLUSIONS

Groundwater is still an important water source in Hanoi, but the concentrations of As, Fe, Mn, $\text{NH}_4\text{-N}$, DOC in groundwater exceed WHO drinking water guidelines putting at risk the millions of Vietnamese people relying on groundwater as sources of drinking water. It was widely accepted that As is derived from the reductive dissolution of As-containing Fe oxyhydroxides in sediments from the Red River delta, Arsenic bound to organic matter and Ferric oxyhydroxides was considered to be released into groundwater when organic matters were degraded under reductive condition.

Crushed AAC could remove metals and heavy metals in wastewater and groundwater with extremely high efficiency up to 100%. Smaller AAC size had a higher percentage of heavy metal adsorption. The efficiency removal metals were also strongly depended on the thickness and filtration speed. AAC material is a sensible and environmentally-friendly reactive medium with a high potential for nature-based solutions.

The use of AAC waste from CDW for wastewater and groundwater treatment shows the potential of for metals and heavy metals removals. Further, using

recycled ACC from CDW would be an effective way for sustainable management of solid waste in Vietnam in the context of circular economy.

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