

Technical Report

# Household Sand Filters for Arsenic Removal

An option to mitigate arsenic from iron-rich groundwater



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**Cover photo:** Household sand filter operated by a family in the Red River Delta

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## EXECUTIVE SUMMARY

Arsenic-rich groundwater is currently being used as drinking water by millions of households in different parts of the world. The problem of arsenic intoxication by contaminated drinking water emerged in the past two decades, when surface water and groundwater from open dug wells, formerly used to cover the drinking water supply in rural areas of many tropical regions, were abandoned for groundwater pumped through small-scale tubewells. As documented, chronic arsenic exposure can lead to severe health problems, such as skin lesions, hyperkeratosis, melanosis, skin cancer and cancer of internal organs.

Arsenic pollution of groundwater has recently been recognized in the Red River Delta of Vietnam through a groundwater study funded by the Swiss Agency for Development and Cooperation (SDC) in the framework of the Swiss-Vietnamese cooperation project ESTNV (Environmental Science and Technology in Northern Vietnam). The groundwater of numerous households in this region is not only contaminated by arsenic, but it also contains high iron concentrations as a result of highly anoxic conditions in the aquifers. Arsenic removal is necessary in urban and communal waterworks, as well as in areas pumping groundwater through family-based tubewells. EAWAG and CETASD with support from SDC have therefore investigated the arsenic removal efficiency from groundwater by household sand filters in rural areas of the Red River Delta.

The tested sand filters comprise two superimposed concrete containers: the upper container is filled with locally available sand and the lower one serves to store the filtered water. Groundwater, which is pumped from the tubewell into the upper container, trickles through the sand into the underlying water storage tank. Arsenic removal is governed by the precipitation of iron(hydr)oxides which form a coating on the sand surfaces. Arsenic then adsorbs to the iron(hydr)oxides and remains immobilised under oxic condition.

The arsenic removal efficiency of sand filters was examined in 43 households whose pumped groundwater contains arsenic concentrations exceeding the WHO drinking water guideline of 10 µg/L. A mean arsenic removal efficiency of 80% was achieved in groundwaters containing 10–420 µg/L arsenic, 0–47 mg/L iron and 0–3.7 mg/L phosphorus. High iron concentrations clearly enhance arsenic removal, whereas increased phosphate levels (>2 mg P/L) partly lower the removal efficiency.

Sand filters use locally available materials, are operated without chemicals, can treat a reasonable amount of groundwater within a short time, and can be easily replicated by the affected communities. The observable removal of iron from the pumped water immediately makes the use of a sand filter intelligible even to people who have never heard of the arsenic problem. Thus, household sand filters are a viable option for arsenic mitigation of iron-containing groundwater in Vietnam and other arsenic affected regions.

This report proposes the implementation of early arsenic mitigation measures to prevent long-term health effects. It also contains leaflets for widespread information on construction, use and maintenance of household sand filters, especially for government authorities, decision-makers, stakeholders, NGOs, ODAs, water specialists, and scientists confronted with arsenic mitigation needs.

### Keywords

Arsenic Removal, Efficiency, Mechanism, Sand filter, Passive precipitation, Groundwater, Drinking water, Origin of arsenic, Health risks, Chronic arsenic poisoning, Implications, Mitigation measures, Information dissemination, Red River Delta, Vietnam.



# 1. INTRODUCTION

The welfare and development of a society are strongly dependent on a safe drinking water supply. Long-term ingestion of arsenic-rich groundwater is not only a threat to human health in the Red River Delta (Vietnam), but also in many other regions in the world. Consumption of arsenic-rich water for more than 7-10 years can lead to chronic health problems, such as fatigue, hyperpigmentation, keratosis, skin cancer, cardiovascular and nervous affections, and, cancer of the skin and internal organs<sup>1</sup>.

## 1.1. Natural Origin of Arsenic

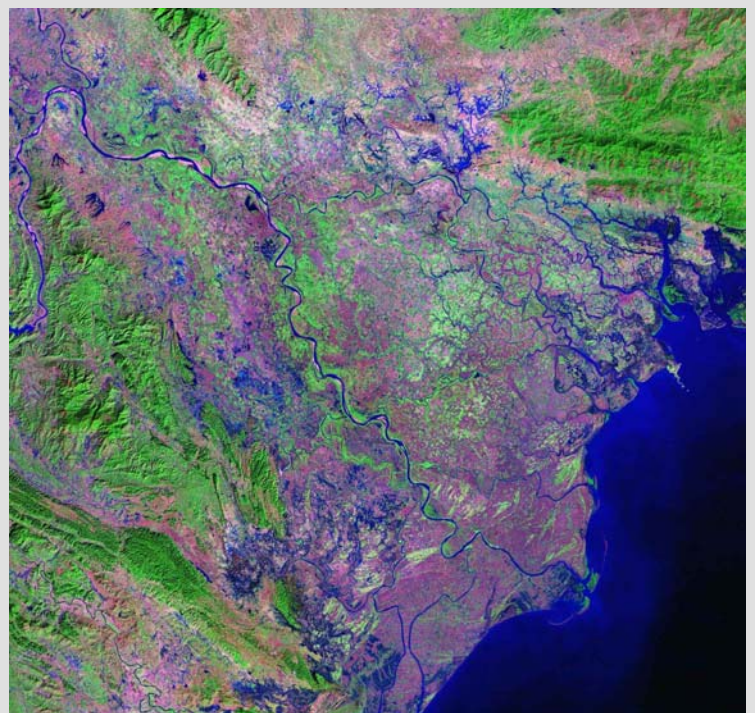
Groundwater pollution by arsenic is often a natural phenomenon attributed to subsurface sediments containing small amounts of arsenic. The arsenic remains fixed in the sediments as long as the groundwater contains sufficient dissolved oxygen. However, arsenic is released from the sediments if these come into contact with oxygen-depleted groundwater. Oxygen depletion in groundwater is often caused by decomposition of organic material (e.g. peat), which is highly abundant in soils of tropical river deltas. This natural process leads to arsenic contamination of groundwater in, for example, the Red River Delta (Vietnam)<sup>2,3</sup> and Bengal Delta (Bangladesh and West Bengal)<sup>4</sup>.

## 1.2. Arsenic Contamination in the Red River Delta

The Red River Delta is one of several tropical regions in the world where high arsenic concentrations in groundwater threaten human health<sup>2,5</sup>. Similar to the high levels found in Bangladesh<sup>3</sup>, the measurements from the Red River Delta revealed arsenic concentrations of 1 to >1000 µg per litre of groundwater<sup>2</sup>. UNICEF estimates that 17% of Vietnam's population is currently using groundwater from private tubewells as drinking water supply<sup>6</sup>.

Until to date, only very few cases of arsenic-related health problems have been diagnosed in Vietnam<sup>7</sup>. Most private tubewells in Vietnam have been used for less than 10 years, while experience shows that it can take 10 or more years before the first arsenic poisoning symptoms become apparent. Yet, the

**Figure 1.** Satellite photograph of the Red River Delta



<sup>1</sup> Hall 2002

<sup>2</sup> Berg et al. 2001

<sup>3</sup> Tran et al. 2003

<sup>4</sup> BGS and DPHE 2001

<sup>5</sup> Berg et al., forthcoming

<sup>6</sup> UNICEF Vietnam 2002

<sup>7</sup> Hanoi University of Science and Geological Society of Vietnam 2000

expected number of arsenic-related health problems occurring in the future should not be underestimated. Comprehensive studies on the distribution of arsenic occurrence and potential health effects are currently conducted in Vietnam.

### 1.3. Sources of Drinking Water in Rural Areas of the Red River Delta

#### A. Groundwater

**Dug well.** Vertical pit of 1-5 m depth for groundwater accumulation, and the traditional system for groundwater collection. Water from dug wells is generally low in arsenic (<20 µg/L) as it is constantly aerated through its contact with air. The water may be contaminated by microbial or chemical pollutants (e.g. bacteria, pesticides).

**Settling tank.** Water containers used for iron precipitation from anoxic groundwater (e.g. groundwater from tubewells). Two adjacent tanks are used for consecutive particle precipitation and settling. Groundwater is pumped into the first tank and a day later scooped into the second tank for a second settling period.

**Sand filter.** Most efficient treatment process for groundwater exhibiting high iron concentrations. In the peri-urban villages around Hanoi, this process is already widespread among households affected by iron-rich groundwater (details are given below). Sand filters should frequently run dry in order to prevent growing of harmful bacteria in standing water. The treated water can be stored and used for several days.

**Tap water.** Water supply purified in public water treatment plants. Groundwater is usually submitted to iron removal and disinfection, but not yet to arsenic removal. Although the iron removal process can also lower arsenic levels, arsenic concentrations may still remain above 50 µg/L<sup>8</sup>. Additional public water treatment plants equipped with simple iron removal are currently constructed in suburban areas to supply tap water to an increasing number of people.

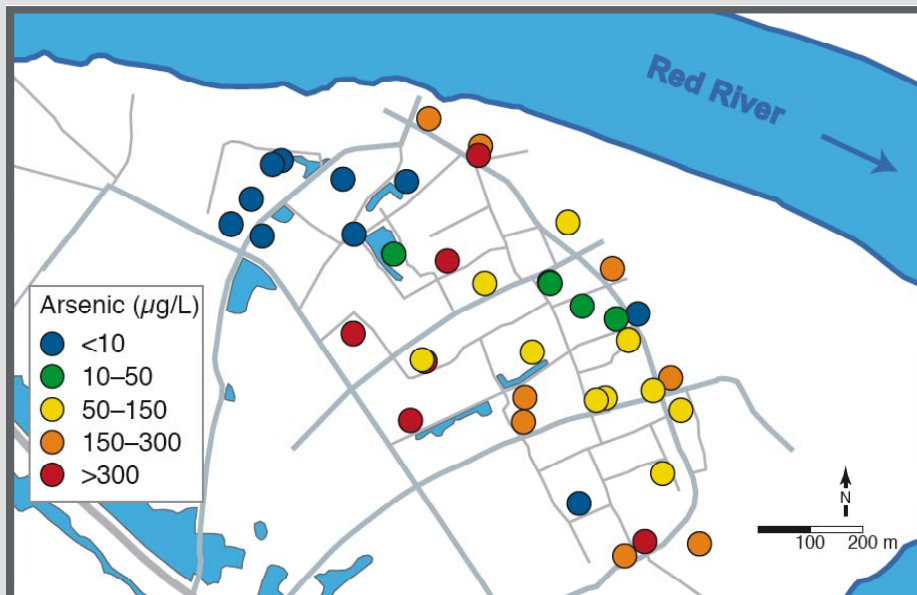
#### B. Other sources of drinking water

**Surface water.** Although the use of surface water for human consumption is of minor importance in the investigated villages around Hanoi, it may be an important source of drinking water in more remote areas.

**Rainwater.** Rainwater runoff collected from the house roofs and stored in large tanks (1-5 m<sup>3</sup>). This water, free of iron and arsenic, is collected to cover the drinking water requirements of a family during the dry season. Construction of the rainwater tanks is quite expensive and the water must be protected from light and dust. Rainwater is increasingly used by households in areas with iron-rich groundwater. If properly protected from light and dust, rainwater can be stored and used for several month.

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<sup>8</sup> Berg et al. 2001



**Figure 2.** Spatial variability of arsenic concentrations in a small village located in the Red River Delta. This example shows that low and high As levels of  $<10 \mu\text{g/L}$  and  $>300 \mu\text{g/L}$ , respectively, can be just a few meters apart

#### 1.4. Spatial Arsenic Variations

The investigated areas reveal an extremely heterogeneous distribution of arsenic levels (see Figure 2). The water of neighbouring households within the same village may exhibit arsenic levels of both, below as well as significantly above the drinking water threshold<sup>9</sup>. This unpredictable variability requires not only simple and efficient arsenic removal technologies on a household level, but also an effective monitoring program to decide on the design and application of mitigation measures.

#### 1.5. Arsenic Mitigation Approach for Private Households

Arsenic mitigation approaches on a household level face several difficulties. An appropriate system for arsenic removal should be efficient, cheap, socially accepted, user-friendly, locally available and operated without the use of chemicals. None of the arsenic removal techniques described in the international literature meet all these criteria. Arsenic removal technologies are often limited to small study areas and therefore do not contribute to regional progress in arsenic mitigation<sup>10</sup>.

Elevated concentrations of arsenic in groundwater are often accompanied by high levels of dissolved iron. Iron concentrations ( $>5 \text{ mg/L}$ ) convey a bad taste to the groundwater, which in Vietnam is sometimes described as "fishy". Some households in rural areas of the Red River Delta have thus started to use simple sand filters or settling tanks to remove the iron from the groundwater. Household sand filters are quite simple to operate and, most important, besides iron mitigation also remove arsenic from the water to a remarkable extent.

<sup>9</sup> Berg et al., forthcoming

<sup>10</sup> USEPA 2000



## 1.6. Objectives of this Report

Since arsenic contamination of groundwater was recognised in Vietnam in 1998<sup>11,12</sup>, the Vietnamese government and NGOs working in the field of water and sanitation have set out to find solutions to the arsenic problem. This report provides an overview of the efficiency of household sand filters with regard to arsenic removal. It proposes the implementation of early arsenic mitigation measures to prevent long-term health effects. Furthermore, it contains information leaflets for widespread education in construction, use and maintenance of household sand filters in Vietnam and elsewhere. The results and recommendations of this report shall assist government authorities, decision makers, stakeholders, NGOs, ODAs, water specialists, and scientists in the implementation of arsenic mitigation measures.

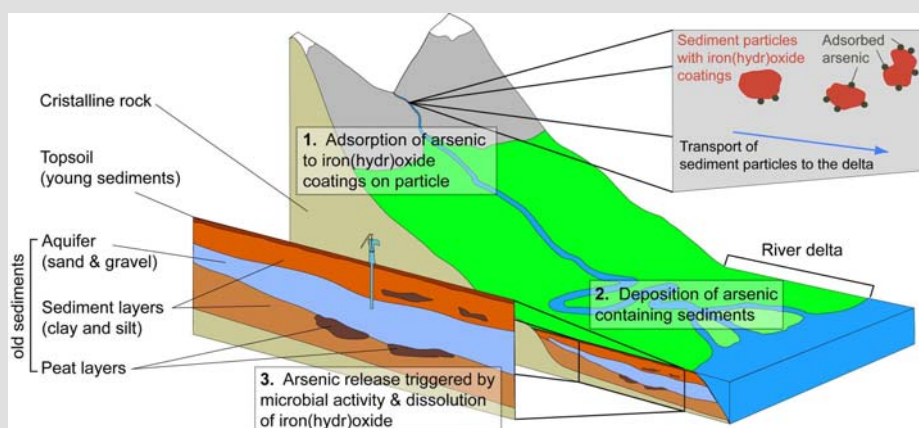
## 2. ORIGIN AND HEALTH EFFECTS OF ARSENIC

### 2.1. Origin of Arsenic

The most commonly accepted theory on the presence of arsenic in groundwaters postulates anoxic dissolution of iron(hydr)oxides and release of previously adsorbed arsenic<sup>13,14</sup>. The arsenic in the sediments and groundwater of the Red River Delta originates from the mountains in the catchment of the Red River, and has been deposited during thousands of years<sup>15</sup>. Mountain erosion leads to a release of rock-forming minerals and arsenic into the hydrosphere. Eroded iron turns to rust, iron(hydr)oxide, and forms particles as well as coatings on the surface of silt and sand. Iron(hydr)oxides are capable of scavenging dissolved arsenic from water and binding it to its surface. Suspended particles with iron(hydr)oxide coatings and adsorbed arsenic are washed into rivers and transported downstream. River water with high loads of particles generally exhibits a characteristic red to yellowish brown colour caused by the iron, a phenomena that gave the Red River its name. Arsenic is thus brought to the river deltas bound to sediment particles and deposited in the soil with the settling particles.

In the flat lowlands of the river delta, suspended particles are deposited during floods. This was the case particularly in ancient times when the flow of the river water was not yet controlled by dykes. For thousands of years, deposits of river sediments have created the soil layers (sediments) that form the entire delta as it is known today. These sediments reach more than a hundred meters

**Figure 3.** Illustration of the widely accepted theory on the origin of arsenic in groundwater of tropical and subtropical river deltas



<sup>11</sup> Berg et al. 2001

<sup>12</sup> Giger et al. 2003

<sup>13</sup> Nickson et al. 2000

<sup>14</sup> Smedley and Kinniburgh 2002

<sup>15</sup> Tong 2002

below the today's topsoil layer. Arsenic adsorbed on the surface of sediment particles is thus buried in the structure of the delta underground. The Red River Delta was formed by sediment layers deposited in the last ~10,000 years.

## **2.2. Dissolution of Arsenic in Anoxic Groundwater**

Arsenic release from particle surfaces is strongly dependent on the level of dissolved oxygen in groundwater. The warm and wet climate in tropical regions of the delta contributes to a fast-growing vegetation. During flooding of the delta, the high sediment load of rivers leads to a rather rapid covering of the topsoil layers, including its vegetation. This process, resulting in the entrapment and subsequent burial of high amounts of organic material (rotting plants, peat), leads to anoxic groundwater conditions (oxygen depletion) in deeper sediment layers.

Some sediment layers in the delta architecture are termed aquifers since they contain a considerable amount of sand and gravel which can be invaded by groundwater. The groundwater in aquifers close to the topsoil is often oxic (dissolved oxygen is abundant). However, organic material such as peat can serve as substrate ("food") for microorganisms to thrive on. These microorganisms consume dissolved oxygen to degrade organic material, thereby leading to an oxygen depletion in the groundwater (anoxic conditions). Under anoxic conditions, some microorganisms can use iron(hydr)oxides as a source of energy instead of oxygen. Degradation of solid iron(hydr)oxide particles releases arsenic formerly attached firmly to the particle surface. Arsenic deposition with sediments in the delta and dissolution under anoxic conditions created by high levels of organic material can lead to the high concentrations of dissolved arsenic in groundwater. The irregular distribution of organic material in the underground can partly explain the highly heterogeneous arsenic distribution observed in many affected areas.

## **2.3. Effect of Extensive Groundwater Abstraction**

A recent study conducted in Bangladesh describes the influence of human activity on elevated arsenic levels in groundwater<sup>16</sup>. This study is based on the theory of arsenic release from iron(hydr)oxides as described above, and attributes the arsenic problem partly to enhanced groundwater pumping for irrigation purposes. Extensive groundwater pumping rapidly lowers the groundwater table and draws down water containing organic material, which may stimulate microbial activity, thereby accelerating oxygen depletion and arsenic release. Due to the high groundwater demand in the Red River Delta, the groundwater table of its aquifers have been lowered by 20–30 meters<sup>17</sup>. This situation could enhance future dissolution and mobility of arsenic.

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<sup>16</sup> Harvey et al. 2002

<sup>17</sup> Berg et al. 2001



Hyperpigmentation



Melanoma



Keratosis  
"Black foot disease"

**Figure 4:** Photos of patients from Bangladesh affected by various stages of arsenicosis

#### 2.4. Health Problems Caused by Chronic Arsenic Poisoning (Arsenicosis)

Arsenic concentrations of 50 µg per litre of water can cause chronic health problems if such water is consumed over a period of 5-10 years<sup>18</sup>. Development of the disease is strongly dependent on exposure time and arsenic accumulation in the body, but age, nutritional habits and lifestyle of the exposed person may also have an influence on the occurrence of health problems.

Skin ailments are generally the first symptoms which develop after a few years of continued arsenic ingestion, i.e., hypopigmentation (white spots on skin), hyperpigmentation (dark spots on skin) and keratosis (break up of the skin on hands and feet). More serious health affections such as skin cancer or cardiovascular and nervous affections are known to appear with a latency of 10 or more years. After 15-30 years of exposure, victims often suffer from lung, kidney or bladder cancer<sup>19</sup>.

**Table 1:** Thresholds for arsenic in drinking water

WHO guideline	10 µg/L
EU	10 µg/L
USA	50 µg/L
USA (in 2006)	10 µg/L
Bangladesh	50 µg/L
Vietnam (since 2002)	10 µg/L

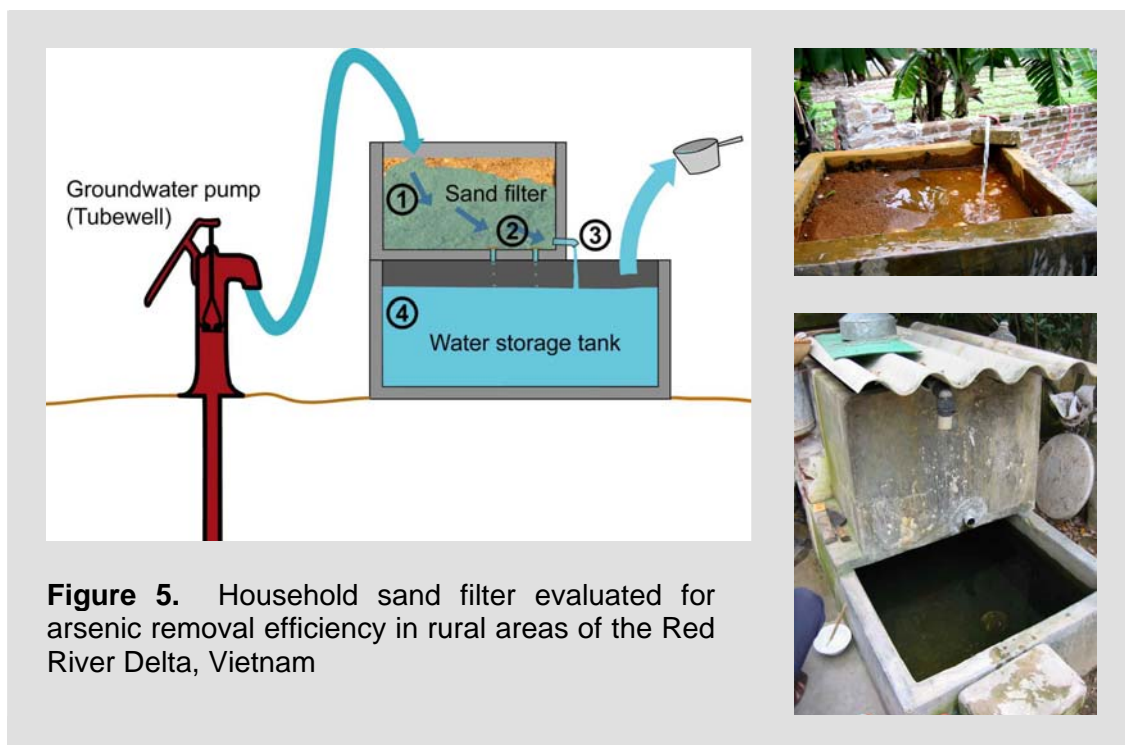
<sup>18</sup> Smith et al. 2000

<sup>19</sup> Mazumder 2003

### 3. CONSTRUCTION, OPERATION AND MAINTENANCE OF HOUSEHOLD SAND FILTERS

#### 3.1. Design and Construction

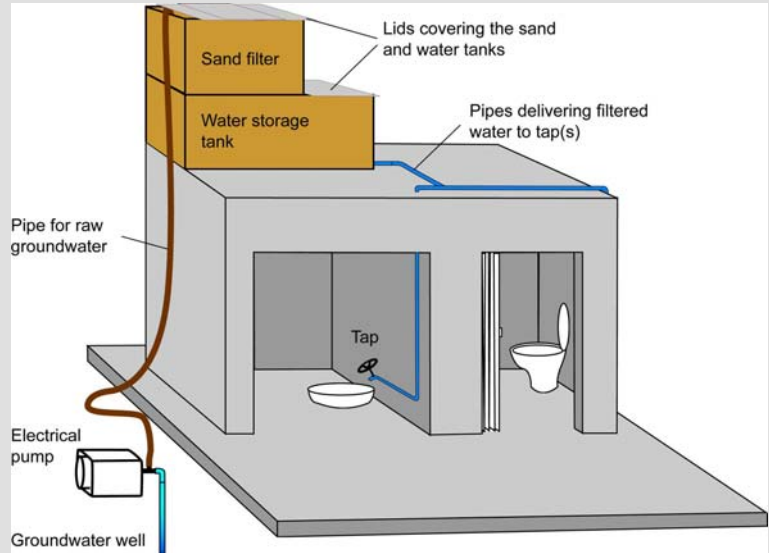
Bricks and concrete are necessary for construction of the two superimposed tanks. The upper tank (①) serves as filter and the underlying container (④) is used to store treated water. The upper tank must have one or a few outlets either at the bottom (②) or in the front wall (③). A simple sieve (e.g. piece of cloth) can be used to prevent the sand from flushing out of the filter.



**Figure 5.** Household sand filter evaluated for arsenic removal efficiency in rural areas of the Red River Delta, Vietnam

The upper tank is filled with locally available sand. The groundwater is pumped from the tubewell (hand pump or electrical pump) into the filter and trickles through the sand layer into the water storage tank. Installation of a tap directly at the outlet of the upper tank (④) is not recommended. The sand filter compartment needs to run dry between two subsequent filtration periods to prevent microbial activity and maintain oxic conditions (see below).

If the sand filter is constructed on the roof of a building (Figure 6), a pipe can be used to deliver treated water from the storage tank to a tap further down. In this case, the roof must be very strong to hold the sand filter which can weigh 2-3 tons!



**Figure 6.** Sand filter installed on a house roof

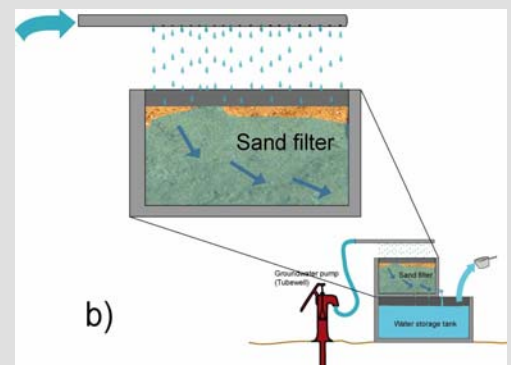
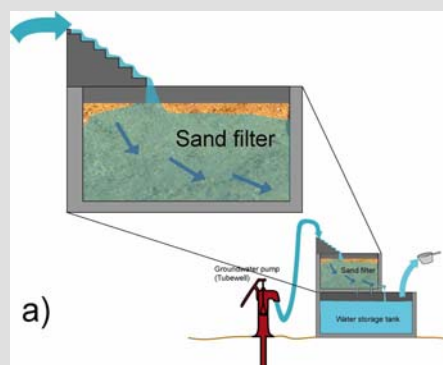
### 3.2. Enhancement of the Oxygen Availability in Sand Filters

The estimated oxygen concentration in a small sand filter (0.05 m<sup>3</sup>) indicates that enough oxygen is present in the dry sand to allow treatment of more than 150 litres of groundwater at a time even in the case of very high iron concentrations (50 mg/L). However, microbial activity in the filter, treatment of much higher groundwater quantities, or a filter design that does not allow complete drainage of the sand body, could lead to oxygen depletion and lower filter efficiency.

Installation of a simple aeration step prior to filtration, such as a sprinkler (a perforated basin or pipe) over the sand container or - even simpler - a cascade over which the pumped water runs down into the sand filter, can further enhance oxygen availability in sand filters.

**Figure 7.** Aeration methods to enhance the oxygen supply in the sand filter:

a) cascade, b) sprinkler





### 3.3. Microbial Activity in Sand Filters

Similar to the microbial activity in aquifers, which eventually leads to the release of arsenic into the groundwater, bacteria can also influence the processes of arsenic removal in sand filters.

Since bacteria are ubiquitous in the environment, colonisation of a sand filter by microorganisms is only a matter of time if the living conditions are favourable. The organic material, on which bacteria feed, can either get into the filter as dissolved organic matter (DOM) or fall into the tank as dirt, dust, leaves, dead insects, etc. Degradation of organic material by microorganisms depletes the oxygen (which is essential for iron oxidation in the groundwater filtration process) and, therefore, reduces the arsenic removal efficiency.

Microorganisms grow best in aqueous environments. Measures to inhibit microbial activity in the sand filter tank are therefore important and include: i) complete drainage of the water from the filter tank after each batch of treatment, which is achieved by placing the water outlet at the very bottom of the filter (see Figure 5); ii) covering the sand compartment with a lid to prevent the influx of solid organic material (e.g., leaves or insects); iii) regular exchange of the filter sand; and iv) removal of microbial colonies by thorough cleaning and brushing of the filter walls every time the sand is exchanged.

### 3.4. Operation and Maintenance

Since the filter sand can get clogged by iron(hydr)oxide precipitates, it should be exchanged every 1-2 months, depending on the iron concentration in groundwater and amount of filtered water. At this point, both tanks should be cleaned to prevent bacterial activity. Used sand can be discarded in backyards, on dust roads, in large rivers or used as construction material (see below). Disposal in gardens or on fields must be avoided as arsenic release and accumulation in plants could be critical. To prevent bacterial activity, the sand filter and the water storage tank should be covered, and only clean utensils should be used to scoop out water from the storage tank.

Sand filter efficiency is highest once the sand is coated with iron(hydr)oxides (red to brown colour). When the filter is loaded with new sand, an ideal filter efficiency can be re-established by filtering groundwater and discarding the filtered water until the sand turns slightly brown.

### 3.5. Handling of Used and Arsenic-contaminated Sand

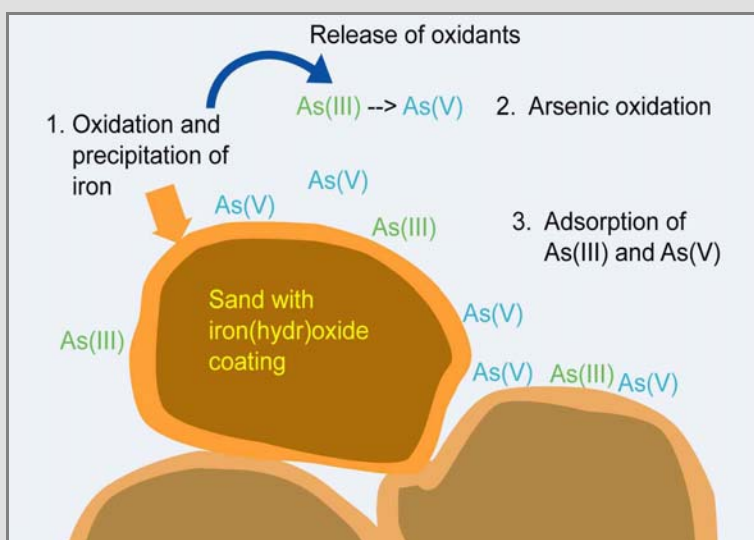
Arsenic can not be destroyed because it is a natural element. Its concentration in groundwater can be significantly lowered by sand filtration, but it will in turn be concentrated on the sand surface (see chapter 4.2.). Concern raised about re-contamination of the environment by discarded arsenic-contaminated filter sand are put into perspective by the following considerations:

- Arsenic does not re-desorb from iron-coated particles as long as oxygen is present. Disposal of used filter sand on roads or in rivers should therefore not be a problem. Disposal on irrigated fields, which could turn anoxic, **must be avoided**. Disposal in gardens or on vegetable fields is also **not recommended**, as anoxic conditions at the plant roots could lead to an accumulation of arsenic in agricultural products.

## 4. PRINCIPLE OF ARSENIC REMOVAL

Arsenic removal in sand filters is governed by precipitation of initially dissolved iron on the surface of sand grains. Dissolved Fe(II) is oxidised by oxygen to Fe(III), which quickly forms insoluble iron(hydr)oxide and precipitates to be readily adsorbed to the sand surface to form a coating. Subsequently, such coatings catalyse further oxidation and precipitation of dissolved iron. Oxidation of Fe(II) releases reactive oxidants, which can oxidise As(III) species to more strongly adsorbable As(V) species. As(V) and - to a lesser extent - As(III) then adsorb to the coated sand particles where arsenic remains immobilised under oxic condition.

In other words, a sand filter reverses the process of arsenic release occurring in groundwater, where anoxic conditions lead to the dissolution of solid iron(hydr)oxide phases and simultaneous release of adsorbed arsenic. If anoxic groundwater comes into contact with air (after pumping), oxygen is rapidly dissolved and leads to oxygen-rich (oxic) water, where iron is precipitating as insoluble iron(hydr)oxides to which the arsenic is adsorbed.



**Figure 8.** Illustration of arsenic adsorption to iron(hydr)oxides

Arsenic removal is thus highly dependent on the iron concentration, i.e., if more iron is initially present, larger surface areas are formed and more oxidants are produced for arsenic oxidation. The effect of other groundwater constituents can be rationalised in the light of the described mechanism. Phosphate and other anions behave in a similar way as arsenic species (oxyanions). They can also adsorb to iron(hydr)oxide surfaces and, therefore, compete with arsenic for the available adsorption sites. Of all the relevant anions present in natural groundwaters, phosphate has the highest adsorption capacity to iron(hydr)oxide surfaces, and is thus a key factor governing arsenic removal<sup>20</sup>.

<sup>20</sup> Luzi et al., forthcoming

## 5. FIELD INVESTIGATIONS: TESTING ARSENIC REMOVAL EFFICIENCY

### 5.1. Methods of Investigation

#### Study area

The presented field study was conducted in three villages located in the Red River delta, namely, Thuong Cat, Hoang Liet and Van Phuc. Samples of raw groundwater and of sand-filtered water were collected from 54 households using small-scale tubewells and sand filters as described above. Only households with groundwater arsenic concentrations above 10 µg/L (43 households) were considered for the data evaluation.

#### Sampling and sample preservation

All of the 54 sites were sampled and investigated two repetitive times in September 2002 and December 2002. Groundwater samples were collected after establishment of stable oxygen readings (portable oxygen sensor) in the pumped water, i.e., typically after 3 to 5 minutes of pumping. All samples were filtered on-site by disposable 0.45 µm cellulose nitrate filters, filled into pre-washed (hydrochloric acid and distilled water) PET bottles, acidified with nitric acid (1%) in order to prevent precipitation of iron and arsenic, and stored in the dark until to analysis.

To study passive precipitation of arsenic and iron, unfiltered and not-acidified samples were exposed to air for 24 hours. The water was then decanted from the precipitate, filtered (0.45 µm), and acidified before analysis.

#### Analysis of arsenic, iron and phosphate

Concentrations of total iron and total arsenic were determined by atomic absorption spectroscopy (AAS). Phosphate concentrations were measured by the molybdate blue method.

#### Quality assurance

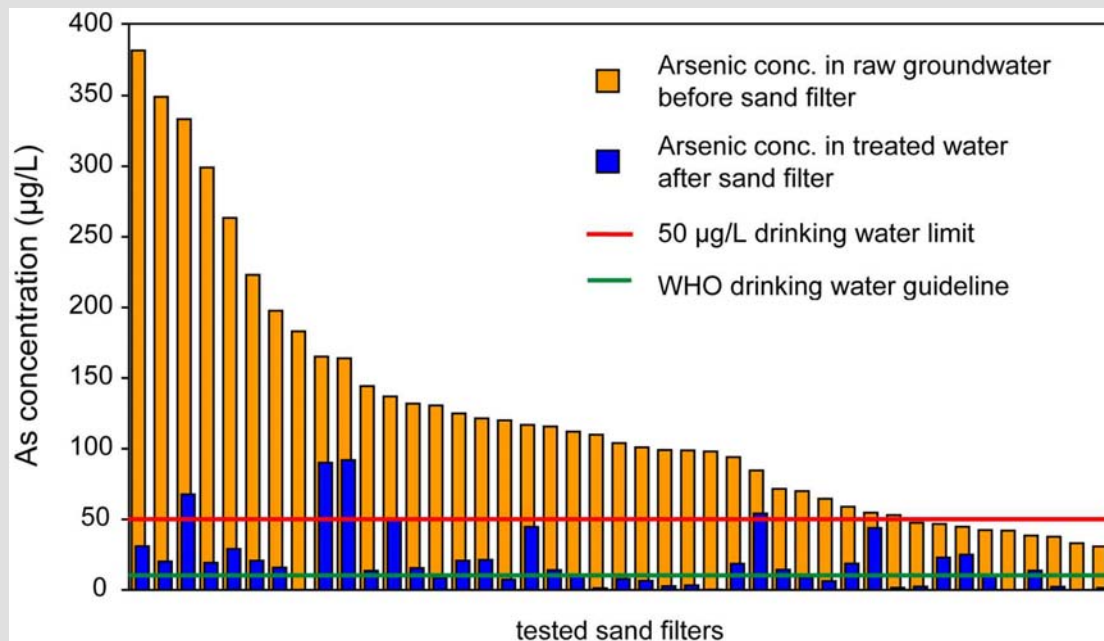
The quality of the measurements was evaluated by analysing all samples at CETASD (Hanoi, Vietnam) as well as at EAWAG (Duebendorf, Switzerland). The results of EAWAG and CETASD were in good agreement for both, arsenic and iron concentrations ( $r^2$  0.91-0.99 for As, 0.96-0.99 for Fe).

### 5.2. Arsenic Removal in Sand Filters

The arsenic removal efficiency of sand filters was investigated in 54 households, of which 43 households were using groundwater with arsenic concentrations exceeding the WHO drinking water guideline of 10 µg/L. Samples from the same 54 households were collected in September 2002 and again in December 2002. The arsenic concentrations determined in the raw groundwater as well as in sand filtered water did not vary by more than 15% between the two replicate investigations<sup>21</sup>. The studies have been carried out in the framework of the Swiss-Vietnamese cooperation project ESTNV (Environmental Science and Technology in Northern Vietnam).

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<sup>21</sup> More details will be given in Luzi et al., forthcoming



**Figure 9.** Arsenic removal efficiency of household sand filters (average values from repetitive investigations conducted in September and December 2002). Only the 43 households with initial groundwater arsenic levels >10 µg/L are displayed

Figure 9 depicts the results of sand filter arsenic removal in the studied households. All filters were capable of lowering arsenic concentrations with efficiencies ranging between 20 to >99%. Residual arsenic levels below the WHO guideline of 10 µg/L were reached by 40% of the studied sand filters, and 90% were below 50 µg/L. The 10% of the households exceeding 50 µg/L after filtration can be attributed to low initial iron concentrations and/or high initial phosphate levels in the groundwater (see chapter 5.4. below).

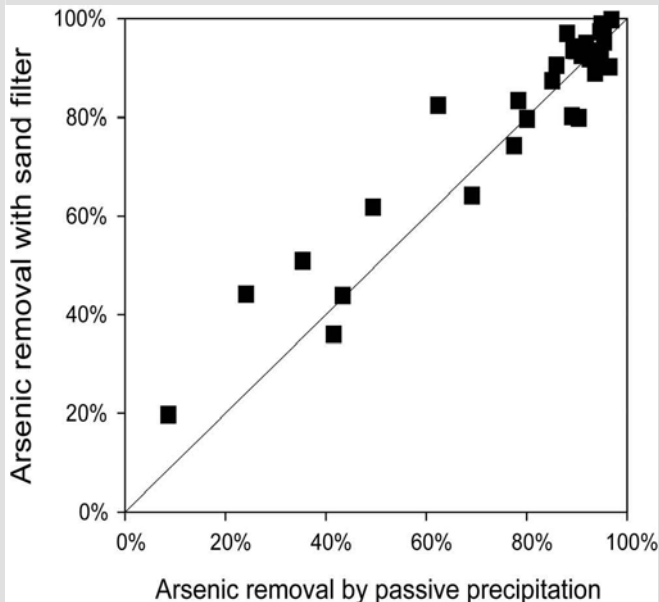
**The mean arsenic removal efficiency of sand filters amounts to 80%**

### 5.3. Passive Precipitation in Settling Tanks

For reasons of comparison, passive precipitation experiments were conducted by exposing to air for 24 hours the raw groundwater collected from the same tubewells. Remaining arsenic concentrations were analysed after (passive) precipitation and sedimentation of iron(hydr)oxide particles. This method simulates the processes occurring in a water settling tank and generates a comparable set of data based merely on water composition and not on filter specifications<sup>22</sup>, such as filter volume, type of sand or flow rate.

As illustrated in Figure 10, the arsenic removal rates by passive precipitation were almost identical to the ones of groundwater treated in household sand filters. Compared to simple settling tanks, the sand filter only performed slightly better if removal rates were below 70%. This indicates that sand filters do not greatly enhance arsenic removal compared to passive

<sup>22</sup> Roberts et al. 2004

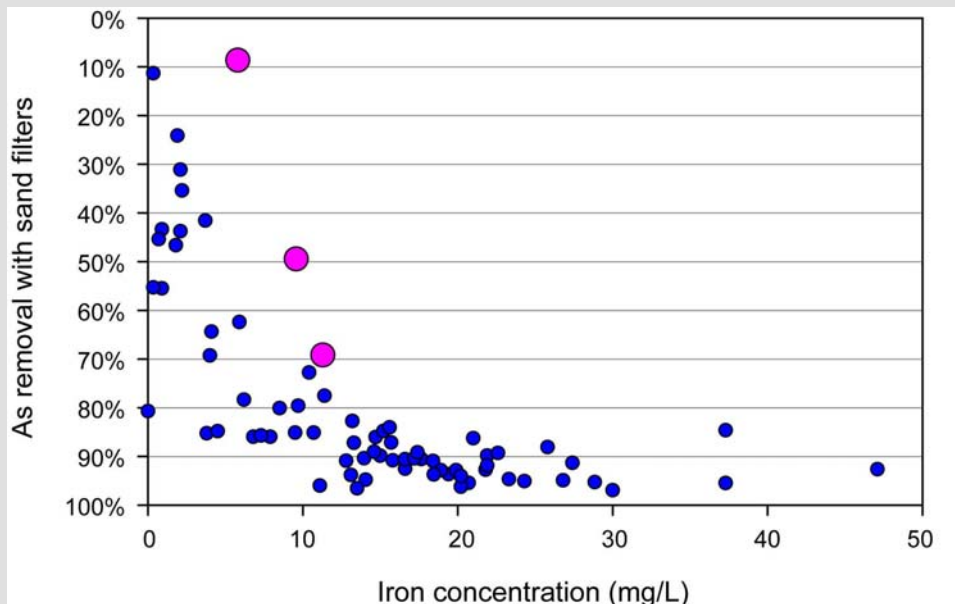


particle sedimentation. It also reveals that filter specifications play a minor role and that groundwater composition is the key factor determining arsenic removal efficiency.

**Figure 10.** Comparison of passive precipitation (settling tanks) and sand filters in arsenic removal rates

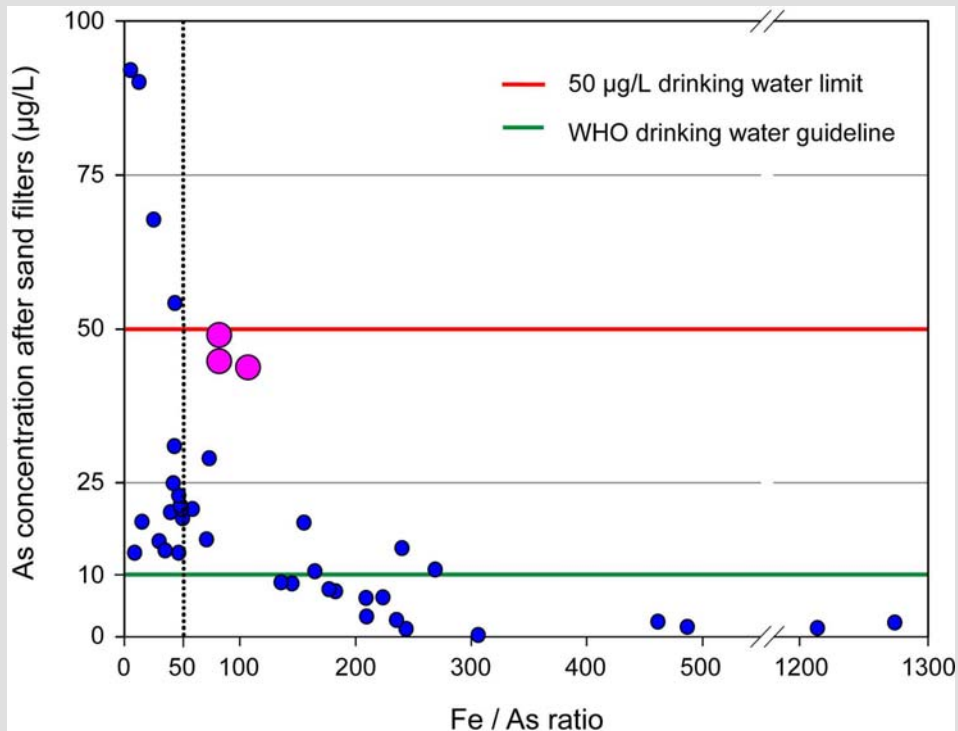
#### 5.4. Role of Dissolved Iron and Phosphate in Groundwater

Dissolved iron is the key parameter governing arsenic removal (see Figure 11). Arsenic removal from groundwater with an initial iron concentration of >12 mg/L is very efficient. However, the arsenic removal rate from water with an initial iron concentration of <1 mg/L is quite poor. High phosphate concentrations (and to a much lesser extent other anions such as silicate, bicarbonate and chloride) can reduce the arsenic removal efficiency.



**Figure 11.** Plot depicting arsenic removal rates as a function of iron dissolved in freshly pumped groundwater. The magnified pink symbols indicate samples with high phosphate concentrations (above 2.5 mg P/L)





**Figure 12.** Residual arsenic concentration after sand filtration as a function of the Fe/As (w/w) ratio. The magnified pink symbols indicate samples with >2.5 mg P/L phosphate concentrations

The proportion at which dissolved iron and arsenic are present in groundwater is a suitable parameter for estimating the arsenic removal potential. A common way to describe this parameter is the Fe/As weight/weight (w/w) ratio, i.e., the iron concentration in mg/L divided by the arsenic concentration in mg/L. Figure 12 illustrates the residual arsenic concentrations measured in the filtered water as a function of the corresponding Fe/As ratios determined in raw groundwater.

It becomes evident that an Fe/As ratio of 50 or more is necessary to reduce arsenic concentrations to levels below 50 µg/L. To reach the WHO drinking water guideline and the Vietnamese drinking water limit of 10 µg/L in all cases, considerably higher Fe/As ratios of >250 are required. The influence of >2.5 mg P/L phosphate concentrations is clearly visible in Figures 11 and 12.

#### Parameters influencing arsenic removal

- The most important parameter is the concentration of dissolved iron in groundwater. The arsenic removal rates amount to >80% for groundwater containing more than 12 mg/L iron, and to less than 60% if iron concentrations are below 3-4 mg/L.
- Phosphate concentrations exceeding 2 mg P/L can hinder the arsenic removal efficiency, as phosphate competes with arsenic for adsorption sites on the iron(hydr)oxide surfaces.
- Iron therefore strongly enhances and phosphate slightly decreases arsenic removal.
- Arsenic(V) can better be removed than arsenic(III) species<sup>23</sup> (see above).

<sup>23</sup> Roberts et al. 2004

### **5.5. Advantages of Sand Filters**

Compared to tanks for passive particle settling, the advantages of sand filters do not arise from an enhanced arsenic removal capacity, but from their practical benefits for the users to operate and manage them. The process of iron and arsenic removal is accelerated by the sand surface and completed within a few minutes. This allows treatment of reasonable quantities of water whenever needed. Clear, filtered water can be stored in the underlying tank. In comparison, passive precipitation and sedimentation in settling tanks require several hours. Furthermore, the treated water in these tanks is still turbid after one day.

- Sand filters and passive precipitation revealed almost identical arsenic removal efficiencies.
- The filter volume or type of sand used in the tested sand filters had no influence on performance.

## 6. CASE STUDIES IN THE RED RIVER DELTA

The distribution of iron and arsenic concentrations in the groundwater is often highly heterogeneous as shown in Figure 2. Since household tubewells pump groundwater from varying depths and use different water treatment systems after pumping (e.g. settling tank, sand filter), the water quality for human consumption varies considerably from place to place. The following case studies conducted in the Hanoi Province describe characteristic households with respect to their groundwater use.

### Family 1

(<10 µg/L arsenic, <2 mg/L iron)

Family 1 lives in a village north of Hanoi City. The groundwater from its tubewell contains little iron and remains clear after pumping. The family members use untreated groundwater for drinking and cooking. The household water storage tank can store water for several days or weeks. Since the arsenic concentration is below 10 µg/L, the groundwater does not pose an increased health risk for this family.



Hand pump and storage tank

### Family 2

(300 µg/L arsenic, 15 mg/L iron)

This family lives south of Hanoi City. The groundwater conveyed by an electrical pump is "tanh", as it contains a lot of iron (15 mg/L) and has a bad taste. The family does not want to drink the water that turns yellow shortly after pumping. Family members have recently constructed a sand filter with the help of neighbours from the same village. The family also collects rainwater as an alternative source of drinking water. Yet, the household is unaware of the high arsenic level (300 µg/L) of its groundwater. However, thanks to the sand filter, over 80% of the arsenic is removed from the groundwater. The filtered water contains less than 50 µg/L arsenic.



Sand filter on top of storage tank

### Family 3

(190 µg/L arsenic, 18 mg/L iron)

Family 3 lives in the same village as family 2. The groundwater is also "tanh" and contains a lot of iron. Instead of installing a sand filter, family 3 uses two water settling tanks. Groundwater is pumped into tank 1 and later scooped into tank 2. More than 80% of the iron and arsenic is removed, but the process is very slow and the treated water remains slightly turbid.



Settling tanks (right: tank 1 for aeration and settling; left: tank 2 for further settling)

### Family 4

(160 µg/L arsenic, <2 mg/L iron)

Family 4 lives north of Hanoi City. The groundwater of most households in this village exhibits low iron and low arsenic (<10 µg/L) concentrations. Yet, the groundwater of family 4 is an exception, as it reveals low iron but high arsenic levels (160 µg/L). Since the family is unaware of the arsenic problem, it does not use any kind of water treatment system. The efficiency of a sand filter under these conditions would be poor. This family is exposed to a high risk of arsenic poisoning.



Electrical pump and storage tank

Of all the case studies described above, family 4 is obviously confronted with the most critical situation. The family members are exposed to a high health risk due to elevated arsenic concentrations, and they are completely unaware of the quality problem as their tubewell water is clear and apparently clean. Unlike family 2, the low iron levels do not prevent the people from drinking untreated tubewell water. Furthermore, under the given conditions of family 4, the efficiency of simple arsenic removal measures, such as household sand filters, would be poor.

The incidence of tubewells with a high arsenic concentration yet extremely low iron level is an exception in the studied villages.



## 7. APPLICABILITY OF THE RESULTS TO OTHER REGIONS OF VIETNAM - AND THE WORLD

### 7.1. Prerequisites

The results presented in the previous chapters are applicable to the study area of the Hanoi Province. Interpolation of these data to the rest of the Red River Delta, the Mekong Delta or other affected regions should only be considered in the light of the groundwater composition of the studied areas. As shown in this report, iron and phosphate are the dominant groundwater parameters influencing the efficiency of arsenic removal. Iron levels in the studied households were generally high (average 13 mg/L) and, thereby, favourable for arsenic removal.

A comprehensive database on the (co-)occurrence of arsenic, iron and phosphate is currently not available in Vietnam to provide an overall estimate of the potential arsenic removal efficiency of household sand filters. Use of sand filters in the studied area diminish arsenic concentrations in all households affected by arsenic-contaminated (>10 µg/L) groundwater. High arsenic levels are often accompanied by high iron concentrations. Only very few cases of elevated arsenic concentrations were detected in groundwater having low iron levels (<1 mg/L). In almost 50% of all the studied households, iron concentrations were high enough (>12 mg Fe/L) to guarantee an arsenic removal efficiency of more than 80%.

**Since groundwater parameters other than iron and phosphate may also influence the arsenic removal efficiency, the local applicability of household sand filters must always be tested before they are promoted in other affected regions, especially if the groundwater composition differs significantly from the tested Red River Delta.**

### 7.2. Estimation of Iron Concentration and Arsenic Removal Efficiency

The efficiency of sand filters in arsenic removal can be roughly estimated from known (measured) iron concentrations or from the intensity (and colour) of iron(hydr)oxide precipitation developing in freshly pumped groundwater after one hour of contact with air (see Table 2).

**Table 2.** Estimated arsenic removal efficiency in sand filters based on dissolved iron concentrations in groundwater

Iron concentration in groundwater	Water colouring caused by iron-precipitation <sup>24</sup>	Estimated arsenic removal in sand filters
>12 mg/L	dark yellow/red	>80%
1-12 mg/L	light yellow	20-90%
<1 mg/L	clear	<20%

<sup>24</sup> Colour developing in freshly pumped groundwater based on turbidity of iron(hydr)oxide precipitates after one hour of contact with air.



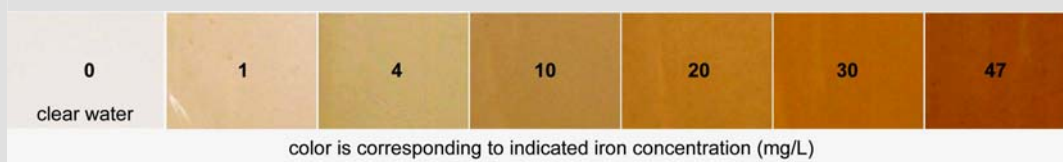
A rough estimate of iron concentrations based on water turbidity and colour intensity (see colour scale below) can easily be established if laboratory analysis of iron is not possible. It must be kept in mind that phosphate concentrations of >2.5 mg/L can decrease the arsenic removal efficiency of sand filters. Phosphate concentrations also have to be considered to obtain a more accurate evaluation of sand filter applicability. However, a clear negative influence of high phosphate concentrations on arsenic removal was only observed in 5% of all the tested households.

### Colour scale for iron concentration estimates in groundwater

The household sand filter efficiency can be estimated on the basis of turbidity and colour developing in freshly pumped groundwater after one hour of contact with air. To obtain accurate results, the water must be shaken or stirred to re-suspend the settled particles before colour reading.

The colour scale presented below is derived from photographs taken from the iron precipitates in natural groundwater samples. PET bottles (6-7 cm diameter) were filled with freshly pumped groundwater of known iron concentration and average phosphate (1-1.5 mg/L) and silicate (15-20 mg/L) levels. The bottles were occasionally shaken and photographed the next day against a white background (indirect sunlight around noon).

*Note: Background, light intensity and other water constituents may influence the perceived water colour.*



iron <1 mg/L no arsenic removal	iron 1-12 mg/L arsenic removal efficiency 20 to 90%	iron >12 mg/L arsenic removal efficiency >80%
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## 8. CONSEQUENCES OF THE ARSENIC PROBLEM FOR VIETNAM

Groundwater is the only drinking water source potentially contaminated by natural arsenic. In rural areas of the Red River Delta, untreated iron-rich groundwater is not first choice for drinking or cooking, as iron affects the taste and appearance of the pumped water. In these regions, groundwater is preferably replaced by rainwater, public tap water, surface water, groundwater from dug wells, or groundwater treated by household sand filters (or settling tanks). All these measures significantly lower the arsenic intake and, hence, reduce the risk of adverse health impacts.

### 8.1. Affected Population

To conduct an accurate evaluation on the arsenic-exposed population of Vietnam, the following questions have to be answered:

Question	Current knowledge
What areas of Vietnam reveal high arsenic concentrations?	High arsenic concentrations were found scattered throughout the Red River Delta <sup>25</sup> . Elevated arsenic concentrations are also expected in the upper Mekong Delta. Some of the other alluvial river deltas may be affected occasionally.
How many people live in these areas?	Red River Delta: 11 million. Mekong Delta: 17 million.
How many households use private tubewells in the affected areas <sup>26</sup> ?	According to UNICEF, 17% of the private Vietnamese households use groundwater from tubewells as drinking water <sup>27</sup> . According to UNICEF, 3 million people in Vietnam are currently exposed to elevated arsenic concentrations, and 10 million are at risk <sup>28</sup> .
How many households with pumped contaminated groundwater apply a sand filter?	No data available.
How efficient are sand filters in arsenic removal?	The average arsenic removal efficiency amounts to 80% (see chapter 5). Arsenic removal is highly dependent on dissolved iron levels. The arsenic removal efficiency is reduced by high phosphate concentrations (>2 mg/L).
What fraction of untreated groundwater is consumed for dietary purposes?	No comprehensive data available.

<sup>25</sup> Berg et al. 2001; Hydrogeological Division II 2000; Department of Geology and Minerals of Vietnam 2001

<sup>26</sup> In some regions, mainly in the south of Vietnam, the groundwater supply uses small-scale pumping stations and treatment plants shared by some 50 households

<sup>27</sup> UNICEF Vietnam 2002

<sup>28</sup> UNICEF Vietnam 2001

Mainly due to the heterogeneity of the arsenic occurrence, the number of threatened households in the contaminated areas of Vietnam cannot be accurately evaluated from the available database. However, it can be concluded that the households which apply a sand filter or a settling tank can significantly lower (80%) the mean arsenic intake.

## 8.2. Reduced Health Risks

Little is known on the number and density of tubewells and household sand filters in arsenic-contaminated areas of Vietnam. Conclusions on the prevention of arsenic related health effects can only be drawn for households already applying a sand filter or if all the households in the affected areas are assumed to use a sand filter<sup>29</sup>.

- In 90% of the households using groundwater with arsenic levels above 50 µg/L, the arsenic concentration can be reduced to less than 50 µg/L, and in 30% to less than 10 µg/L. The risk of severe health effects in these households can be lowered considerably by sand filters.
- In the overall study area, 40% of all households using groundwater with arsenic concentrations exceeding the WHO drinking water guideline of 10 µg/L can even reduce arsenic levels to less than 10 µg/L with a sand filter and, therefore, prevent any further health risks.
- In the studied households, the arsenic concentration in sand-filtered water never exceeded 100 µg/L. Health problems caused by arsenic will therefore require far more time to develop or become less severe in households applying a sand filter.

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<sup>29</sup> Conclusions are drawn under the assumption that high arsenic and iron concentrations of co-occur, as it has been observed in this and many other studies

## 9. SUGGESTIONS FOR THE VIETNAMESE NATIONAL ARSENIC MITIGATION PLAN

Sand filters can be of key importance to bridge the gap until the national action plan develops better solutions for arsenic mitigation. Promotion of household sand filters appears simple, as this system is already adopted by parts of the rural population of Vietnam. Furthermore, construction and operation of sand filters is simple and inexpensive. The filters use locally available materials, are operated without chemicals and can treat a reasonable amount of groundwater within a short time. The observable removal of iron from the pumped water immediately makes the use of a sand filter intelligible even to people who have never heard of the arsenic problem.

Arsenic contamination of groundwater in the Red River Delta has fortunately been identified at an early stage. Due to the relatively short exposure time of the affected people up till now, very few people have developed health problems so far. Yet, since symptoms of chronic arsenic poisoning can take 10 or more years to develop, the number of people being affected by arsenic related health problems must not be underestimated in the future. Preventive mitigation measures are therefore of utmost importance.

Planned arsenic mitigation programs in Vietnam<sup>30</sup> address the arsenic problem on various levels. The government action plan foresees the training of water supply and health staff, as well as projects to intensify communication, information and cooperation in Vietnam and on an internationally level. It will also encompass baseline studies on the occurrence of arsenic and release mechanism(s) in groundwater, monitoring of large areas, and research on arsenic removal technologies. Arsenic removal is required in urban and communal waterworks<sup>31,32</sup>, as well as on a very small scale in tubewells of private household throughout the affected areas.

The following strategies could support arsenic removal efforts, particularly in the light of arsenic-related health prevention efforts.

### **A. Knowledge extension on water use habits and sand filter applicability**

- A1 Determine the ratio of tubewell water (sand filtered/untreated) being used as drinking water in households of arsenic-contaminated regions.
- A2 Map iron and phosphate concentrations as a function of arsenic levels to determine the applicability of household sand filters in affected areas on the basis of the results presented in this report.
- A3 Identify areas ("hot spots") where high arsenic concentrations and low iron levels co-occur in the groundwater and thus sand filters are not effective with regard to arsenic removal.

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<sup>30</sup> Ministry of Agriculture and Rural Development 2002

<sup>31</sup> Duong et al. 2003

<sup>32</sup> Pham et al. 2003

## **B. Promotion of household sand filters and alternative sources of drinking water**

- B1 Provide advice on the construction of a sand filter to all the families pumping iron-rich water. Prepare manuals, leaflets or posters to facilitate the transfer of knowledge in rural areas (see examples in Appendices 1 and 2).
  - B2 Educate government officials in the benefits of household sand filters. Involve local authorities (i.e., Communal Peoples Committees) in the distribution of information material.
  - B3 Supply poor families with construction material.
  - B4 Promote alternative sources of drinking water in areas with low iron / high arsenic occurrence. Recommend the use of other available sources of drinking water (dug wells, rainwater), or supply arsenic-free water by installing a communal water treatment plant in these areas.
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### Useful Internet Sites

- |  |                             |
|--|-----------------------------|
| <a href="http://www.who.int/water_sanitation_health/dwq/arsenic">www.who.int/water_sanitation_health/dwq/arsenic</a> | (WHO)                       |
| <a href="http://www.bgs.ac.uk/arsenic">www.bgs.ac.uk/arsenic</a>   | (British Geological Survey) |
| <a href="http://www.arsenic.eawag.ch">www.arsenic.eawag.ch</a>   | (EAWAG)                     |
| <a href="http://www.eawag.ch/~berg/arsenic/">www.eawag.ch/~berg/arsenic/</a>   |                             |
| <a href="http://www.es.ucl.ac.uk/research/lag/as">www.es.ucl.ac.uk/research/lag/as</a>                               | (University College London) |
| <a href="http://www.asia-arsenic.net">www.asia-arsenic.net</a>   | (Asia Arsenic Network)      |
| <a href="http://www.unu.edu/env/arsenic/proceedings.htm">www.unu.edu/env/arsenic/proceedings.htm</a>                 | (UNU)                       |
| <a href="http://www.epa.gov/safewater/arsenic.html">www.epa.gov/safewater/arsenic.html</a>                           | (US EPA)                    |

## APPENDICES


**Proposed leaflet for dissemination of information on the arsenic problem and use of sand filters  
(Version 1, illustrated by Mike Meier and Hoang Anh)**

**Arsenic and iron removal from groundwater**




Recommendations to improve the quality of tubewell water.

page 1



Some tubewells produce water with a high concentration of iron. This can be the case if hand pumps or electrical pumps are used.

The pumped water is "tanh". It has a bad taste and its colour turns yellow, red or brown shortly after pumping.




page 2

Iron does not pose a health problem, however, drinking or cooking of iron-rich water is undesired for reasons of taste and appearance.

Unfortunately, iron-rich water from tubewells often also contains arsenic, a very poisonous metal. Arsenic is invisible and tasteless, but far more dangerous to health than iron.

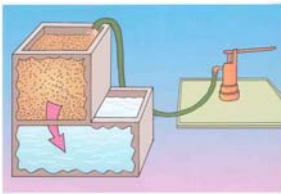
Consumption of arsenic-rich water, will lead to symptoms such as skin pigmentation changes as well as skin or other forms of cancer.



page 3

Arsenic is a heavy metal and CANNOT be removed by boiling water!

However, if iron is present in the tubewell water, use of a sand filter is a simple solution to remove both iron and arsenic from groundwater.



Construct two tanks using concrete and bricks. The upper tank is used as a sand filter and must have an outlet for the water to flow into the water storage tank below. The outlet can consist of

page 4

holes at the bottom or of a pipe in the front wall of the sand container. Place a fine sieve (i.e., a piece of cloth) between sand and outlet.


Fill the upper tank with locally available sand and pump your groundwater into the sand filter. The water flowing from the sand will be clear and will contain much less arsenic.

Replace the sand and clean the walls of the tanks every 1-2 months. Dispose the used sand in your backyard, on dust roads, in the river or use it as construction material. Do not dispose used sand in your fields or in your garden.


As sand filters may not work efficiently with water containing little iron, try to use other sources of drinking water.

page 5

Dug wells and rainwater are two alternative sources of drinking water containing no or little arsenic.



*dug wells*




*rainwater tank*

Recommendation: To prevent infectious diseases, water should always be boiled before drinking.

page 6


**Proposed leaflet for dissemination of information on the arsenic problem and use of sand filters  
(Version 2, illustrated by Mike Meier and Trang Duyet Thanh)**

**Arsenic and iron removal from groundwater**




Recommendations to improve the quality of tubewell water.

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Some tubewells produce water with a high concentration of iron. This can be the case if hand pumps or electrical pumps are used. The pumped water is "tanh". It has a bad taste and its colour turns yellow, red or brown shortly after pumping.



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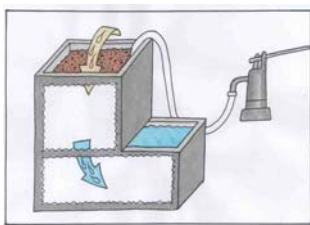
Iron does not pose a health problem, however, drinking or cooking of iron-rich water is undesired for reasons of taste and appearance. Unfortunately, iron-rich water from tubewells often also contains arsenic, a very poisonous metal. Arsenic is invisible and tasteless, but far more dangerous to health than iron. Consumption of arsenic-rich water, will lead to symptoms such as skin pigmentation changes as well as skin or other forms of cancer.



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Arsenic is a heavy metal and CANNOT be removed by boiling water!

However, if iron is present in the tubewell water, use of a sand filter is a simple solution to eliminate both iron and arsenic from groundwater.



Construct two tanks using concrete and bricks. The upper tank is used as a sand filter and must have an outlet for the water to flow into the water storage tank below. The outlet can consist of

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holes at the bottom or of a pipe in the front wall of the sand container. Place a fine sieve (i.e., a piece of cloth) between sand and outlet.


Fill the upper tank with locally available sand and pump your groundwater into the sand filter. The water flowing from the sand will be clear and will contain much less arsenic.

Replace the sand and clean the walls of the tanks every 1-2 months. Dispose the used sand in your backyard, on dust roads, in the river or use it as construction material. Do not dispose used sand in your fields or in your garden.


As sand filters may not work efficiently with water containing little iron, try to use other sources of drinking water.

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Dug wells and rainwater are two alternative sources of drinking water containing no or little arsenic.



*dug wells*



*rainwater tank*

Recommendation: To prevent infectious diseases, water should always be boiled before drinking.

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