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Faculty of Tropical AgriSciences

Proposal of Appropriate Technology for Arsenic Mitigation in the Water in Vietnam

BACHELOR'S THESIS

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Declaration

I hereby declare that I have done this thesis entitled Luu Minh Trí Tran independently, all texts in this thesis are original, and all the sources have been quoted and acknowledged by means of complete references and according to Citation rules of the FTA.

In Prague 20.7.2020

....

Luu Minh Trí Tran

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Abstract

Vietnam belongs to one of the Asian tigers, has experienced dynamic economic growth in the last decades. But with the process of industrialization and rapid growth of the population, questions of environmental pollution and access to clean water becomes more sensitive in recent years. In most provinces, underground water is still the main source of water for drinking or cooking. The level of Arsenic contamination in Hà Nam province is very high. Despite using a sand filtration system, which shows up to be effective (it remove almost 90% of arsenic level in water), the level of arsenic occurred in water still remains higher than national standards.

The main objective of this paper study was to map the situation of the problem with Arsenic water contamination in the Hà Nam province in the northern part of Vietnam. This thesis is based on a literature review of scientific articles available in Academic databases, E.g. science direct, web of science, or Academic library. According to data we obtain from our research, we designed a proposal of water treatment technology to purify and controlling of Arsenic level.

Key words: Vietnam, Hà Nam province, underground water, water purification technologies, arsenic, filtration, laterite, reverse osmosis

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List of the abbreviations used in the thesis

As	Arsenic
ATSDR	Agency for Toxic Substances and Disease Registry
BMDL	Benchmark Dose (Lower Confidence Limit)
BFD	Black Foot Disease
$^{\circ}C$	Degrees Celsius
Fe	Iron
GDP	Gross Domestic Product
g/cm^3	mass in gram per cubic centimetres
JEFCA	Joint Expert Committee for Food Additives
JHPN	Journal of Health, Population and Nutrition
km^2	square kilometer
km	kilometer
K	Kelvin
m^3	cubic meter
mg/kg	milligram per kilogram
mg/m^3	milligram per cubic meter
mg/l	milligram per liter
NGOs	Non-Governmental Organisation
O_2	Oxygen
PVD	Peripheral Vascular Disease
PTWI	Provisional Tolerable Weekly Intake
UNICEF	United Nations International Children´s Emergency Fond
UNDP	United Nations Development Program
USD	United States Dollar
USEPA	United States Environmental Protection Agency

WHO	World Health Organisation
WB	World Bank
WPP	Water Purification Plant
μg	micrograms
$\mu g/m^3$	micrograms per cubic meter
$\mu g/l$	micrograms per liter
Ωm	omega meter

1. Introduction

With the rapid population growth and increasing demand for natural resources, nowadays the trend became unsustainable and its sources are being exhausted. The total population has tripled in the last six decades, from 2.5 billion in 1950 to 7.6 billion in 2019 (World Bank, 2019). The freshwater demand also has increased with the population growth, from 1.3 trillion m3 to 4 trillion m3 in 2014 (Worldindata, 2014). The freshwater sources are limited and with increasing consumption and demand, the freshwater becomes less available. It´s estimated that 2.2 billion people don´t have access to properly treated water or have to drink from contaminated water. Therefore the issue of scarcity of water sources and drinking water is becoming one of the key topics. Measurement is needed to prevent future water crises, where future generations will face a shortage of water sources. Many factors are affecting the availability of water sources such as climate change, human activity, overuse of water sources (agriculture, industry), water pollution, or natural disaster. Among the causes, Arsenic (As) is considered as one of the most serious problems of water contamination, affecting many regions in the world, such as South America, a big part of Russia, or many regions in South and South-east Asia. The most affected countries in Asia are Bangladesh, India, China, or Vietnam. United States Agency for Toxic Substances and Disease Registry listed Arsenic as number 1 of hazardous substances (Hai Nguyen, 2019). As is known for its carcinogen effect and is assigned to a Group A by the USEPA (Van Ngyuen, 2008). According to the WHO limit of arsenic in water shouldn´t exceed 10 μg/L.

Arsenic is a metalloid element and in the environment occurs naturally in its both form, organic (atom of arsenic are bonded with carbon) and inorganic (without carbon). Inorganic arsenic, the most abundant type, occurs with many other elements, particularly sulfur, oxygen, and chlorine. Inorganic arsenic is the type associated with more adverse health effects for humans. (Traci Pedersen, 2016).

The problem with arsenic contamination is one of the serious problems in Vietnam. It's estimated that approximately 17 million people are affected around the Red River and Mekong river. Millions of these don’t have access to clean or properly treated water. Often these families are poor and can´t afford a house filter. In the

Mekong delta river, the total arsenic concentration ranged between 1-845 μg/L. The average concentration was 39 μg/L. The worse situation occurred in the northern part of Vietnam, where average concentration is 159 μg/L (concentration range between 1-3050 μg/L). It is way more than WHO limits (Hay Nguyen, 2019).

2. Aims of the Thesis

2.1. Main objective

The main objective of this thesis is to analyse, design and propose proper technology to purify, reducing and controlling amount of arsenic or other heavy metal in water to acceptable level, to prevent illnesses connected with consuming contaminated water.

2.2. Specific Objectives

One of the objective was to review the situation of arsenic pollution in Vietnam and its impact on environment, health etc. The second objective was to evaluate current purification technologies in Vietnam and review their effectiveness in arsenic mitigation.

3. Methodology

This bachelor thesis was based on information analysis of the data, which were available from academic databases, mainly the scientific articles from periodicals and papers in English language. The scientific databases which were used in this thesis as a source of information were science direct, web of science or Google scholar.

4. Literature Review

4.1. About Arsenic

Arsenic is a naturally occurring element that is distributed in the Earth´s crust. Arsenic can be found everywhere. Arsenic is widely represented in the environment as its the 20th most widespread element in the earth's crust (Eisler, 2007). It can be present in water, air, food, and soil. In the past arsenic was heavily used in agriculture, like pesticides. But nowadays Arsenic is being banned in most countries due to its toxic characteristics. Arsenic is also used in other industries, e.g. in medicine or the industrial sector. Arsenic can be also released into the environment during volcanoes and mining processes. In general, we recognized two forms of arsenic, organic and inorganic. The inorganic form of arsenic is highly toxic for the human body and it more dangerous than its inorganic form (NIEHS, 2019).

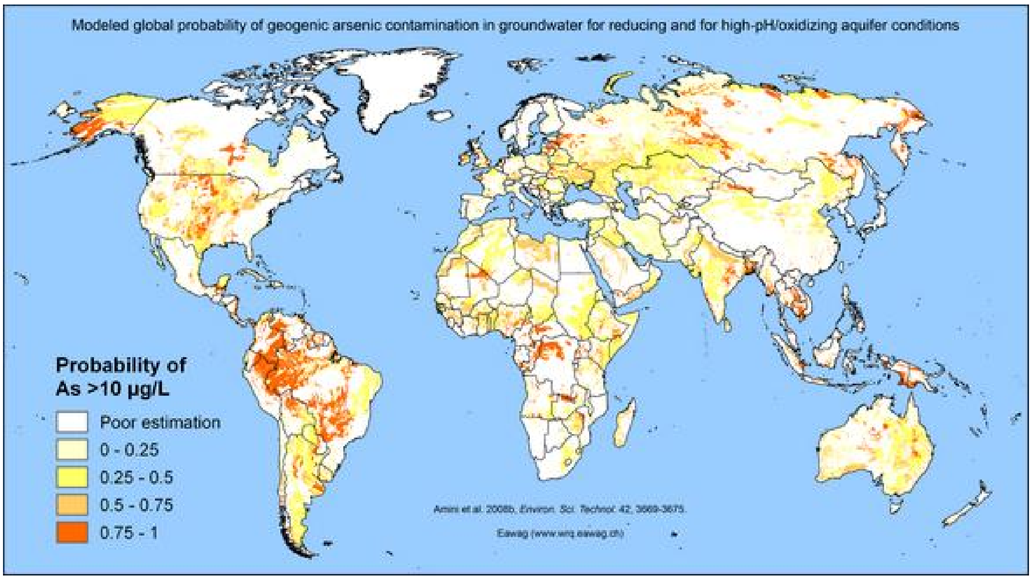

Figure 1 Geogenic Contamination Map

Source: gapmaps

In most cases, people are exposed to elevated levels of an inorganic form of arsenic through drinking contaminated sources of water, using contaminated water for cooking and irrigation of food crops, or eating contaminated food. People working in some part of the industry, as mining or heavy industry, can be also exposed to the elevated level of arsenic. A small amount of arsenic is also contained in tobacco. Untreated long-term exposure to inorganic arsenic can lead to chronic arsenic poisoning. The main symptoms of long-term exposure to arsenic from drinking water and food are connected with skin, skin cancer or skin lesions are the most characteristic effects. Long-term consumption of contaminated water can to also lead to damage to the lungs, liver, or other systems of the body. It has also been associated with illnesses such as cardiovascular disease and diabetes. Exposure to arsenic in utero and early childhood has been linked to negative impacts on cognitive development and increased deaths in young adults. In 2001 Arsenic was listed as a highly toxic element and ranked at the top in the priority list of hazardous substances by Agency for Toxic Substances and Disease Registry in the United States. Arsenic is naturally present at high levels in the groundwater. Drinking the contaminated water sources become a serious problem issue and pose the greatest threat to public health in many countries, especially in Asia, such as Vietnam, Bangladesh, China, or India. Arsenic contamination of groundwater is widespread and in several regions where contamination of groundwater is significant. Nowadays at least 140 million people in 50 countries have been drinking from sources contaminated by arsenic at the level above the WHO provisional guideline of 10 µg/l (WHO and Thi Ngyuen, 2019).

4.1.1. Arsenic

Name	Arsenic
Symbol	As
Colour	Grey
Classification	Metalloid
Crystal structure	Rhombohedral
Atomic Number	33
Number of neutrons	42
Atomic mass	74.9216 amu
Electrons per shell	2, 8, 18, 5
Melting point	817.0 °C
Boiling point	613.0 °C

Table 1 Arsenic Elemental Characteristic

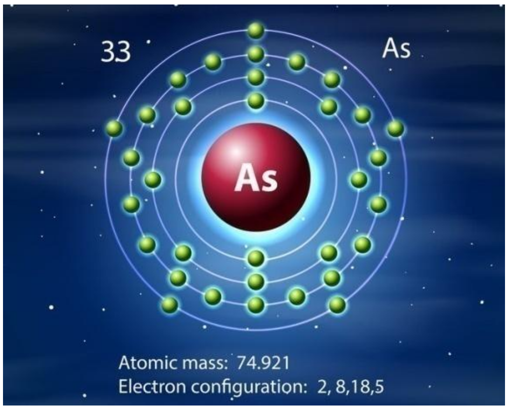

Figure 2 Atomic Structure of Arsenic

Source: VectorStock

4.1.2. Chemistry and Geochemistry of arsenic

Arsenic, atomic number 33, belongs to the VB group in the periodic table. Arsenic is a metalloid, and it occurs in various oxidation states (-III, 0, +III and +V) in nature. In natural water, arsenic is mostly found in inorganic forms as tri-valent arsenate arsenic (III) and pentavalent arsenate arsenic (V). The concentration of arsenic in the earth's crust normally ranges from 1.5 - 5 mg/kg. The arsenic concentration in soil naturally ranges from 22 0.1 to 40 mg/kg, and the average concentration range from 5 to 6 mg/kg. Arsenic contaminates groundwater and surface water through processes such as erosion, dissolution, and weathering (Md. Fayej Ahmad,2012).

Arsenic forms compound with sulfur very well and is a part of many sulphidic minerals, and it is also characterized by strong binding to iron (Koplík et al., 1997). Typical arsenic-containing minerals include realgar As4S4, arsenopyrite FeAsS, löllingite FeAs2. In the rocks, it accompanies, for example, ores of nickel, cobalt, antimony, silver, gold, and iron, it is also contained in coal deposits. Therefore, there is often a higher content of arsenic in the environment near smelters and metallurgical mines. Arsenic is obtained as a by-product in ore processing, arsenic oxide, which is formed during metallurgical processing of ores, is captured on electrostatic precipitators and is the basis for the production of virtually all arsenic preparations (Bencko et al. 1995).

4.1.3. Sources of Arsenic Contamination

Sources of environmental contamination by arsenic are divided into two groups, namely natural and anthropogenic. Natural causes include weathering, volcanic activity, biological activity. It is the weathering of rocks containing arsenic that is the cause of one of the biggest contamination problems in the world. During the formation of the Himalayas, there was a very rapid rise of the rock to 3-4 km and the release of a large amount of weather, which were transported by the Ganges during the monsoon floods to its delta. The core of the Himalayas is made up of migmatites and granitoid, and pyrite and arsenopyrite are released during their weathering. Although arsenopyrite is easily weathered, arsenic is immediately adsorbed by manganese and iron hydroxides (Cílek, 1998).

Arsenic also enters the environment as a result of human activity. The main sectors contaminating the environment with arsenic include industry and agriculture. The importance of arsenic in society is constantly changing. While in some areas its use has fallen sharply (eg pesticides or the use of arsenic for wood coatings, in other sectors it remains (eg semiconductors, pigments) and the potential for its use (medicine, veterinary medicine, chemical weapons) is the subject of various research.

Industrial sources of arsenic pollution include mining and heavy metal processing. However, the emission of risk elements varies depending on the type of mining activity. For example, coal mining is a major source of arsenic, iron, cadmium, and other elements that contaminate the soil around the coal basin. Metallurgical processes that take place at high temperatures, such as melting or casting, cause the emission of metal particles in the form of steam. Steam containing elements such as arsenic, cadmium, copper, lead, selenium, and zinc, in combination with water in the atmosphere, subsequently forms an aerosol which is dispersed by either wind (dry deposition) or rainfall (wet deposition), causing soil contamination and water bodies (Nagajyoti, 2010). Although the toxicity of arsenic was well known, its compounds were used also as pesticides in agriculture until the second half of the twentieth century, when they were replaced by more effective organic compounds. However, although use has been phased out, there has been an increase between 1980 and 2000 due to the use of arsenate copper. Copper arsenate has been applied as a pesticide in viticulture (Housecroft, Sharpe 2014).

4.1.4. WHO Response

WHO includes arsenic as one of 10 chemicals of major public health concern. Setting guideline values, reviewing evidence, and proving the recommendation of risk management is part of WHO´s work to reduce arsenic exposure. WHO publishes a guideline value for arsenic its guidelines for drinking water quality. These guidelines are intended for use as the basis for regulation and standard-setting worldwide. The European Union limit for arsenic concentration is 10 μg/L, in drinking water. World Health Organisation (WHO) supports the EU and recommended the same value. On the other hand, there are still some developing countries that are struggling to establish and implement measures to reach standards of 50 μg/L in affected areas. This guideline is designated as provisional because of difficulties in removing arsenic from water. The WHO´s guideline was in previous studies supported by a JEFCA provisional tolerable weekly intake of 15 μg/kg of body weight, assuming 20% was allocated to drinking water. However, JECFA recently re-evaluated arsenic and concluded that the existing PTWI was very close to the lower confidence limit on the benchmark dose for a 0.5% response (BMDL0.5) calculated from epidemiological studies (specifically for an increased risk of lung cancer) and was therefore no longer appropriate. The PTWI was therefore withdrawn (FAO/WHO, 2011). JECFA concluded that for certain regions of the world where concentrations of inorganic arsenic in drinking-water exceed 50–100 µg/l, some epidemiological studies provide evidence of adverse effects. There are other areas where arsenic concentrations in water are elevated (e.g. above the WHO guideline value of 10 µg/l) but are less than 50 µg/l. In these circumstances, there is a possibility that adverse effects could occur as a result of exposure to inorganic arsenic from water and food, but these would be at a low incidence that would be difficult to detect in epidemiological studies. Every endeavor should be made to keep concentrations of arsenic as low as reasonably possible and under the recommended value by WHO when resources are available. Nowadays millions of people in many regions across the world are still exposed to the arsenic level which is much higher than the guideline value (is most of the cases the value is even higher than 100 µg/L), therefore reducing exposure for these people should be considered as the public health priority. Member States may set higher limits or interim values as part of an overall strategy to progressively reduce risks while taking into account local circumstances, available resources, and risks from low arsenic sources that are contaminated microbiologically. The WHO/UNICEF Joint Monitoring Programme for Water Supply, Sanitation, and Hygiene monitors progress towards global targets on drinking water. Under the new 2030 Agenda for Sustainable Development, the indicator of "safely managed drinking water services" calls for tracking the population accessing drinking water which is free of feacal contamination and priority chemical contaminants, including arsenic (FAO/WHO, 2011).

4.1.5. Effect of arsenic on human health

It confirmed that inorganic arsenic has a carcinogen effect and is extremely toxic on the human body and is the most significant chemical drinking-water contaminant globally. Arsenic also occurs in an organic form, which is less harmful to our health. In cases of long-term exposure to arsenic in drinking water is related to increased risks of several types of cancer (skin, lungs, bladder, or kidney cancer). Arsenic poisoning mostly affects the skin, like hyperkeratosis and changes of pigmentation. These effects have been confirmed and demonstrated in many studies using different methods. Exposure-response relationships and high risks have been observed for each of these endpoints. These effects have been most thoroughly studied in Taiwan but the considerable evidence of the effects of arsenic poisoning comes from many studies from other countries as well. In cases where the ingestion of drinking water with a concentration of arsenic is 50 µg/l or higher, increased risks of lung and bladder are observed. There is also a higher risk of skin lesions reported. Occupational exposure to arsenic, primarily by inhalation, is causally associated with lung cancer. Exposure-response relationships and high risks have been observed. Increased risks have been observed when cumulative exposure levels ≥ 0.75 (mg/l) × year (e.g. 15 years of exposure to a workroom air concentration of 50 µg/l). Smoking of tobacco has been investigated in two of the three main smelter cohorts and was not found to be the cause of the Increased lung cancer risk attributed to arsenic. However, it was found to be interactive with arsenic in increasing lung cancer risk. Even with some negative findings, the overall weight of evidence indicates that arsenic can cause clastogenic damage in different cell types with different end-points in exposed individuals and cancer patients. For point mutations, the results are largely negative. (Environmental Health Criteria 224 EHC, Green Facts, 2004)

Figure 3 Symptom of arsenic poisoning

Source: Healthtism

4.1.6. Symptoms

Arsenic can interfere with the body´s metabolism and seriously disrupt it. We divided the symptoms of arsenic poisoning into acute, or severe and immediate, or chronic, where the damage to health is occurring during long-term exposure. Acute arsenic poisoning tends to be quite dramatic due to its symptoms. The course and severity of the poisoning mostly depend on the method, level, or length of exposure. A person who has swallowed arsenic may be experienced immediate symptoms within 30 minutes. Between immediate or acute symptoms we include drowsiness, headaches, confusion, dark urine, severe diarrhea, vomiting, abdominal pain, or excessive salivation. In most of the case hemolysis (red blood cell breakdown) also occurs. Arsenic causes damage to vital organs, in extreme cases, acute intoxication can lead to coma and death of the patient. In the case where arsenic has been inhaled, or a person has ingested a less concentrated amount, symptoms may take a longer period to develop. With the arsenic poisoning progress, the patient may start experiencing convulsions, and the pigmentation of their fingernail may change. Other symptoms associated with more severe cases of arsenic are a metallic taste in the mouth and garlicky breath, excess saliva, problems swallowing, blood in the urine, cramping muscles, hair loss, stomach cramps, convulsions, excessive sweating, vomiting, diarrhea. Arsenic poisoning typically affects the skin, liver, lungs, and kidneys. People with disabilities have a higher risk of developing skin cancer. In the final stage, symptoms include seizures and shock. This could lead to a coma or death. Arsenic is stored in the hair (Medical News Today).

Figure 4 Blackfoot Disease

Source: Healthtism

4.1.7. Diagnosis

A case of arsenic poisoning can be confirmed by pathological testing. Arsenic poisoning must be diagnosed by a doctor to get the proper treatment and this also can help the doctor to find out underlying cause to limit or avoid future exposure. In regions and occupations with a certain risk of arsenic exposure, it is important to monitor the levels of arsenic in the people at risk. It's possible to measure high levels of arsenic in the body by test via the blood, fingernails, hair, or urine. Urine tests are most commonly used in cases of acute exposure. Urine samples should be done within a few days (1-2 days) of the initial exposure for getting accurate when the poisoning occurred. The urine test diagnosing can be also used in case of apparent arsenic poisoning. All other tests can be used in case of long-term exposure of a least six months. The hair test or fingernails test can be used to determine the level of arsenic exposure for a longer period (up to 12 months). All these tests can give an accurate indication of arsenic exposure levels and measure a high amount of arsenic in the body. On the other hand, they don´t what and determine effects it may have on the patient´s health from exposure (Medical News Today).

4.1.8. Treatment

There is no specific method used to treat arsenic poisoning. Eliminating or limiting arsenic exposure is one of the most effective ways to treat the condition. It requires weeks or months to full recovery from arsenic poisoning. It depends on the length and level of exposure. The severity of the symptoms also can play a role in total recovery. The treatment depends on the level and stage of arsenic poisoning. Some methods are used to remove arsenic from the human body before they can cause any damage. Other methods are used to repair or just to minimize the damage that has already occurred. Treatment methods include: removing contaminated clothes, thoroughly washing and rinsing affected skin, blood transfusions, taking heart medication in cases where the heart starts failing, using mineral supplements, observing kidney function. Another method is bowel irrigation, where a special solution is going through the gastrointestinal tract and used for flushing out o the content. This method removes traces of arsenic and prevents it from being absorbed into the gut. The next method which can be used to treat arsenic poisoning is Chelation therapy. This method uses certain drugs (dimercaptosuccinic acid, dimercaprol) which can selectively, and with efficiency inactive substances, they can isolate arsenic from the blood proteins. This method is usually begun through an intravenous line. The drug and the bound arsenic are then excreted through the urine. Vitamin E and selenium supplements are also used as alternative remedies to limit the symptoms of arsenic exposure (Medical News Today).

4.1.9. Prevention

Arsenic removal systems in homes can be used, if the levels of arsenic in an area are confirmed as unsafe. Systems can be purchased for the home to treat drinking water and reduce the arsenic levels. This is for a short-term solution until the arsenic contamination can be dealt with at the source. Testing nearby water sources for traces of arsenic, chemically examining the water can help to identify poisonous sources of arsenic. Taking care when harvesting rainwater: In areas of high rainfall, arsenic poisoning can be prevented by ensuring the process of the collection does not put the water at risk of infection or cause the water to become a breeding ground for mosquitos. Considering the depth of wells the deeper the well, the less arsenic its water is likely to have (Mike Paddock, 2018, Medical News Today).

4.2. Arsenic Polution in Vietnam

4.2.1. Introduction Vietnam

Figure 5 Flag of Vietnam

Source: ChinhPhu.Vn

Vietnam, officially the Socialist Republic of Vietnam, is located in south-east Asia. Vietnam is bordered by China in the north, by Cambodia with Laos in the West and by the South China Sea in the East. The total surface area is 331,230 km2, compared it is roughly 4 times bigger than the Czech Republic (World Bank, 2019). The total population of Vietnam is 97 338 000 people, which is ranked 15th most populated country (worldmeter, 2020). The density is 314 people/km2. The capital of city Vietnam is Hanoi, which is located in the northern part. But the biggest city in Ho Chi Minh city. Most of the population is without religion or they belong to local folk religion. In Vietnam there also Buddhism (12% of the population), but in South Vietnam was gradually banned. During French colonization, Catholicism was also spread in the country (nowadays around 6.9% of the population). The official language is the Vietnamese language, during French colonization the French language was also used as an official language.

The state is divided into 63 administrative areas of which 58 provinces and 5 cities under administration (Ho Chi Minh City, Hanoi, Cần Thơ, Đà Nẵng, and Hải Phòng. The highest mountain of Vietnam, but also of all Indochina It is 3,143 meters high (Chinhphu, 2015) The mountain lies in the Hoang Lien Son, also called the Tonkin Alps, and the Mekong River, the longest river in Asia, flows in Vietnam. In general, the weather is warmer in the south than in the north because of the milder climate. The country's weather is also strongly influenced by monsoons. The hottest month is April when the monthly average temperatures reach 35 ° C, but throughout the year the average monthly temperatures are around 32 ° C to 34 ° C. of Hồ Chí Minh cities is 1,300 mm (Worldweatheronline) The weather in Hanoi is much colder in most of the year than in H v Chí Minh. The average annual temperature is 23.9 ° C. The hottest months are from June to August when average monthly temperatures range from 25-26 ° C to 32 ° C. The coldest month at the beginning of the year in January and February. Average monthly temperatures range from 15 ° C to 19 ° C. The annual total rainfall in the capital Vietnam is 1,278 mm. On average it rains up to 187 days. (Holiday-weather) Weather also varies in mountain areas where winter temperatures drop to 10 ° C.

Vietnam is one of the Asian tiger economies, because of its economic growth. The annual growth of GDP is roughly about 7%. The GDP of Vietnam is 187.7 billion USD, in constant prices. Approximately 39.4% of the total population works in the Agriculture sector, 25% are employed in the industrial sector and 34.7% of people work in services (World Bank, 2019). The most important agricultural products in Vietnam are rice, sugar cane, cassava, tea, or coffee (Britannica).

4.3. Arsenic situation in Vietnam

Contamination of water sources by geogenic arsenic become a global treat of public health and many regions around the world. Natural contamination of groundwater by arsenic is an emerging issue in some countries of Southeast Asia, including Vietnam, Thailand, Cambodia, and Myanmar. It´s estimated that around more than 100 million people in southern and southeast Asia are using water with arsenic contamination exceeding the WHO recommended maximum value of 10 µg/L (Postma, 2017). Ground-water contamination by arsenic resulted in significant health effects on humans in many countries such as India, Vietnam, Bangladesh, Taiwan, or Chile. In these regions, there are densely areas or cities, and ground-water is the main or only source of drinking water. Ground-water its main drinking water source for local communities. It´s estimated that approximately 13 million people use water from tube-wells in Vietnam. In numerous regions in Vietnam were found elevated arsenic concentration. It is estimated that 10 million inhabitants in the Red River delta are at risk of chronic arsenic poisoning, In the Mekong delta, it´s estimated around 0.5-1 million people. But only a few cases of arsenic health issues related to arsenic poisoning are recognized in Vietnam compared to other countries such as Bangladesh or West Bengal. This difference it presumably causes in Vietnam and Cambodia, arsenic-contaminated tube-well water has been using since the middle or end of the 1990-s. Because symptoms of chronic arsenic poisoning in most of the cases take more than 10 years to develop, the number of future arsenic-related ailments in Cambodia and Vietnam is likely to increase. Thus the early study of this area and mitigation measures should be a high priority (Berg et al, 2007).

Arsenic contamination of groundwater in the Cambodian part of the Mekong delta area was firstly identified in 2000. This problem was investigated and addressed with the close collaboration of local authorities and international NGOs. The first study about groundwater contamination by arsenic was published by Polya et al. in 2005. A study case for arsenic contamination was published in 2007 by Berg et al.

Groundwaters that are located at large alluvial deltas of the Mekong River in southern Vietnam and Cambodia and the Red River in northern Vietnam are exploited for drinking water by private tube-wells. This demand was increasing since the mid-1990s when most of the province stopped use the surface water and shallow dug. In several regions in Vietnam and Cambodia groundwater is the main water supply. In the study carried out in 2007 was focus on to determine the magnitude groundwater arsenic pollution in the Mekong delta, find the severe problem where arsenic concentrations ranged from 1–1610 µg/L in Cambodia (average 217 µg/L) and 1–845 µg/L in southern Vietnam (average 39 µg/L), respectively. This study also evaluated the situation in Red River delta in North Vietnam. In this region, groundwater arsenic concentrations vary from 1–3050 µg/L (average 159 µg/L) (Ngyuen, 2019). In all studied region, the origin of the groundwater arsenic pollution seem to be of natural and is caused by reductive dissolution of arsenic bearing iron phases buried in aquifers. The occurrence of arsenic in the study area in the investigated aquifers points to the natural geogenic origin is similar to the case in Ganges delta. But we also cannot exclude arsenic contamination in the Red River delta by anthropogenic activity, through agricultural chemicals, leakage of the landfill, or ming wastes, although there is no indication or evidence. The Mekong and the Red River deltas belong to one of the most productive agricultural areas of South East Asia. Both deltas have young sedimentary deposits of Holocene and Pleistocene age. (Berg, 2007).

Contamination of groundwater by Arsenic belongs is a serious public health risk in Vietnam. UNICEF estimation is that approximately 10–15 million people use water from tube-wells from drinking. Several scientific studies have shown that high arsenic contamination occurs in groundwater in the number of provinces in the Red River delta in North Vietnam. Several research studies conducted between 1995-2000 has found arsenic concentration in water samples in the several areas in North Vietnam (Sơn La, Phú Thọ, Hai Phong, Nam Định, etc where the level of arsenic contamination exceeded both international and Vietnamese acceptable standard levels for arsenic in drinking water (Huy, 2014). According to a case study published in 2010, approximately seven million people in the Red River Delta region use groundwater contaminated with arsenic, manganese, selenium, and barium. The levels of arsenic contamination in many locations surveyed in Ha Nam and Hung Yen were found to be as high as in Bangladesh (Huy, 2014)

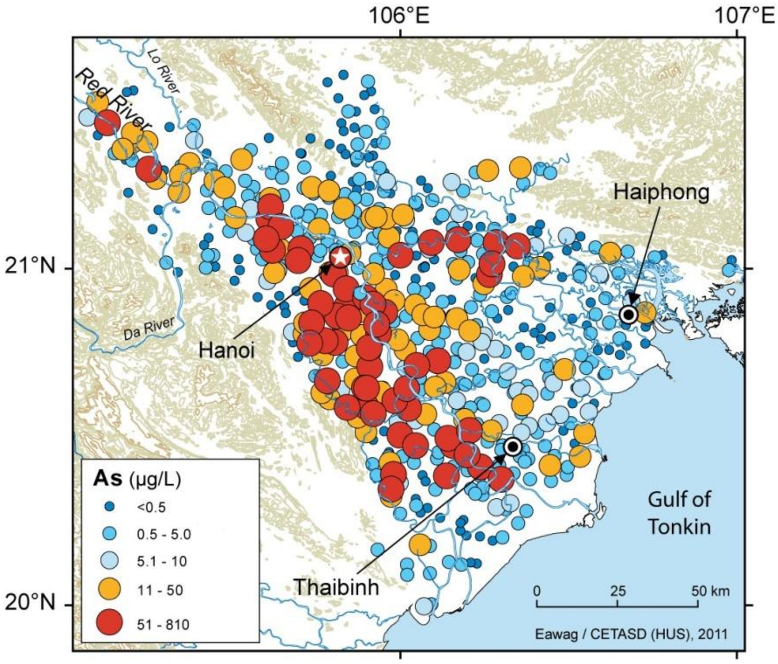

Figure 6 Map of Arsenic Contamination in the Red River Delta

Source: Winkel 2011

4.3.1. Mobilisation of Arsenic in the Red River delta

Arsenic can get into the ecosystem in two ways: naturally or by anthropogenic emissions. On the big delta river complexes of South and South-East Asia, arsenic enters the system in association with Fe-oxides which together with clays and sands have been deposited on the floodplain. Once the sediment becomes part of the saturated groundwater zone anoxic conditions develop because of organic matter degradation. Organic matter degradation leads to the reduction of As-containing Fe-oxide, resulting in the release of Fe(II) and As(III) to the groundwater3,4,5. Secondary processes that may affect the groundwater arsenic concentration, comprise the adsorption and desorption of arsenic to the sediment (Stopelli, 2020).

Geogenic As in groundwater results from the dissimilatory reductive dissolution of iron Fe(III) in river and aquifer sediments by microbes, coupled to the oxidation of organic matter in anaerobic environments. These Fe(III)-reducing conditions are prevalent in Holocene river floodplains and young river delta regions in East and South Asia. These zones often contain high levels of dissolved As and reduced, greyish sediments. The second type of aquifer is composed of older Pleistocene sediments, characterized by suboxic to moderately reducing conditions (usually manganese

Mn(IV)-reducing), which preserve Fe(III)-bearing orange and brown sediments and have dissolved As concentrations below the WHO guideline value of 10 µg As/L (Stopelli, 2020).

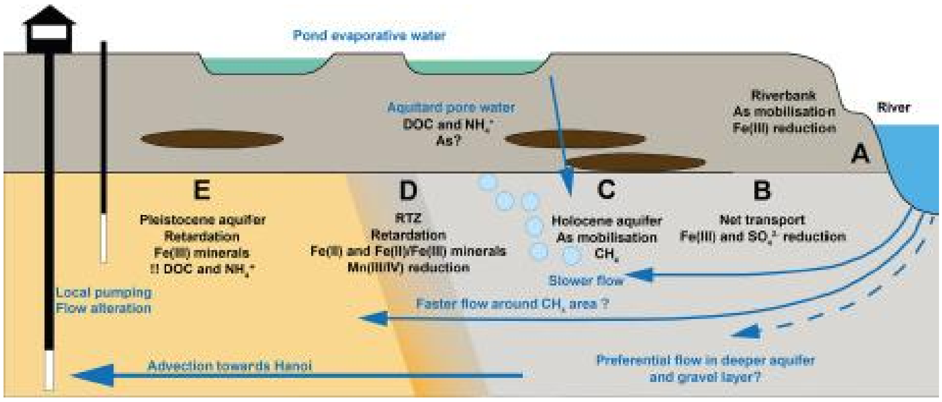

Figure 7 Mobilisation of Arsenic in North Vietnam

Source: Stopelli et al., 2020

groundwater flow direction

		Pleistocene aquifer (22–25 m)				RTZ			Holocene aquifer (22-25 m)		Bank	River
Geochemical zones		E				D			C	B	A	
As processes		Pristine/Retardation				Retardation			Mobilisation	Transport	Mobilisation	
Local well ID		A-24	2	4	36	32	31	11-25	5	12	-	-
Well code used here			E2	E1		D2		D1	C	B		
As	µg/L	3.8	6.3	1.7	1.4	97	295	393	509	143	123	2.3
Fe	mg/L	0.4	0.8	0.3	1.3	9.4	11	11	13	9.5	6.8	<0.05
Mn	mg/L	2.0	0.4	1.2	2.3	3.9	0.9	0.4	0.1	0.8	7.3	0.0
DOC	mgC/L	1.4	2.0	1.7	1.6	3.4	3.9	4.0	9.2	1.5	8.2	1.9
C-alkalinity	mmol HCO_3^-/L	2.3	7.0	8.3	9.5	10	10	9.7	13	8.5	19	1.7
CH_4	mg/L	<0.13	<0.13	<0.13	4.3	37	31	18	46	0.31	-	-
NH_4^+	mgN/L	0.1	24	15	13	19	23	21	67	0.6	6.2	0.3
PO_4^{3-}	mgP/L	0.04	0.10	0.07	0.03	0.3	0.4	0.5	1.6	0.7	0.00	0.03
O_2	mg/L	<0.05	<0.05	<0.05	<0.05	<0.05	<0.05	<0.05	<0.05	<0.05	-	6.80
NO_3^-	mgN/L	<0.05	<0.05	<0.05	<0.05	<0.05	<0.05	<0.05	<0.05	<0.05	<0.05	0.95
S	mgS/L	2.7	<0.1	<0.1	<0.1	<0.1	<0.1	<0.1	0.1	0.8	12	2.5
E_h	mV	85	112	146	113	10	11	17	36	19	-	408

Table 2 Mobilisation of Arsenic

4.3.2. Hà Nam province

The study area, Hà Nam province, is located in the northern part of Vietnam, approximately 60 km southern from Hanoi. The total area of the province is 862 km2, which is the second smallest province in Vietnam. The total population of the province is 847 000 (2014, gso.gov.VN). Province is divided into six sub-divisions: 4 districts

(Bình Lục, Kim Bảng, Lý Nhân, Thanh Liêm) and provincial cities (Phủ Lý, Duy Tiên). Between the years 1975-1985 was a period of implementing five-year plans throughout the whole country, including Hà Nam province, as economical reformation. This period was however very difficult due to social and economic difficulties, slow production growth and low production efficiency, lack of infrastructure. Nowadays Hà Nam province has achieved certain development and economical growth but still belongs between the poorest provinces. In the province, there are four main rivers: Red River, Đáy River, Sông Nhuệ, Châu Giang. The annual average temperature is around 23-34 °C. The highest average temperatures are in June and July. The coldest months are December and January. There are two main seasons (summer and winter). The average rainfall is 1900 mm/year (Hanam.gov).

4.3.3. Contamination of groundwater and risk assessment for arsenic exposure in Hà Nam province

I chose Hà Nam province for my thesis. According to a case study published in 2010, approximately seven million people in the Red River Delta region use groundwater contaminated with arsenic, manganese, selenium, and barium. The levels of arsenic contamination in many locations surveyed in Hà Nam province and Hưng Yên were severe and were found to be as high as in Bangladesh (Huy, 2014)

In Hà Nam province the depths of the tube-wells mostly ranged from 16–40 m, the groundwater was considered in study to be from the shallow Holocene aquifer. Approximately 87% of households used groundwater treated by sand filtration systems. Originally, sand filters were installed for iron removal since iron concentrations are commonly high in the groundwater (Pham, 2017). Groundwater in the studied areas was found seriously contaminated by iron, manganese, ammonium, and arsenic. The concentration of arsenic ranges was similar to other regions in the Red River delta but significantly higher than in the Mekong River delta as reported in the study by Berg et al. in 2007. The average total arsenic concentrations in the groundwater of studied areas in Hà Nam province Vĩnh Trụ, Bồ Đề, and Hòa Hậu were 348, 211, and 325 µg/L, respectively during the whole year. The arsenic level in the groundwater of Nhân Đạo (located on the bank of the Red River) was much lower than in other studied villages.

Only 5 out of 10 samples in ND were detected at levels that exceeded the Vietnamese standard for arsenic in drinking water (10 µg/l) (Ngyuen, 2008).

4.3.4. Sand filtration

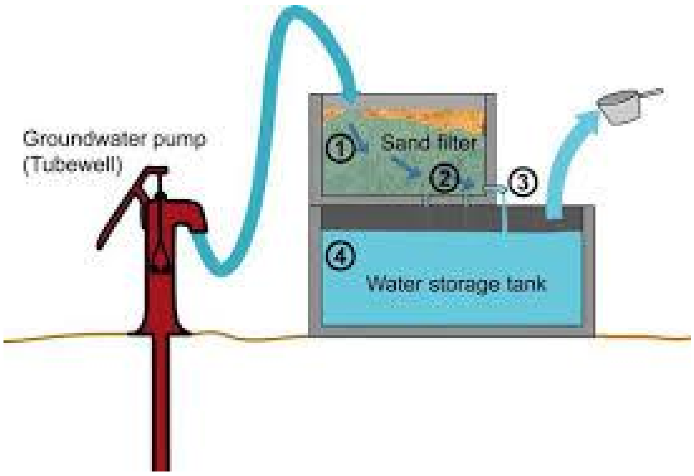

Figure 8 Sand filtration system use in North Vietnam

Source: Berg et al., 2004

Sand filtration systems are widespread in Hà Nam province and are commonly used for purification of water from wells. Treated water by sand filtration systems is one of the main water sources consumed directly by the local peoples. Many people use treated water for washing and cleaning as well. There were many studies investigated the efficiency of the sand filter systems. Sand filtration system shows up as an efficient method of how to remove arsenic from water. Sand filtration can remove up to 90% of arsenic from water. High concentrations of iron in the groundwater played important roles in improving the efficiency of arsenic removal by sand filtration, as the result of the co-precipitation mechanism. Despite the efficiency of removal, the sand filter system is still not enough to reduce the arsenic concentration to the required safe level recommended by WHO. The percentage of treated groundwater containing arsenic concentrations higher than the standard was still high. The percentage of treated groundwater containing arsenic concentrations higher than the Vietnamese standard was still extremely high (70% in VT, 40% in BD, and even 100% in HH) except for the ND village. This is attributed to the Fe/As ratio (mg/mg) and the high levels of anions such as bicarbonate, silicate, and phosphate in the groundwater. Meng et al. (2001) reported that Fe/As ratios of greater than 40 (mg/mg) were required to decrease arsenic to less than 50 µg/L (Bangladesh drinking water standard). According to the effects of anions on arsenic removal reported by Meng et al. (2002), the presence of three anions significantly decreased arsenic removal. The average Fe/As ratio in the ND village was more than 800, while the average Fe/As ratios in other villages ranged from 52–113.

Figure 9 Sand Filtration Plant in North Vietnam

Source: Berg et al., 2004

Higher levels of these anions were observed in the groundwater in Ha Nam province. Especially, high bicarbonate concentrations were found in the VT, BD, and HH villages. These results suggest that the improvement of the current sand filtration operation is needed to reduce arsenic below the arsenic drinking water standard (Ngyuen, 2008).

	Raw groundwater				Treated groundwater			
Province	As- III (µg/l)		As- total (µg/l)		As- total (µg/l)		% Arsenic Removal	
	February	September	February	September	February	September	February	September
Vinh Tru Mean Range Medium n	 334 10-489 338 10	 251 93-361 302 9	 366 13-582 364 10	 331 84-479 377 9	 33 Nd-82 13 10	 40 3-192 17 9	 92 71-100 84 10	 85 18-97 96 9
Bo De Mean Range Medium n	 211 107-334 181 10	 186 85-297 179 9	 219 112-350 198 10	 203 94-288 208 9	 14 3-48 6 8	 40 7-156 11 5	 96 76-99 97 8	 84 45-97 93 5
Hoa Hau Mean Range Medium n	 306 224-390 283 10	 299 202-376 317 8	 322 238-439 285 10	 327 248-377 361 8	 26 14-48 21 8	 36 6-95 32 6	 92 86-94 82 8	 90 74-98 92 6
Nhan Dao Mean Range Medium n	 50 <5-123 37 10		 51 <5-127 44 10		 <5 <5 <5 9		 100 100 100 9	

Table 3 Arsenic concentration in raw treated groundwater, Arsenic Speciation of groundwater

Source: Ngyuen et al., 2008

4.4. Technology proposal

After a literature review of available studies and analyzed the data and the purification system used in Hà Nam province I have been proposing several solutions for mitigation and control level of arsenic in the water. The description of proposed technologies that would be potentially used to improve the quality of water and efficiency in the water purification process will be described in this section. Resources and water quality are crucial to human health and children's development. If the water sources were contaminated and polluted, many lives could be endangered. In addition, care must be taken to ensure access to water resources for the poorest people, especially favela areas, which suffer from a major lack of access to safe drinking water. Our proposed technologies combined with the current technology. Our new technologies to mitigate the arsenic level in the water described below.

4.4.1. Ion Exchange technology

Figure 10 Ion Exchange Plant

Source: Samco

Ion exchange is being used in various biochemical and ecological manufacturing areas for extended periods. But, nowadays its use in water softening is very common, which involves the removal of Mg2+ and Ca2+ ions from hard water, either at water purification plant or by implying proper time for using a treatment procedure and also for industrial applications, for example, the formulation of pure demineralized water (Atalay and Ersöz, 2016).

Ion exchange is the exchange of ions with ionized species in water with ion exchangers, ie H+, and OH- ions. The process is reversible and can be regenerated by washing with excess ions. The principle of this technology is as follows. Water flows through the bed of ion exchange resins where the ions in solution migrate into the beads. Here, depending on the relative densities of the changes, they compete for exchange sites. The resins are 1 mm thick porous 52 particles made of highly cross linked, high ion exchange sites with high ion exchange rates. (Elga veolia 2019)

Deionization beads are cationic or anionic and exchange either H+ ions for cations, which may be Na+, Ca 2+, or OH-ions for anions, which may be Cl-, NO 3-. The hydrogen ion from the cation exchanger is combined with the hydroxyl ion exchanger to form clear water. (Elga veolia 2019)

The ion exchange resin beds are available as containers and are commonly used for some time before replacement. This occurs when cations and anions have replaced most of the active sites H+ and OH-. Once depleted, they can be regenerated by washing with excess desirable ions using strong acids and bases. This reverses the process and removes unwanted cations and anions. This process requires the use of chemicals. (Elga veolia 2019)

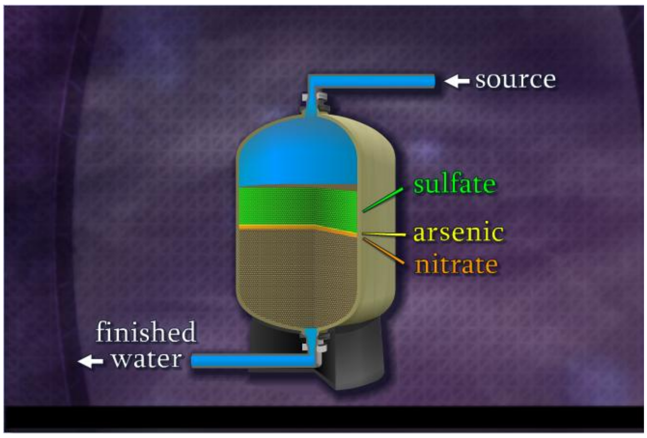

Figure 11 Ion Exchange Technology Scheme

Source: EPA

4.4.2. Reverse osmosis

RO distillation system is recognized as the principal significant and extensively used technology for the formulation of pure water from mineral-rich water. It is estimated that almost half of the installed water purification systems prefer RO technology all over the world, due to its easy adaptability and comparatively low energy expenses and higher efficiencies than concentrations required for other thermal procedures used for water purification (Fritzmann et al., 2007). Recently, great attention is given toward the advancement and supplication of a pure water system due to various complications associated with water pollution, rising human population, and industrial advancement (Werber et al., 2016).

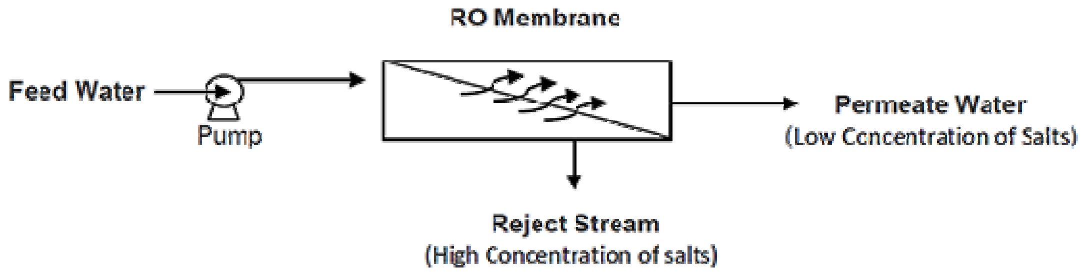

Figure 12 Reverse Osmosis

Source: lenntech

Reverse osmosis is a type of filtration using the pressure and a semi-permeable, thin membrane with pores small enough to pass pure water through while rejecting molecules larger than membranes such as dissolved salts or other impurities such as bacteria or inorganic substances. This method is an effective way to remove the impurities from water, and this method removes up to 99% of impurities.

Reverse osmosis is the method using a high-pressure pump (4 to 16 bar) to increase pressure on the salt side of the Reverse osmosis and make the water across the semi-permeable membrane. This will leave almost all of the dissolved salts in the reject stream. The level of pressure depends on the level of salt concentration of the feed water. Permeate water is the desalinated water that is demineralized or deionized. The reject stream is a water stream which carries the concentrated contaminants that did not pass through the reverse osmosis membranes.

As the feed water enters the RO under certain pressure the water molecules pass through the semi-permeable membrane and other molecules (bacteria, inorganic substances or other impurities) larger than the membranes are not able to pass and are discharged through the reject stream, which goes to drain or can be used again as feed water in some circumstances to be recycled through the RO system to save water. Permeate or product water is water that passed through the RO membrane and in most of the case it usually has about 95-99% of the dissolved salts and other impurities removed from it (puree water, 2019).

Reverse osmosis is a typical thin-film polyamide and is stable over a wide pH range. However, it may be damaged by oxidizing agents such as chlorine. Before using this method, it is necessary to clean the water from all possible oxidizing agents. Reverse osmosis is used to remove contaminants from water and water pollution that is less than 1 nm in diameter. More than 90 % of the ionic impurities, most organic impurities, and almost all particles, bacteria, and bio-molecules are removed from the filtrate or water permeate. This technology is suitable for removing inorganic compounds, microorganisms, and bacteria, organic compounds, and particles from water. (Elga Veolia 2019) A classic RO-based system comprises four main procedures: pre-treatment, high-pressure forces, salt parting, and post-treatment (Shenvi et al., 2015).

Figure 13 Reverse Osmosis Treatment Plant

Source: SR Engineering

4.4.3. Biosorption Mechanism

This method can remove the toxic substances from the water by using the physiochemical pathways (Kabir and Chowdhury, 2017). This is the relatively new method that is more extensively used for the exclusion of heavy metals from contaminated water. Biosorption is obtained from the nonliving biomass such as lignin bark, shrimp wastes, algal, and microbial mass, for example, bacteria, fungi, and yeasts. Algae have evidenced to be potential heavy metal biosorbents (He and Chen, 2014).

The biosorption method includes two phases as subsequent liquid phase (solvent) and solid phase (biosorbent), which has a capacity to absorb specific substances from the relative classes to be sorbed (metal ions).

4.4.3.1. Laterite as low-cost adsorbent in a sustainable decentralized filtration system (experiment case in Vietnam 2018)

The major techniques include ion exchange, chemical precipitation-coagulation, adsorption, membrane, and phytoremediation (Glocheux et al., 2013; Luong et al., 2018). Of these techniques, adsorption is considered the most cost-effective method for removing arsenic in household and small community levels because of its high removal efficiency, low energy consumption, simplicity in design and operation, and minimal waste generation. Iron- and aluminium-containing materials are considered to be suitable adsorbents because they possess a high affinity to arsenic (Giles et al., 2011; Pena et al., 2005).

Laterite is formed commonly in hot and wet tropical areas and is distributed widely in many areas throughout Vietnam (Thach That and Tam Duong areas). This material can be used as a potential adsorbent for arsenic removal due to the natural presence of Fe and Al oxides/hydroxides in its composition (Glocheux et al., 2013).

In this study, the natural laterite from Thach That (NLTT) together with six other local low-cost mineral and waste materials were first tested in the laboratory with synthetic water spiked with arsenic for their ability to remove arsenic. Based on the initial laboratory results, the NLTT material was selected and evaluated in a detailed batch study for its performance in arsenic removal. NLTT was then packed in the newly developed community water treatment system for a long-term trial with real contaminated groundwater. The new system has been implemented in the childcare center in Hoang Tay commune since June 2018. This paper presents the results concerning the performance of the locally available low-cost NLTT in removing arsenic over 6 months: firstly, from synthetic water through detailed batch adsorption studies; and secondly and subsequently, testing its use in the community water filtration system with natural groundwater. The community filtration system also incorporated the simultaneous removal of iron and pathogens.

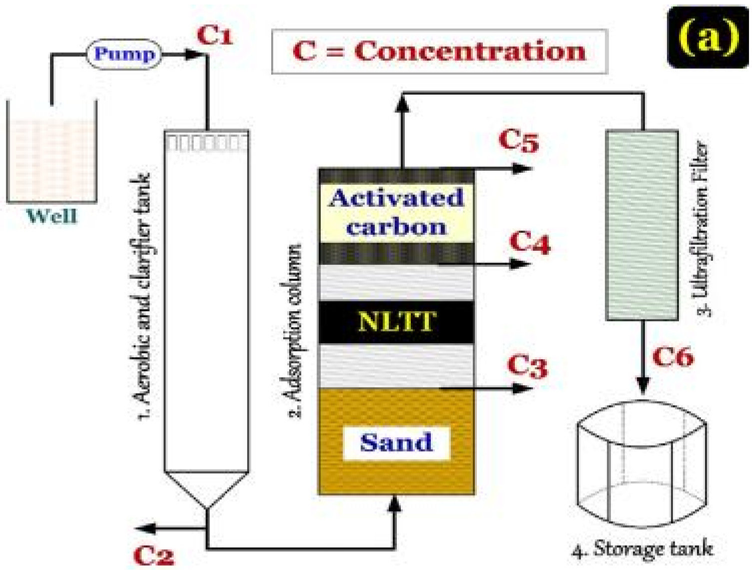

Figure 14 Laterite Purification Plant Scheme

Source: Ngyuen, 2019

5. Conclusions

The main objective and outcome of the study was the proposal of the design of water purification technology to improve the efficiency of purifying water and improving the mitigation of arsenic in Hà Nam province. This study was based on a literature review of several study cases, reports, or articles available on scientific journals such as science direct, web of science, or google scholar.

The evaluation of the analysis of the system used in the Hà Nam province to provide the water for the consumer's results highlighted the critical points which are there is no external system to purify the water from highly contaminated arsenic. Therefore, based on that information, we designed an auxiliary water purification unit which would improve the output of the main treatment center. The implementation of the new design of the auxiliary water purification unit with modern technologies should be recommended to the results highlighted. By the implementation of the new proposed design, the quality of the water produced is not only improved but it also provides the continuous supply of water to the consumers. The new system can supply the water when there is no electricity available because of the high altitude of the water tower.

Between all proposed technologies the reverse osmosis is one of the most effective options, where it can remove up to 99% of impurities. It can remove many dissolved substances efficiently but still produce good tasting water. RO also does not add any chemical to the water. On the other hand, one of the crucial disadvantages of this technology is its expensive price, when it makes hardly affordable for the poor region in developing countries like Hà Nam province. Reverse osmosis units can be expensive. The cost of a unit along with installation may run from several hundred to one thousand dollars or more. The next disadvantage is that RO produces more wastewater in comparison to clean water output. On one gallon there are around 2-20 gallons of wastewater. Also, the RO membranes are subject to decay and require periodic replacement. As they decay, the quality of the treated water becomes poorer. The next proposed technology is Ion Exchange could be suitable technology. Ion Exchange technology is relatively simple and cheap to implement. It demands a relatively small initial capital investment. It is a very effective and efficient method of water softening. The wastewater that is produced by ion exchange machines is also used for water treatment. Ion Exchange removes dissolved inorganic effectively. On the other hand, it does not effectively remove particles, pyrogens, or bacteria. One of the last proposed methods is the Biosorption mechanism. For example, activated carbon can be used as an effective adsorbent of arsenic, but this material can be relatively high cost. Nguyen et al study published in 2019 show up that among locally available low-cost materials in Vietnam, natural laterite from Thach That, Hanoi (NLTT) was found to be the most promising material for removing from groundwater. The biggest advantages are its low-cost and availability of material from local sources. This material was able to reduce the arsenic level under the international recommended level. A new filtration system packed with low-cost NLTT was designed and successfully implemented in a childcare center in Hà Nam province, Vietnam to remove groundwater arsenic. The system consists of a combined aeration and clarifier tank, an adsorption column, an ultra filter, and a storage tank. The adsorption column had a sand layer at the bottom followed by NLTT and GAC layers. Monitoring results from different sampling points in the filtration system during the first 6 months of operation confirmed this system produced safe drinking water with arsenic levels below the WHO and Vietnam drinking water limits. The filtration system successfully removed many other contaminants from the water.

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