

The Level of Arsenic Pollution in the Plains' Groundwater in the Streams of the Red River, MA River and Mekong River of Vietnam

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Abstract - Groundwater polluted by arsenic is still an environmental issue of particular concern worldwide. High concentration of arsenic in groundwater have been reported in many countries around the world, such as Chile, Mexico, China, Argentina, part of the USA, as well as in West Bengal (India), Bangladesh and Vietnam. An estimated 150 million people worldwide are affected. Arsenic is known as a famous carcinogen - the "king of poison". In the Red River Delta, Ma River Delta, Mekong River Delta, the risk of arsenic pollution has been warned. People are exposed to and absorb arsenic for long period (5-10 years) through drinking water, which can lead to chronic intoxication to arsenic. Symptoms include skin horns, skin cancers, visceral cancers (bladder, kidney, lung), blood vessels in the legs and feet, diabetes, hypertension and reproductive disorders. The article focuses on the level of groundwater pollution in the Red River Delta, Ma River Delta, Mekong River Delta of Vietnam. The extent of arsenic spread in groundwater, its effect in groundwater and some solutions to treat arsenic in groundwater. The issue was studied from the results of field surveys in the study areas, to summarize, compare and analyze according to objective reality. Data used from 2007 to 6/2018.

Keywords - Pollution; Groundwater; Sediments; Arsenic; Ma River; Red River; Mekong River.

I. INTRODUCTION

1.1. Arsenic and its toxicity to the people

In the nature, arsenic is a component of the earth's crustal deposits, because of the geological activity, arsenic is released into the groundwater and surface water, although only at low concentrations of some $\mu\text{g/l}$. However, in some parts of the world, groundwater has a very high level of arsenic because chemical structure is favorable for the dissolution of arsenic. This phenomenon is found in lowland deltas, which have annual floods, slow flow of water, and low oxygen levels in arid anaerobes favoring the release of arsenic from the soil. Areas with high arsenic level in groundwater as reported are typically large deltas or basins

along major rivers in the world such as the Paraiba do Sul Plain in Brazil, the Bengal Plain, the Mekong Delta - Cambodia, the Danube Basin in Hungary, the Hetao River Basin in Mongolia, the Zenne River Basin in Belgium, Tulare Lake in the USA...

The presence of arsenic in groundwater in many areas, has severely affected the health of millions of people in the world, Southeast Asia and Vietnam in particular. The inorganic compounds of Arsenic are a poison, and long-term exposure to arsenic can cause life-threatening illnesses. Therefore, the World Health Organization (WHO) has set a limit on the concentration of Arsenic in drinking water is $10\mu\text{g/l}$. It is estimated that only in the Red River Delta, in

Vietnam in 2016, there are about 11 million people, especially in rural areas where up to 3 million people may be exposed to Arsenic because of its high level in drinking water.

1.2. Study area

In Vietnam, groundwater is often exploited on both the Holocene and Pleistocene floor. These two floors are separated by meters of clay. Vietnam's groundwater has high availability of arsenic because arsenic-rich soils have been released. Then, over the time of industrial development, the level of pollution increases; more dangerous and alarming when many rural areas use shallow groundwater with high concentrations of arsenic as drinking and living water. According to statistics, there are 17 million Vietnamese people using arsenic-contaminated groundwater, which affects physical and mental health with many acute and chronic illnesses. In particular, children are the most severely affected.

Arsenic pollution in Viet Nam, a survey by UNICEF shows that it is found in all soils, rocks, sediments formed a thousand years ago, with varying concentrations. Arsenic from rocks melts into groundwater. Based on the origin and characteristics, the territory of Vietnam can be classified into three major types of arsenic contamination areas: mountains, deltas, coastal zones. In which, the deltas of the Ma River, Red River, and Mekong River are contaminated with arsenic due to the consolidating streams. Numerous studies have shown that groundwater in the delta region is heavily used for living and production purposes, which are at risk of natural arsenic contamination.

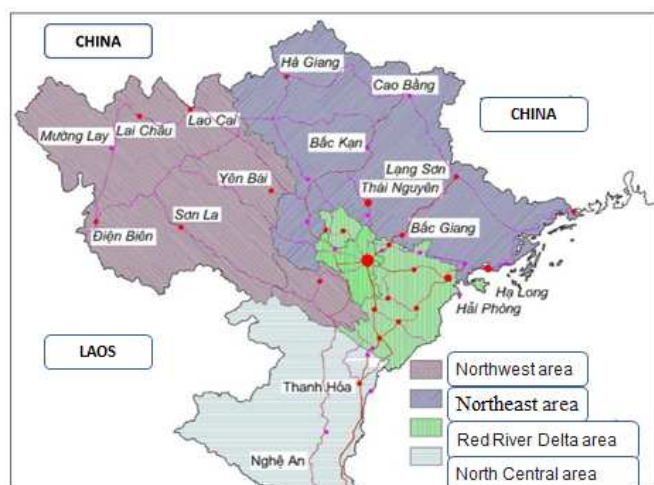


Figure 1: The map of the Red River Delta, Ma River Delta, Mekong River Delta, 2017

Arsenic in the study area is mainly concentrated in riverine areas. The depth of wells varies from 15m to 40m, in residential areas is from 20m to 200m. Contamination sources from coastal marine sediments are composed of fine-grained sandy soils that are less organic gray-green and contain no pyrite. Freshwater aquifers in existing river sand sediments usually do not have isolated clay layers. There is a risk of salinity intrusion including arsenic from the upper floor (for wells > 60m) and around (for wells from 20-40m).

II. IDENTIFYING THE ISSUES

2.1. The level of arsenic pollution in groundwater in the streams of the Ma River Delta

According to the General Statistics Office of Vietnam in 2017, the Ma River basin covers an area of 28,400 km² and the administrative boundaries of 5 provinces: Lai Chau, Son La, Hoa Binh, Thanh Hoa and Nghe An in Vietnam. The average height is 762 m, the average slope is 17.6%, the river basin density is 0.66 km/ km². The average water flow is 52.6 m³/s in one year. The flow of the Ma River lies in the territory of two countries, Laos and Vietnam, which mainly flows between mountainous and midland forests. Alluvium of the Ma River is source for Thanh Hoa to be the third largest plain in Vietnam.

Randomized survey throughout the Ma River Delta. The result shows that the area of the delta affected by arsenic ranges from 4% to 33%. Specifically, percentage of areas exposed to arsenic was 33% in Thanh Hoa, 21% in Hoa Binh, 17% in Nghe An, 3.7% in Lai Chau and Son La. Analysis of sediment samples shows that 82% of samples have less than 10 µg/l, 11% of arsenic samples are in the range of 10 - 50 µg/l, 4% of samples have more than 50 µg/l. Typically, The Phung Mountain Village of Song Ma district, Son La province, the arsenic concentration in water samples exceed 50 µg/l. (University of Natural Sciences, Hanoi National University, 2017).



Figure 2: Arsenic exposed area in groundwater in the Ma River Delta, 2017

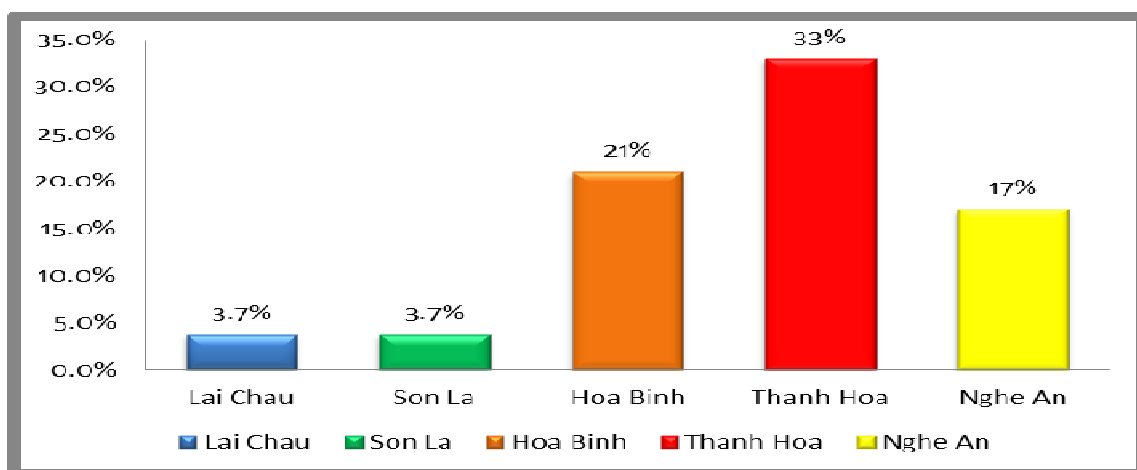


Chart 1: Description of area of arsenic exposure in the delta area of Ma River (% of area covered by arsenic), 2007 to 2017

Table 1: Statistics on arsenic exposure in groundwater in the Ma River Delta, from 2007 to 2017.

No	Provinces	Population in 2017 (people)	Wells	Level of arsenic contamination ($\mu\text{g/l}$)	area of exposure (%)
1	Lai Châu	39.750	400	10 $\mu\text{g/l}$ - 50 $\mu\text{g/l}$	3.7%
2	Son La	1.134.300	400	10 $\mu\text{g/l}$ - 50 $\mu\text{g/l}$	3.7%
3	Hòa Bình	670.000	400	10 $\mu\text{g/l}$ - 50 $\mu\text{g/l}$	21%
4	Thanh Hóa	3.540.000	1322	50 $\mu\text{g/l}$ - 200 $\mu\text{g/l}$	33%

5	Nghệ An	2.952.000	1336	50 µg/l - 150 µg/l	17%
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Through analysis, the polluted samples are mainly concentrated in upstream areas of Ma River, Son La, Phu Tho, Bac Giang, Hung Yen, Hanoi, Ha Nam, Nam Dinh, Thanh Hoa. They all exceed the permitted standards for drinking water of the International and Vietnam.

2.2. The level of arsenic pollution in groundwater in the streams of the Red River Delta

According to the General Statistics Office of Vietnam in 2017, the Red River Delta is a large area of North Vietnam, distributed in 11 provinces and cities such as Vinh Phuc, Hanoi, Bac Ninh, Ha Nam, Hung Yen, Hai Duong, Hai Phong, Thai Binh, Nam Dinh, Ninh Binh, Quang Ninh. Total area: 23,336 km², accounting for 7.1% of the country.

Randomized survey throughout the Red River Delta. The result shows that the area of the delta affected by arsenic ranges from 14.7% to 55%. Specifically, percentage of areas exposed to arsenic was 55.3% in Ha Nam, 38.3% in Hanoi, 16.7% in Hung Yen, 14% in Nam Dinh and Bac Ninh; Analysis of sediment samples shows that the arsenic concentration varies widely, from <0.1 µg/l to > 810 µg/l. Of which, 72.6% of the samples are less than 10µg/l, adapting arsenic standards of the Ministry of Health of Viet Nam, 16.3% of arsenic samples are between 10 and 50 µg/l, 8.4% of arsenic samples are between 50 and 200 µg/l, and 4% of samples contain very high concentration of arsenic, greater than 200 µg/l. (University of Natural Sciences, Hanoi National University, 2017).

Table 2: Statistics on arsenic exposure in groundwater in the Red River Delta, from 2007 to 2017

No	Provinces	Population in 2017 (people)	Wells	Level of arsenic contamination (µg/l)	Area of exposure (%)
1	Vĩnh Phúc	1.020.600	400	11 µg/l - 50 µg/l	14%
2	Hanoi	6.844.100	3.345	50 µg/l - 800 µg/l	38,3%
3	Bắc Ninh	1.079.900	461	11 µg/l - 50 µg/l	14%
4	Hà Nam	811.126	2.775	50 µg/l - 900 µg/l	55,3%
5	Hưng Yên	1.145.600	1.325	50 µg/l - 300 µg/l	16,7%
6	Hải Dương	1.735.100	1.350	11 µg/l - 500 µg/l	16%
7	Hải Phòng	1.904.100	400	50 µg/l - 100 µg/l	17%
8	Thái Bình	1.868.800	1.335	50 µg/l - 200 µg/l	35%
9	Nam Định	1.836.900	1.550	50 µg/l- 300 µg/l	14%
10	Ninh Bình	915.900	400	50 µg/l - 200 µg/l	16%
11	Quảng Ninh	1.177.200	400	50 µg/l- 100 µg/l	19%

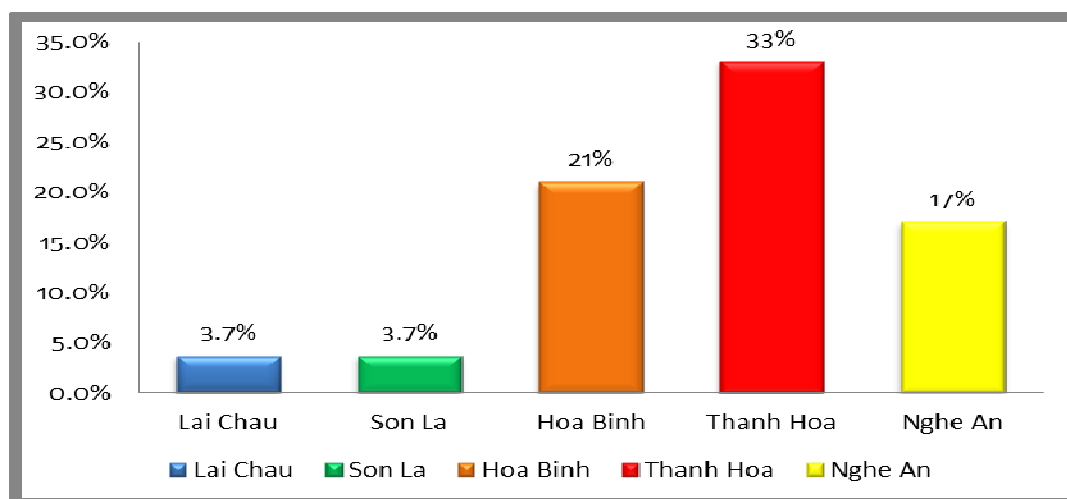


Chart2: Description of area of arsenic exposure in the delta area of Ma River (% of area covered by arsenic), 2007 to 2017.

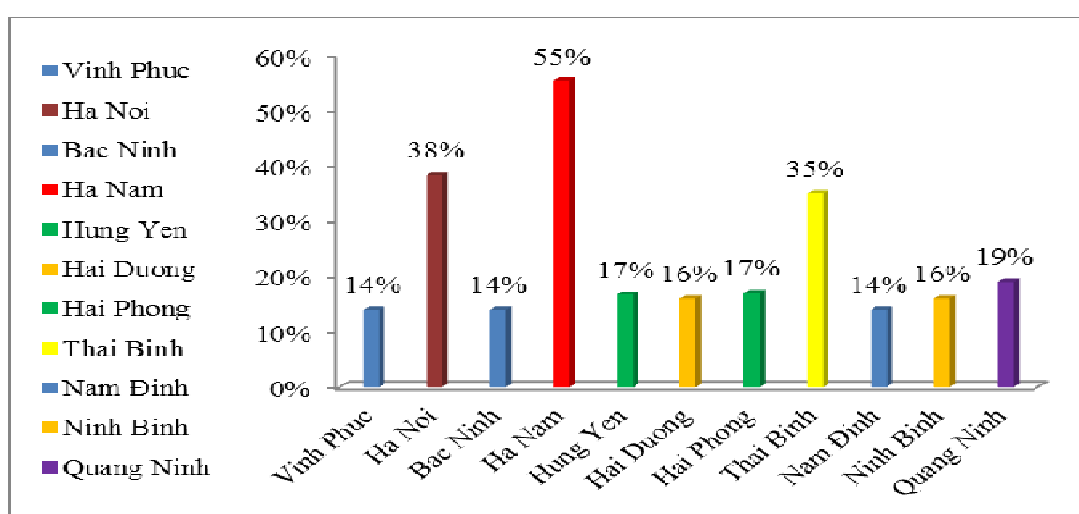


Chart 3: Describe the% area of arsenic exposure in the delta area of Ma River (% of area covered by arsenic), 2007 to 2017

However, the pollution is mainly concentrated in the left bank of the Red River, flowing through some densely populated provinces such as Ha Nam, Hanoi, Nam Dinh, Hung Yen and Thai Binh. Many wells in this area have high arsenic concentration of 200-300 $\mu\text{g/l}$ (20 to 30 times higher than drinking water standards). In the Duong River basin (tributary of the Red River), there appears to be less pollution. It is the territory of Bac Ninh and Hai Duong. The mountainous areas of midland and coastal areas are less likely to be contaminated with arsenic in well water. In comparison with the whole samples, arsenic level exceeds groundwater standards of 45% in Ha Nam, 17% in Hung Yen, 10% in Nam Dinh and Bac Ninh. The remaining provinces have less than 10%. However, the pollution rates

in each area will change as the sample increases. Many water samples in contiguous areas have very high arsenic concentration ($> 200 \mu\text{g/L}$). For example, in Dan Phuong, Hoai Duc, Thanh Oai, Thuong Tin, Phu Xuyen (Ha Tay), Duy Tien, Ly Nhan (Ha Nam). There are communes with a rate of arsenic pollution of nearly 100%. (University of Natural Sciences, Hanoi National University, 2017)..

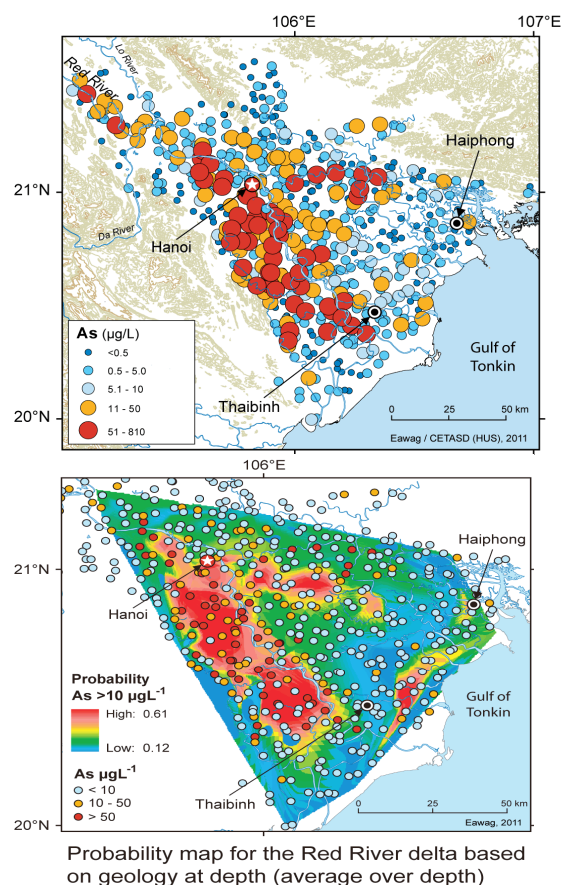


Figure 3: Arsenic exposed area in groundwater in the Red River Delta, 2017

2.3. The level of arsenic pollution in groundwater in the streams of the Mekong River Delta

According to the General Statistics Office of Vietnam in 2017, the Mekong River Delta is the southernmost region of Vietnam, also known as the Southern Delta or the South West with Can Tho City and 12 provinces: Long An, Tien Giang, Ben Tre, Vinh Long, Tra Vinh, Hau Giang, Soc Trang, Dong Thap, An Giang, Kien Giang, Bac Lieu and Ca Mau.. The total area of the provinces and cities in the Mekong Delta is 40,548.2 km² and the total population of the provinces in the region is 17,330,900 people. The Mekong Delta accounts for 13% area of the country but over 19% of the country's population.

Randomized survey throughout the Mekong River Delta. The result shows that the area of the delta affected by arsenic

with above 10 µg/l ranges from 11.7% to 67%. Specifically, the arsenic exposure area is 67% in An Giang, 51% in Dong Thap, 46% in Kien Giang; 33% in Long An, 11% in Vinh Long and Tra Vinh. Analysis shows that contaminated samples are focused in riverside areas, the depth of wells varies from 15m to 40m, indicating that

arsenic concentration varies with flow and influenced by salt water; the level is less than 0.1 µg / l to more than 810 µg/l. Of which, 77.6% of the samples are less than 10µg/l, 8% of arsenic samples range from 10 to 50 µg/l, 14.4% of samples contain arsenic greater than 50 µg/l, and 4% of the samples have very high arsenic concentration, greater than 200 µg/l. (Report from UNICEF, 2007 to 2016).

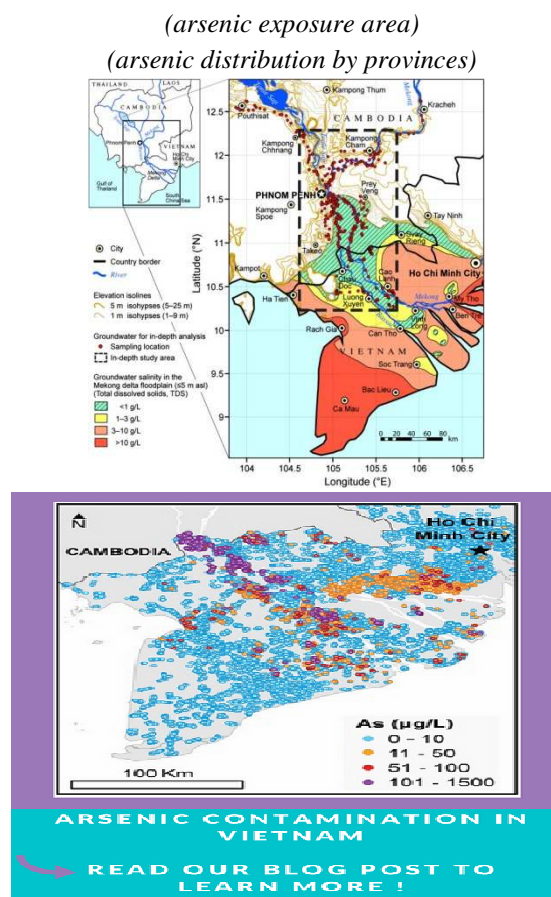


Figure 4: Arsenic exposed area in groundwater in the Mekong River Delta, 2017

Table 3: Statistics on arsenic exposure in groundwater in the Mekong River Delta, from 2007 to 2017

No	Provinces	Population in 2017 (people)	Wells	Level of arsenic contamination (µg/l)	Area of exposure (%)
1	Cần Thơ	1.214.100	6.257	11 µg/l - 100 µg/l	11%
2	Long An	1.458.200	6.657	11 µg/l - 50 µg/l	33%
3	Tiền Giang	1.692.500	5.763	11 µg/l - 50 µg/l	11%
4	Bến Tre	1.258.500	6.256	11 µg/l - 50 µg/l	15%
5	Vĩnh Long	1.033.600	6.766	100 µg/l - 1500 µg/l	11%
6	Trà Vinh	1.015.300	6.755	50 µg/l - 800 µg/l	11%
7	Hậu Giang	769.700	6.331	50 µg/l - 100 µg/l	13%
8	Sóc Trăng	1.301.900	5.321	50 µg/l - 100 µg/l	44%
9	Đồng Tháp	1.676.300	6.917	11 µg/l - 1000 µg/l	51%
10	An Giang	2.153.701	8.992	11 µg/l - 1500 µg/l	67%
11	Kiên Giang	1.726.200	6.714	50 µg/l - 100 µg/l	46%
12	Bạc Liêu	873.400	5.332	11 µg/l - 30 µg/l	46%
13	Cà Mau	1.217.100	5.811	11 µg/l - 30 µg/l	44%

However, arsenic-contaminated areas are predominantly in Cambodia border such as An Giang and Dong Thap. Many wells in this area have arsenic concentration of 10 µg/l to 50 µg/l (Reported by Nguyen Khac Hai, 2006). In the Mekong Delta, the provinces that have Arsenic concentration above 10 are mainly along the Tien River, Hau River and Dong Thap Muoi (Gordon Stanger et al, 2005).

The analysis of sediment samples at the depth of 42m, shows that the arsenic, SO₄²⁻ is quite high in the soil layer composed of clay, usually at a depth of 5 to 36m. No pyrite is detected in all sediment samples. Freshwater aquifers in river sand sediments usually do not have isolated clay layer. There is a risk of saline intrusion from the upper floor (for wells > 60m) and around (for wells from 20 - 40m).

Particularly in An Giang, up to 40% of arsenic-contaminated wells are under 50ppb, 16% of the infected are over 50ppb. Arsenic contamination are mainly in four districts: An Phu, Tan Chau, Phu Tan and Cho Moi. In a total of 4,876 groundwater samples, 56% of which were polluted with arsenic.

In Dong Thap, more than 67% of the 2,960 groundwater samples have been detected arsenic contamination. In particular, Thanh Binh district has a high rate of arsenic, 85% samples are more than 50ppb. Over 51% of the samples in more than 3,000 are found to have been contaminated

with arsenic in Kien Giang.

In Ho Chi Minh City, Phu Nhuan district has a density of 900 wells/km². Illegal drilling and groundwater extraction will increase the possibility of deterioration to underground water quality. Arsenic pollution in groundwater, bottled water, rural water supply in Ho Chi Minh City is negligible. It can be considered as not contaminated.

III. DISCUSSING THE ISSUE

3.1. Level of pollution by the depth of the groundwater aquifer

During the study, arsenic exposure, according to the depth of wells, ranges from 5m to 135m. Sample analysis shows that most wells with a depth of more than 80m are not contaminated with arsenic, accounting for 9% of the survey. Deeper wells are often found in coastal communes of Quang Ninh, Hai Phong, Nam Dinh and Thai Binh. In these communes, the shallow aquifer is often saline, so fresh groundwater is usually exploited at a depth of 100m. Remaining wells with a depth of 15-60m are often contaminated with concentration of > 50µg/l. However, at the same depth, the level of pollution varies in different regions.

Studies at the aquifers of the Ma River Delta show that these aquifers have anaerobic conditions, characterized by the decomposition of organic carbon along with the

decomposition of Fe oxide and the formation of methane. Arsenic concentration in this area increase by depth and reach the highest value of 550 µg/l. The release of arsenic in the whole study area is homogeneous, with no dispersion phenomena as in Bangladesh. In groundwater, there are the presence of both Arsenic (III) and Arsenic (v), but mainly Arsenic (III), and it has a good correlation with NH₄⁺. In addition, the studies also suggest that Arsenic presence in the aquifer is because of the dissolution of Fe hydroxides under the influence of organic matter decomposition.

3.2. Level of pollution by flow distance

When studying on flow, drilling soil along the river basin, twopoints apart marked as points L and H points (700m apart), the Arsenic concentrations in groundwater are very different (point L <10 µg/l and H 170-600 µg/l). In this area, the aquifer has a depth of 20 to 50m in the Holocene. The results show that there are no significant differences in mineralogical and geochemical sedimentation except for the redox state of Fe ox hydroxide. At the H point (high Arsenic concentration), most of Arsenic in sediment is adsorbed on black sand - indicating the presence of Fe (II) and Fe (III) mixtures. At the point L (low Arsenic concentration),

arsenicis found to be associated with yellow Fe (III) sediments - indicating oxidation conditions in the aquifer. Fe concentration at H (14 mg/l) compared with L (1-2 mg /l) and high concentrations of NH₄⁺ (10 mg / l), HCO₃⁻ (500 mg / l) and DOC (3 mg / l) at point H, it is in line with the dissolution mechanism of Fe minerals and the arsenic release.

3.3. Impact on the health of the people living in the river basin

According to the United Nations Children's Fund (UNICEF), Vietnam has about 20.48% of the population, meaning about 17 million people are using well water, of which only the Red River Delta alone has about 11 million people can come into contact with groundwater with high arsenic concentration. Especially in rural areas, it is estimated that up to 3 million people are exposed to arsenic because of using contaminated groundwater as drinking water.

Risk of arsenic exposure

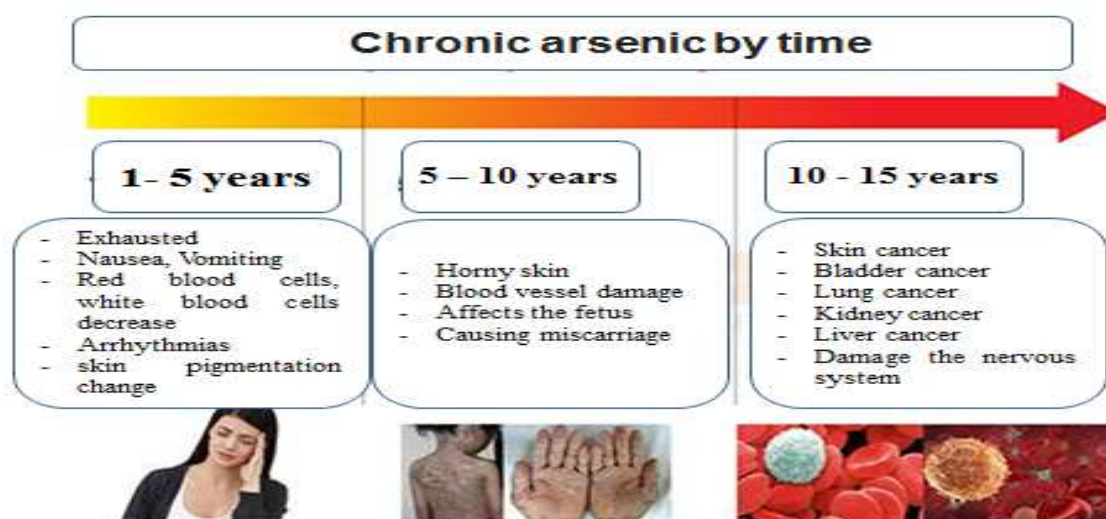


Figure 5: Harmful effects when being exposed to arsenic, 2018

IV. SOLUTIONS TO OVERCOME HARMFUL EFFECTS

4.1. State management in mineral exploitation of river basins

One of the reasons for the increase of arsenic concentration in water is due to illegal mining activities in upstream areas of the river basin; industrial construction along the river basins causes perforations of groundwater aquifers. According to statistics of the general plan for

development of industrial zones in Vietnam up to 2015 with a vision to 2020, the Red River Delta currently has 76 industrial zones and the South West with 51 industrial zones. However, the Vietnamese Government needs to re-construct the North Delta, South East and Southwest to adapt to climate change. Planning for industrial development in the northern and southern delta up to 2025 with a vision towards 2035 in a sustainable way.

4.2. Arsenic treatment technology

(Hanoi University of Science and Technology, 2017).

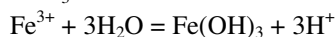
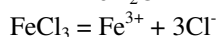
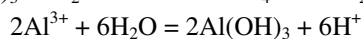
According to Vietnam's environmental and chemical scientists, it is possible to propose some solutions in the current situation, which are able to meet domestic water demand, when water plants do not have arsenic treatment.

Table 4: Technologies that are capable of treating arsenic for the river basins in Vietnam, 6/2018

Type of technology	The percentage of arsenic in ground water removed
Ion exchange	95
Precipitation of Alumium	95
Reverse Osmosis Filtration	>95
Oxidation and sand filtration	80
Coagulation and sand filtration	95

Coagulation– Precipitation of Aluminum: This is the method of treating arsenic based on precipitation. By pumping water then liberated to oxidize iron, manganese, producing iron hydroxide and precipitated manganese. Arsenic (III) is simultaneously oxidized to Arsenic (V), capable of absorbing to the surface Ironhydroxyt or manganese, then settling to the bottom of the tank. (Hanoi University of Science and Technology, 2017).

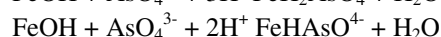
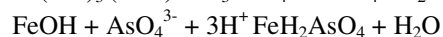
In arsenic treatment by dissolving the aluminum ($\text{Al}_2(\text{SO}_4)_3 \cdot 18\text{H}_2\text{O}$), Iron (FeCl_3 , $\text{Fe}_2(\text{SO}_4)_3 \cdot 7\text{H}_2\text{O}$) into water. Al^{3+} , Fe^{3+} ion are hydrolyzed immediately after the salts are dissolved at the appropriate pH to produce hydroxide.



These coagulations will pull particles as well as

absorbing ions, organic matter in water. Arsenic is also absorbed on these coagulations.

$\text{H}_2\text{AsO}_4^- + \text{Al}(\text{OH})_3$ Al-As (complex) + other products



(FeOH: stands for surface)

Under pH <8, Arsenic (III) exists in the non-partitioned form, Arsenic (V) exists in the anionic form, so the Arsenic (III) poorly coagulates. As a consequence, oxidation of Arsenic (III) to Arsenic (V) is necessary before the coagulation process. Studies on the ability of treating arsenic with the salts of Fe^{3+} + show that at the appropriate pH concentration, arsenic treatment may reach 99%. (Department of Environmental Health, Institute of Hygiene and Public Health, Ho Chi Minh City)

Table 5. The number of input water does not detect arsenic with detection limit 0.2($\mu\text{g/l}$)

Input water does not detect arsenic with detection limit 0.2($\mu\text{g/l}$)						
Arsenic content after filtration						
Column filter Times	1	2	3	4	5	6
1	26,8	13,5	0,84	0,98	0,75	11,8
2	21,9	9,6	not detected	not detected	not detected	15,5
3	12,3	7,45	not detected	not detected	not detected	12,8
4	5,03	8,00	not detected	-	-	13,8
5	2,04	6,21	not detected	-	-	11,25
6	2,06	4,35	-	-	-	6,60
7	2,08	-	-	-	-	4,58
8	1,89	-	-	-	-	2,73
9	1,26	-	-	-	-	2,31
10	1,23	-	-	-	-	-

Absorbing by activated alumina: Activated alumina is used effectively to treat water with high dissolved solids. This method is relatively convenient, especially for poor rural areas. Pouring the water through the filter material. The process period of the equipment depends on the quality and the concentration of the source water. The higher the iron concentration in the source water is, the higher efficiency of the arsenic removal is. (Hanoi University of Science and Technology, 2017)

Arsenic can also be absorbed by iron hydroxide; Treating arsenic in water with iron oxide coating on granular materials; Arsenic treatment with rusted metal; arsenic treatment by FePO_4 ; Treating arsenic with materials from Manganese; Using ferns to remove arsenic in water; treating arsenic with sand filtration system...

V. CONCLUSION AND RECOMMENDATION

5.1 Conclusion

So far, many studies on arsenic pollution in the aquifers of the world and Vietnam have been published. However, the cause of aquifers contaminated by arsenic is still a matter of controversy among scientists.

Arsenic in the study area is derived from coastal marine sediments released into saltwater aquifers with very high concentrations of SO_4^{2-} and Cl^- . High arsenic concentrations are mainly in riverine areas with wells from 15m to 40m. High arsenic concentration in cultivated land appears in areas where arsenic-contaminated groundwater is used for irrigation.

5.2 Recommendation

Limiting drilling wells in Holocene aquifers in depths of 20-60m in areas along Hau River and Tien River in An Giang province. The well drilling technique should be tested (well-sreen filled), in case of exploitation of water depth of more than 60m in order to avoid contamination of the lower layer. Arsenic-contaminated wells should be properly filled to limit arsenic contamination to the lower aquifer. Conducting study on the risk of arsenic contamination and salinity (SO_4^{2-} and Cl^-) in farmland and where arsenic-contaminated groundwater is used for irrigation. In the coming time, arsenic-contaminated water should not be used for irrigating vegetables and aquaculture. In arsenic-contaminated groundwater wells ($> 200\text{ppb}$), other sources of water need to be found for irrigation and livelihoods.

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