Extended Field Trial of Household Iron Removal Plants to Remove Arsenic from Groundwater

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Abstract
The use of household sand filters or Iron Reduction Plants (IRPs) to remove dissolved iron is widespread in rural areas of Viet Nam particularly in the Red River area. These devices also have capacity to reduce arsenic concentration and therefore present an attractive method of providing safe water if they can be successfully adapted and maintained to remove arsenic. The National Institute of Occupational and Environmental Health (NIOEH) have developed a standard IRP design with improved capacity for removal which is simple and easy to maintain. A field trial of NIOEH filters in 100 households in two villages was undertaken in 2005 with the support of WHO.

The two villages had contrasting groundwater chemistry. Groundwater in Don Xa village had a median arsenic concentration of 64.3 ppb and a median iron concentration of 6.25 mg/L. In contrast Dung Tien had a median concentration of 24.6 ppb As and 3.76 mg/L Fe. In Don Xa the efficiency of arsenic removal was increased from 87.1% to 97.8% with installation of improved IRPs and in Dung Tien village arsenic removal increased from 50.4% to 64.1%. The percentage of wells meet the urban standard of WHO /Viet Nam of 10ppb increased, from 71% to 96 % in Don Xa village and from 41% to 66% in Dung Tien. User satisfaction with the improved design was high in both villages. The data suggest that the use of existing IRPs can ensure most wells will reach the Viet Nam rural standard of 50 ppb arsenic but it also indicates that improved designs are capable of reaching the urban standard of 10 ppb in the majority of wells.

Introduction
The arsenic contamination of groundwater in Viet Nam had not been investigated until the late 1990's when discovery of widespread arsenic contamination of tube wells in Bangladesh and the similar geological conditions between Bangladesh, the Red River and Mekong River Deltas suggested the possibility of arsenic contamination in these areas. Since the early 90's a number of Government organizations and institutions in Vietnam have undertaken a range of investigation concerning arsenic contamination of groundwater, focussing on rural areas in Red River and Mekong River Deltas. These studies have revealed arsenic contamination of groundwater to be both high and widespread particularly in the Red River Delta.

The national testing program being carried out by the Government of Viet Nam with support from UNICEF suggests that arsenic contamination is most severe in Red River area where in some provinces up to 50% of tube-wells have arsenic concentration in excess of 50ppb. Most private tube wells in Vietnam have been in use for less than 10 years and experience has shown that it can take 10 or more years before the first arsenic poisoning symptoms become apparent. Currently there is no official estimate available of population exposed to arsenic in

drinking water in Viet Nam, however, the World Bank (2005) quote a UNICEF estimate of the "Population at Risk" as 10 million.

Human exposure to unsafe levels of arsenic in drinking water has been identified as a priority environmental health issue in Vietnam and the Government of Viet Nam is currently developing a National Action Plan to respond to the emerging arsenic issue, including provision of household water treatment (filters and chemical treatment) to remove arsenic.

The use of household sand filters or Iron Reduction Plants (IRPs) to remove dissolved iron is widespread and well accepted in rural and sub-urban areas of Viet Nam particularly in the Red River area. These devices also have the capacity to reduce arsenic concentration and therefore present an attractive method of providing safe water if they can be successfully adapted and maintained to remove arsenic. The promotion of IRPs to provide arsenic safe water would be consistent with the National Action Plan if the devices were capable of reducing arsenic to acceptable levels, were easy to use, cheap and were acceptable to the community.

Objectives

The objectives of this field trial of NIOEH's improved IRP in two villages in the Red River Delta is to test arsenic removal efficiency under field conditions and to investigate user satisfaction with the improved design.

Methods

Two villages, Don Xa village in Ha Nam province and Dung Tien village in Ha Tay province, were selected for the field trial. Groundwater sources in both villages have high concentrations of arsenic and iron and the use of IRP's is common in both villages.

An initial survey of household water use was undertaken at the start of the project for 100 households selected randomly in each village. These households were using groundwater for drinking and washing. Arsenic levels in the water supply of each household were measured using field test kits and fifty households from each village with arsenic levels above 10 ppb were selected for participation in the field trial of the improved IRP.

Each IRP was sampled in the condition it was found. Samples of untreated inflow and outflow from existing filters were collected from each household and were analysed for pH, iron (Fe II and total Fe), arsenic (As) by using methods in S*tandard Methods for Examination of Water and Wastewater* (APHA, 1989).

Existing IRPs were then modified or new IRPs constructed to be consistent with the NIOEH design and a second round of water quality testing was undertaken 6-8 weeks after construction. Samples of filtered water and IRP outflow were analysed for total iron and arsenic using the methods described above. A member of each household was also interviewed concerning the ease or operation and satisfaction with the NIOEH designed IRP.

Results

Water Quality

A summary of the water quality of the groundwater sources in Dung Tien and Don Xa villages is presented in Table 1. The groundwater in both villages have near neutral pH's and are contaminated by both iron and arsenic. Some 94% of water sources tested in Dung Tien and 98% or sources tested in Don Xa have iron concentrations in excess of the National Guideline (0.5mg Fe/l). The households selected for participation in the trial also had high levels of arsenic contamination. The median concentration of arsenic in groundwater sources in Don Xa village was 64.3 ppb with 100% of households exceeding the 10ppb and 60% exceeding 50 ppb. In Dung Tien the median arsenic concentration was 24.7 ppb which is significantly lower than in Don Xa (Mann Whitney U Test $p < 0.000001$) with 86% of participating household water sources exceeding 10 ppb and 18% exceeding 50 ppb.

Table 1.Summary of water quality of groundwater sources in Dung Tien and Don Xa villages*.

Parameter	Dung Tien (n = 50)			Don Xa (n = 50)		
	Median	Min	Max	Median	Min	Max
pH	6.74	6.17	7.94	6.73	6.25	7.47
Fe^{2+} (mg/l)	0.38	0.01	8.55	4.75	0.02	10.35
Fe^{3+} (mg/l)	2.40	0.03	7.12	1.45	0.01	5.8
Total Iron (mg/l)	3.76	0.06	12.25	6.25	0.03	14.15
As (ppb)	24.6	1.8	75.8	64.3	21.8	155.1

* The dataset is relatively small, the water quality data is are not normally distributed. Non-parametric statistics have therefore been used on the groundwater data throughout this report.

High levels of arsenic are often associated with high levels of iron since both are released by the microbially mediated reduction of iron oxyhydroxides. However, data from the two investigated villages shows that the correlation between arsenic and iron is weak.

Existing Iron Reduction Plants

The existing IRPs used in the villages are slow sand filtration plants and generally use a local 'black' sand as the filter material. There is no standard or even common designs and dimensions of the IRPs and thickness of the sand layer vary greatly between households. In addition, the design and size of the IRPs are not related to the size and water requirements of the household. Almost all households use 0.35 KW electric pumps to deliver water to the IRPs. Figure 1 and 2 show some common types of the existing IRPs.

Villagers report that the iron removal efficiency of the existing IRPs is initially high but decreases rapidly with use. The flow rate of filtered water is also rapidly reduced because of clogging of filter sand. Villagers also complained that cleaning the existing IRPs is difficult as washing the sand bed requires the sand be taken out of filter tank.

Figure 1 & 2.
Existing IRPs.

NIOEH sand filter systems (Improved IRPs)

A total of 50 NIOEH sand filters were installed in participating households in each village. The NIOEH filter (developed with the support of UNICEF) overcomes many of the disadvantage of the existing IRPs with increased filtration capacity, increased efficiency of iron and arsenic removal, and an improved procedure for maintenance (sand washing and back flushing). The key features of the NIOEH design is indicated in Box 1; and NIOEH sand filter system and some it's components are showed in figure 3, 4 and 5.

Box 1. ***Key features of the NIOEH design include:***

1. Standard design;
2. Spray system to aerate and disperse incoming water over full area of filter;
3. Use of yellow sand (yellow sand has grains coated with iron oxy-hydroxides which promotes Fe/As precipitation);
4. Inclusion of a washing valve to improve maintenance.

Figure 3.
Electric Pump

Figure 4.
Spray system

Figure 5.
NIOEH sand filter system

Efficiency of arsenic and iron removal by the existing and the improved IRPs.

A summary of the water quality results collected in the first and second round of testing to evaluate the efficiency of the existing and the improved IRPs is provided in Table 2 and Table 3.

The overall median arsenic and iron removal efficiency of the existing IRPs for both villages was 66% and 79% respectively. All IRPs lowered the arsenic concentration of raw inflow water to some extent, besides, iron removal efficiency was highly variable and was significantly different in the two villages. Overall, nearly 29% of IRPs in Don Xa and nearly

59% of IRPs in Dung Tien did not reduce arsenic levels to within acceptable limits for urban drinking water (10 ppb) although all outflow samples were less than the rural limit of 50 ppb.

The efficiency of arsenic removal of the improved IRPs in the two villages increased significantly from a median value of 66% to 85% but degree of improvement was different in each village. In Don Xa the efficiency of arsenic removal increased (p=0.003 Wilcoxin matched pairs test) from a median of 87.1% to 97.8% and the percentage of IRPs providing water that reached the Viet Nam standard for urban areas (10ppb) increased from 71% to 96% with all outflow samples less than 50ppb arsenic. In Dung Tien village arsenic removal efficiency also increased significantly (p=0.005, Wilcoxin matched pairs test) but only from 50.9% to 64.1%. However, the percentage of wells that met the Urban National Standard (10ppb) increased from 41% to 66% and the median concentration of arsenic in the outflow water was reduced to 8.9 ppb, which is less than the National Standard of 10 ppb.

The median Fe removal efficiency was increased from 79% to 97% and the percentage of filters meeting the National Standard of 0.5mg/L increased from 45% to 85%. The degree of improvement, however, was also different in the two villages. The median efficiency of iron removal in Don Xa only increased from 96.6% to 97.9% after installation of the improved IRP and the percentage of IRPs providing water that reached the National Standard (0.5 mg/litre) increased from 60 % to 84% largely as a result of the improvements to very poorly performing IRPs. The improvement in iron removal Dung Tien village was much greater, the median iron removal efficiency increased significantly from 59.3%% to 94.2% with installation of the improved IRPs and the percentage of wells that met the National Standard increased significantly from 31% to 86%.

Table 2. Efficiency of arsenic removal of the existing and the improved IRPs.

Village	**Number of sample**	**Efficiency in As removal**			**Median conc. of As (ppb) (min-max)**	
		Median percentage removal (%)	**Percentage of sample with As conc. (%)**		**Before filtration**	**After filtration**
			≤ 10 ppb	**≤ 50 ppb**		
Don Xa						
- *Existing IRPs*	42	87.1	71	100		
- *NIOEH Sand Filter*	50	97.8	96	100	64.3 (21.84 -155)	4.8 (0 – 17.60)
Dung Tien						
- *Existing IRPs*	49	50.9	41	100		
- *NIOEH Sand Filter*	44	64.1	66	100	24.7 (1.80 – 75.80)	8.9 (0.13 – 32.30)

Table 3. Efficiency of iron removal of the existing and the improved IRPs.

Village	Number of sample	Efficiency in Fe removal		Median conc. of Fe (mg/l) (min-max)	
		Median Percentage removal (%)	Percentage of sample with Fe conc. ≤0.5mg/l (%)	Before filtration	After filtration
Don Xa					
- *Existing IRPs*	40	96.6	60		
- *NIOEH sand filter*	50	97.9	84	6.25 (0.03 -14.15)	0.12 (0.03 – 2.90)
Dung Tien					
- *Existing IRPs*	38	59.3	31		
- *NIOEH sand filter*	50	94.2	86	3.76 (0.06 – 12.25)	0.16 (0.03 – 10.39)

User satisfaction with the improved IRPs

The user satisfaction survey was undertaken at the same time as the 2nd round of water quality testing. The evaluation survey was conducted in approximately 100 households in each village (selected in the pre-surveillance step), of which 50 households have the improved IRPs, showed a high degree of satisfaction with the improved IRPs:

- Approximately 80% of households installed with the improved IRP agreed that the water quality improved considerably in terms of transparency and taste.
- 67.6% of households said the improved IRPs are easier to operate compared with existing IRPs and 99% of households said the maintenance is simple and easy.
- Interviewing the households where the improved IRPs have not been installed found that 91% of the households wished to access and learn to operate the improved IRPs.

Conclusions

The use of household sand filters or Iron Reduction Plants (IRP's) to remove dissolved iron is widespread and well accepted in rural and sub-urban areas of Viet Nam particularly in the Red River area. Arsenic contamination has been recognized in the groundwater resources of the Red River Delta and Mekong Delta River regions of Viet Nam. Although the majority of the population in the two studied villages are aware of arsenic contamination of groundwater and the health risks are known, potential of existing iron reduction plants for arsenic removal is not widely known as yet.

A trial of the improved IRPs developed by NIOEH in two studied villages showed that the improved design significantly improved arsenic and iron removal and solved many of the disadvantages of the existing IRPs.

The evaluation survey showed that the improved IRPs of the NIOEH were well accepted by the community in two studied villages and that the improved IRPs are capable of producing water with less than 50 ppb. The majority, but not all IRPs could also meet the WHO Standard of 10ppb and lowered the median concentration of arsenic to less than 10 ppb.

Given the success of this trial in lowering arsenic levels, the degree of satisfaction expressed by the users, and the current widespread use of IRPs we feel the improved IRPs can now be expanded to larger operational use. This trial should not be considered as providing as the

completion of investigation of IRPs and a number of areas need further monitoring and assessment. The different efficiency of arsenic removal of the improved IRPs in two village suggests that expanded studies of the operation of the household level IRPs with regard to the effect of groundwater composition on the efficiency of arsenic removal should be undertaken. In addition, the IEC activities on clean water and sanitation as well as the training courses on the water treatment for the community play a very important role in increasing the efficiency of using the IRPs and should be expanded in future projects.

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