

ARSENIC IN DRINKING WATER

A CAWST Literature Summary
March 2009 Edition





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CAWST is a Canadian non-profit organization focused on the principle that clean water changes lives. Safe water and basic sanitation are fundamentals necessary to empower the world's poorest people and break the cycle of poverty. CAWST believes that the place to start is to teach people the skills they need to have safe water in their homes. CAWST transfers knowledge and skills to organizations and individuals in developing countries through education, training and consulting services. This ever expanding network can motivate individual households to take action to meet their own water and sanitation needs.

One of CAWST's core strategies is to make knowledge about water common knowledge. This is achieved, in part, by developing and freely distributing education materials with the intent of increasing its availability to those who need it most.

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Introduction

This literature summary provides short summaries of reports and research papers that have been conducted on arsenic in drinking water, including the following topics:

- Arsenic, occurrence, and its chemical specifications
- Health impacts of arsenic exposure
- Arsenic removal technologies and field and laboratory studies

All documents are categorized and listed in the following order:

1. Peer reviewed, published papers
2. High quality, unpublished papers
3. Informal reports (e.g. field studies, PowerPoint presentations, press releases, personal communication)

PART 1: ARSENIC, OCCURRENCE AND CHEMICAL SPECIFICATIONS

CATEGORY 1 – PUBLISHED PAPERS

Towards a More Effective Operational Response: Arsenic Contamination of Groundwater in South and East Asia Countries

Reference: World Bank and Water and Sanitation Program (2005). Towards a More Effective Operational Response: Arsenic Contamination of Groundwater in South and East Asia Countries. Washington, DC, USA.

Available at: <http://go.worldbank.org/TES9NHSIPO>

Volume 1 of the report shows the global and regional (South Asia) distribution of arsenic contamination and explains the mechanisms of arsenic mobilization. The highlights include:

- The concentration of arsenic in natural waters is usually below the WHO guideline value of 10 µg L⁻¹.
- Arsenic mobilization is particularly favored under reducing (anaerobic) conditions which can bring about the dissolution of iron oxides and the associated desorption of arsenic. Such conditions tend to occur in shallow aquifers in Quaternary strata underlying the region's large alluvial and deltaic plains: Bengal basin, Irrawaddy delta, Mekong valley, Red River delta, Indus plain, Yellow River plain.
- Uncertainty remains regarding the source, mobilization, and transport of the arsenic in aquifers.
- An important finding of aquifer surveys has been the large degree of spatial variability in arsenic concentrations, even over distances of a few hundred meters. Temporal variability also occurs.

See Paper 1 in Volume II for more information about:

- Arsenic distribution in South and East Asia
- Hydrochemistry of arsenic
- Groundwater management for drinking water and irrigation
- Recommendations for surveying and monitoring

Introduction to Ground Water Geochemistry

Reference: Hitchon B., E.H. Perkins and W.D. Gunter (1999) Introduction to Ground Water Geochemistry. Geoscience Publishing Ltd, Sherwood Park, Alberta, Canada

Available at (needs to be purchased):

www.sciencedirect.com/science?_ob=ArticleURL&_udi=B6VDG-42SPVJT-T&_user=10&_rdoc=1&_fmt=&_orig=search&_sort=d&view=c&_acct=C000050221&_version=1&_urlVersion=0&_userid=10&md5=5667cb1ee4d5ab66d449eea0f3da2ef9

The arsenic section provides detailed information on:

- General geochemistry
- Aqueous geochemistry

Source and Behaviour of Arsenic in Natural Waters

Reference: Smedley P.L. and D.G. Kinniburgh (2005). United Nations Synthesis Report on Arsenic in Drinking Water, Chapter 1. World Health Organization.

Available at: www.who.int/water_sanitation_health/dwq/arsenicun1.pdf

This document provides a detailed presentation of arsenic in natural waters and covers the following topics:

- Arsenic aqueous specifications
- Arsenic concentrations in different types of water
- Distribution of arsenic
- Distribution of arsenic species in water bodies
- Arsenic redox and kinetic
- Sources of arsenic
- Mineral interactions
- Global distribution of groundwater arsenic problems

Environmental Health and Human Exposure Assessment

Reference: Rasmussen, L. and K.J. Andersen (2005). United Nations Synthesis Report on Arsenic in Drinking Water, Chapter 2. World Health Organization.

Available at: www.who.int/water_sanitation_health/dwq/arsenicun2.pdf

This document explains the importance of assessing exposure to arsenic by testing arsenic level in drinking waters as well as in food. It says that the most toxic forms of arsenic are inorganic forms (dominant in surface and groundwater) while the organic forms are much less toxic (common in fish products). Since inorganic forms are present in drinking waters and food products, there is a need to measure and control the real amount of inorganic arsenic ingested by humans. The document well describes laboratory and field based analytical methods for arsenic testing in food and water.

Arsenic in Drinking Water

Reference: Petrusevski, B., S. Sharma, J.C. Schippers and K. Shordt (2007). Arsenic in Drinking Water, Thematic Overview Paper 1, International Water and Sanitation Centre, The Hague, Netherlands.

Available at: www.irc.nl/page/33113

Parts 4 and 5 of this Thematic Overview Paper provide detailed information about:

- Worldwide occurrence of arsenic
- Sources of arsenic
- Arsenic chemistry and specifications

PART 2: ARSENIC HEALTH IMPACTS

CATEGORY 1 – PUBLISHED PAPERS

Towards a More Effective Operational Response: Arsenic Contamination of Groundwater in South and East Asia Countries

Reference: World Bank and Water and Sanitation Program (2005). Towards a More Effective Operational Response: Arsenic Contamination of Groundwater in South and East Asia Countries. Washington, DC, USA.

Available at: <http://go.worldbank.org/TES9NHSIPO>

Volume 1 presents health impacts and data on population affected by arsenicosis in South and East Asia. However, there is still no clear picture of the epidemiology of arsenic. The study also recommends that arsenic removal measures should be considered within the wider context of safe water supply.

See the Paper 2 in Volume II for more information about:

- Arsenic health effects
- Recommended values
- National standards

Exposure and Health Effects

Reference: Abernathy, C. and A. Morgan (2005). United Nations Synthesis Report on Arsenic in Drinking Water, Chapter 3. World Health Organization.

Available at: www.who.int/water_sanitation_health/dwq/arsenicun3.pdf

This document provides a review of arsenic health effects. It explains the exposure risk to arsenic according to different factors such as type of drinking water, food ingested and occupation (i.e. exposure in industries). The two forms of arsenic (inorganic and organic) are described, as well as biomarkers of arsenic exposure: hair, nails, blood and urine.

Acute and chronic effects of arsenic consumption are presented. Acute effects or short-term effects are due to the ingestion of large doses of arsenic (from 2 g). Such ingestion usually results in symptoms within 30 to 60 minutes: metallic or garlic-like taste, burning lips, dysphagia and vomiting. Non fatal but serious acute effects have been observed in children after exposure to 0.7 mg of As₂O₃ (Cullen et al., 1995). Chronic effects or short term effects are also described, including: vascular diseases, cancer, diabetes, neurological effects and reproductive effects.

Arsenic in Drinking Water

Reference: Petrusovski, B., S. Sharma, J.C. Schippers and K. Shordt (2007). Arsenic in Drinking Water, Thematic Overview Paper 1, International Water and Sanitation Centre, The Hague, Netherlands.

Available at: www.irc.nl/page/33113

Part 2 of this Thematic Overview Paper provides detailed information about arsenic exposure, effects, forms and symptoms.

PART 3: ARSENIC REMOVAL TECHNOLOGIES

CATEGORY 1 – PUBLISHED PAPERS

Kanchan™ Arsenic Filter (KAF) Project in Nepal – MIT and ENPHO

Reference: Ngai, T., Shrestha, R., Dangol, B., Maharjan, M., and S. Murcott. (2007) Design for Sustainable development – Household drinking water filter for arsenic and pathogen treatment in Nepal. *Journal of Environmental Science and Health Part A.* (2007) 42, 1879-1888.

Abstract available at:

www.informaworld.com/smpp/content~content=a783095262~db=jour

Reference: Ngai, T., Dangol, B., Murcott, S., and R. Shrestha (2005). *Kanchan™ Arsenic Filter – A Simple Solution for Arsenic Problem*. Massachusetts Institute of Technology (MIT) and Environment and Public Health Organization (ENPHO). Kathmandu, Nepal. ISBN: 99946-34-22-4. First edition. April 2005.

Available at: http://web.mit.edu/watsan/worldbank_summary.htm

Reference: Ngai, T., Murcott, S., and R. Shrestha (2004). *Kanchan™ Arsenic Filter (KAF) – Research and Implementation of an Appropriate Drinking Water Solution for Rural Nepal*. Paper to the 9th Forum on Arsenic Contamination of Groundwater in Asia, Asia Arsenic Network and Research Group of Applied Geology. Japan. November 20-21, 2004.

Available at:

<http://web.mit.edu/watsan/Docs/Other%20Documents/KAF/Ngai%20%20Asia%20Arsenic%20Network%20symposium%20paper%202004.pdf>

This project was funded by the World Bank Development Marketplace Global Competition 2003, and implemented and evaluated by Massachusetts Institute of Technology (MIT) and the Environment and Public Health Organization (ENPHO) of Nepal.

Over 2,500 Kanchan™ Arsenic Filters were distributed by various agencies during the project period. Three versions of the KAF were distributed, namely concrete (over 900 units), Hilltake plastic (over 600 units), and Gem505 plastic (over 1,000 units). Almost all of these filters are used by households affected by arsenic contamination in their drinking water.

Two rounds of “blanket” monitoring of all existing filters were conducted. The first round monitoring took place between February 2004 to May 2004. The second round took place between Dec 2004 to February 2005. Parameters monitored during the first round including arsenic removal, iron removal, pH, flow rate, phosphate concentration, as well as GPS location, household demographic, filter cleaning frequency, filter usage rate, and user feedback.

Of the 966 filters tested for arsenic during the first round, over 95% of them were able to meet the Nepali arsenic interim standard of 50 ug/L. Average arsenic removal was in the range of 90-95%. The filters that showed unsatisfactory arsenic removal were later found to be defective - the filters were either installed incorrectly (e.g. use of incorrect sized

sand and gravel), or improperly operated and maintained by the users. The average iron removal efficiency was about 90-95%. A few filters were unable to significantly remove iron. They were later found to be defective in the installation process as well.

The arsenic monitoring results during the second round is unavailable.

Rapid Assessment of Household Level Arsenic Removal Technologies: Phase II Executive Summary

Reference: Sutherland, D. (2001). Rapid Assessment of Household Level Arsenic Removal Technologies: Phase II Executive Summary. Bangladesh Arsenic Mitigation Water Supply Project, Water Aid Bangladesh.

Available at: www.wateraid.org/documents/phs2execsum.pdf

Also available: Phase I report www.wateraid.org/documents/phs1report.pdf and Phase II full report www.wateraid.org/documents/phs2fullrpt.pdf

This report is the conclusion of a two phase project in Bangladesh. It is a comparative assessment of the performance and acceptability of the following seven arsenic removal technologies used at the household level:

- Alcan Enhanced Activated Alumina
- BUET Activated Alumina Filter
- DPHE/Danida Two Buckets System
- GARNET Home-made Filter
- Sono 3-Kolshi Method
- Steven's Institute Technology
- Tetrahedron Ion Exchange Resin Filter

The conclusions show that three following technologies reduced arsenic below the Bangladesh Drinking Water Standard (BDWS) of 0.05 mg/L: Alcan, BUET and Sono. The Steven's and Tetrahedron technologies performed well at many tubewells but failed to reduce arsenic below the BDWS.

The technologies do not appear to increase significantly any of the water parameters tested beyond BDWS (except for DPHE/Danida with manganese and aluminium). The study also shows that additional numbers of non-harmful bacteria result from using the technologies.

Regarding social acceptance, 63 household were asked to test and to rank the different technologies according to overall preference. Results show that Alcan came first because of high flow rate and low operation and maintenance requirements; and Sono came second because of its cheaper price, improved water taste and smell, and low maintenance.

Explanations of each technology are given in the Phase I Report. Information regarding waste management issues is covered in the Phase II Main Report.

High-level Arsenite Removal from Groundwater by Zero-Valent Iron

Reference: Lien, H.-L., and R.T. Wilkin (2004). High-level Arsenite Removal from Groundwater by Zero-Valent Iron. *ELSEVIER, Chemosphere* 59 (2005) 337-386, accepted October 2004.

Available at: www2.nuk.edu.tw/cee/Lien%20Publication/Chemosphere-2005-ASAP.pdf

The authors conducted batch and column studies to:

- Assess the effectiveness of zero-valent iron for arsenic remediation in groundwater
- Determine the removal mechanisms of arsenic
- Evaluate the implications of these processes with regard to the stability of arsenic and long-term remedial performance of the permeable reactive barrier (PRB) technology.

They prepared a high concentration arsenic solution (50 mg/L) with arsenite to simulate groundwater at a heavily contaminated site in the USA. The study indicates that the removal of arsenic is a two-step reaction with fast initial disappearance of arsenite followed by a slow subsequent removal process. Flow-through columns showed that arsenic removal rate constants decreased with time and arsenic breakthrough was observed in the column study. Arsenic removal capacity of zero-valent iron was determined to be approximately 7.5 mg As/g Fe.

Arsenic Removal with Iron(II) and Iron(III) in Waters with High Silicate and Phosphate Concentrations

Reference: Roberts, L.C., S.J. Hug, T. Ruettimann, MD.M. Billah, A.W. Khan, and M.T. Rahman (2003). Arsenic Removal with Iron(II) and Iron(III) in Waters with High Silicate and Phosphate Concentrations. *Environmental Science & Technology*, Web Published November 18, 2003, Vol. 38 No.1, 2004

Available at: <http://pubs.acs.org/doi/abs/10.1021/es0343205>

The authors compared the efficiency of arsenic removal with Fe(II) and Fe(III) from different simulated ground waters. They found that application of Fe(II) instead of the usually applied Fe(III) is advantageous, as oxidation of Fe(II) by dissolved oxygen causes partial oxidation of As(III) and iron(III) hydroxides formed from Fe(II) have higher sorption capacities. Addition of Fe(II) leads to better arsenic removal than Fe(III) and multiple additions of Fe(II) further improved the removal of As(III).

The study shows that lowering 500 µg/L As(III) to below 50 µg/L As(tot) in filtered water required >80 mg/L Fe(III), 50–55 mg/L Fe(II) in one single addition, and 20–25 mg/L in multiple additions. Moreover, with As(V), 10–12 mg/L Fe(II) and 15–18 mg/L Fe(III) was required. In the absence of Si and P, removal efficiencies for Fe(II) and Fe(III) were similar: 30–40 mg/L was required for As(III), and 2.0–2.5 mg/L was required for As(V).

The field study with 22 tube wells in Bangladesh shows that passive treatment (by iron) efficiently removed phosphate, but iron contents were generally too low for efficient arsenic removal.

A Biomaterial Based Approach for Arsenic Removal from Water

Al Rmalli, S.W., Harrington, C.F., Ayub, M. and P.I. Haris (2005). A Biomaterial Based Approach for Arsenic Removal from Water. The Royal Society of Chemistry 2005, Web Published March 7, 2005.

Available at: www.rsc.org/publishing/journals/EM/article.asp?doi=b500932d

This study presents data on using a biomaterial derived from non-living dried water hyacinth roots (*Eichhornia crassipes*) as a way to remove arsenite and arsenate from aqueous solution. Previous studies showed that removal of arsenite or arsenate employing living plants was not efficient.

For the laboratory tests, a 100 mg/L arsenic(III) stock solution and powder of washed and dried water hyacinth collected from a pond in Dhaka, Bangladesh were used. Results indicate that quantitative removal of arsenate from a solution at pH 6.0 was achieved in 60 minutes, using 30 mg/ml of dried root material leaving solutions of 200 µg/L of arsenate with 9.50 µg/L As(III) and 7.85 µg/L As(v).

The authors discuss how water hyacinth is considered to be an environmental “plague” throughout many tropical and subtropical parts of the world and in Bangladesh, and India, the plant grows abundantly in ponds, lakes and rivers. It has been reported that water hyacinth biomass can be produced at a rate of 160 to 1000 kg/hectare/day depending on the nutrient and temperature conditions.

In this study, the water hyacinth roots exposed to 1500 mgAs/L removed up to 50 mgAs/g of roots. Assuming an arsenic solution concentration of 1500 mg /L, approximately 30 grams of dried roots would be required to remove 1500 mg of arsenic from 1 litre of water over a 24 hour time period. Therefore, to treat 1000 litres of water 30 kg of roots would be required. This would be sufficient to provide the drinking water needs of a village consisting of hundreds of people.

The Removal of Arsenic from Potable Water

Reference: Pureflow© Filtration Systems Bulletin A2.9432.4

Available at: www.wateronline.com/download.mvc/Article-The-Removal-Of-Arsenic-From-Potable-W-0001

This document is a general presentation of different techniques used for arsenic removal. It explains briefly the processes of: reverse osmosis, granular ferric hydroxide (GFH), ion exchange, activated alumina, lime softening, coagulation-filtration, electrodialysis (ED) and electrodialysis reversal (EDR), nano-filtration and coagulation assisted membrane process (CAMP). The study recommends pilot testing at each well site before implementing a technology.

Towards a More Effective Operational Response: Arsenic Contamination of Groundwater in South and East Asia Countries

Reference: World Bank and Water and Sanitation Program (2005). Towards a More Effective Operational Response: Arsenic Contamination of Groundwater in South and East Asia Countries. Washington, DC, USA.

Available at: <http://go.worldbank.org/TES9NHSIPO>

Volume I, pp 37-49:

This Volume explains the different ways to mitigate arsenic in drinking water. It says that arsenic mitigation requires the following steps:

- The assessment of the scale of the problem (now and over time) which involves field testing, laboratory testing, and monitoring
- The identification of appropriate mitigation strategies involving technological, economic, and socio-cultural analysis of possible responses
- The implementation involving awareness raising and direct action by governments, donors, NGOs, and other stakeholders at local, national, and regional levels

The Volume explains that a simple cost-benefit methodology has been developed. It takes into account data limitations and provides decision makers with an approach for rapid assessment of the socioeconomic desirability of different mitigation policies under various scenarios. In particular, the methodology permits an analysis of options in order to choose between different approaches in dealing with:

- The risk that arsenic might be found in an area where a project is planned
- Options where a project's goal is arsenic mitigation

The Volume also discusses how to deal with the political environment of arsenic mitigation as arsenic has become a highly politicized topic in the international development community and within some affected countries.

Volume II, Paper II:

This Paper gives more information regarding arsenic mitigation in the context of the overall water supply sector and incentives to different stakeholders to address arsenic contamination.

Volume II, Paper III:

This Paper details arsenic removal techniques from drinking water and proposes alternative water supply options. It explains the functioning and compares the following treatments:

- Oxidation-sedimentation
- Coagulation-Sedimentation-Filtration
- Sorptive filtration
- Membrane techniques

Technologies for Arsenic Removal from Drinking Water

Reference: Feroze, A., Ashraf, A. and Z. Adeel (eds) (2001). Technologies for Arsenic Removal from Drinking Water. Bangladesh University of Engineering and Technology, Dhaka, Bangladesh and the United Nations University, Tokyo, Japan.

Available at: www.unu.edu/env/arsenic/Proceedings.htm

This is a compilation of papers presented at the International Workshop on Technologies for Arsenic Removal from Drinking Water. The most relevant papers are as follows.

Safe Water Technology for Arsenic Removal

Reference: Johnson, R. and H. Heijnen

Available at: www.unu.edu/env/arsenic/Han.pdf

This paper describes the functioning and summarizes the efficiency of technologies for arsenic removal, with special reference to experiences gained from field applications.

Removal of Arsenic from Drinking Water by Precipitation, Adsorption or Cementation

Reference: Robins, R.G, Nishimura, T. and P. Singh.

Available at: <http://www.unu.edu/env/arsenic/Robins.pdf>

This paper discusses common methods that have been applied commercially in the mineral industry for arsenic removal, recovery and disposal. The processes described include: precipitation, adsorption and cementation.

Evaluation of Performance of Sono 3-Kolshi Filter for Arsenic Removal from Groundwater Using Zero Valent Iron through Laboratory and Field Studies

Reference: Munir, A.K., Rasul, S.B., Habibuddowla, M., Alauddin, M., Hussam, A. and A.H. Khan.

Available at: <http://www.unu.edu/env/arsenic/Munir.pdf>

In this study, the '3-Kolshi' water filtration system was tested for its efficacy in removing arsenic, other trace metals and anions from the groundwater of Bangladesh.. About 6000 L of groundwater containing 80-1900 mg/L of arsenic was filtered. The filtered water contained about 10 mg/L metals. The filtration process was monitored for a year by measuring As (total), As (III), 23 other metals, 9 anions, pH, conductivity, temperature and flow rate.

The effect of flow rate on arsenic removal has been studied separately for three tube wells with arsenic concentration of 166-212, 211-238 and 1435-1642 mg/L (ppb) over a period of 4-8 months. The results demonstrate that the optimum flow rate is about 7 L/hour for achieving an arsenic concentration down to the level of 7-13 ppb from the initial level of about 200 ppb. The optimum flow rate is 8.4 L/hour for achieving an arsenic concentration of about 20 ppb from the initial level of 1600 ppb. Any possibility of pathogenic contamination during the use of the system as a household utility can be removed with a 4-litre hot water cycle, once in a week. This contamination is not inherent to the system.

Arsenic Removal from Groundwater by Household Sand Filters: Comparative Field Study, Model Calculations, and Health Benefits

Reference: Berg, M., Luzi, S., Trang, P.T. K., Viet, P.H., Giger, W. and D. Stuben. (2006) Arsenic Removal from Groundwater by Household Sand Filters: Comparative Field Study, Model Calculations, and Health Benefits Center for Environmental Technology and Sustainable Development (CETASD), Environ. Sci. Technol. 2006, 40, 5567-5573
Abstract available at: <http://pubs.acs.org/doi/full/10.1021/es060144z>

This field study tested the arsenic removal efficiencies of 43 household sand filters in rural areas of the Red River Delta in Vietnam. Raw groundwater from the same households and additional 31 tube wells were sampled to investigate arsenic co-precipitation with hydrous ferric iron from solution. From the groundwater containing 10-382 µg/L As, <0.1- 48 mg/L Fe, <0.01-3.7 mg/L P, and 0.05-3.3 mg/L Mn, similar average removal rates of 80% and 76% were found for the sand filter and co-precipitation experiments, respectively. Removal efficiencies of Fe, phosphate, and Mn were >99%, 90%, and 71%, respectively. Residual arsenic levels below 50 µg/L were achieved by 90% of the studied sand filters, and 40% were even below 10 µg/L. Fe/As ratios of g50 or g250 were required to ensure arsenic removal to levels below 50 or 10 µg/L, respectively. Phosphate concentrations >2.5 mg P/L slightly hampered the sand filter and co-precipitation efficiencies. The overall arsenic elimination was higher than predicted from model calculations based on sorption constants determined from co-precipitation experiments with artificial groundwater.

Arsenic in Drinking Water

Reference: Petrusevski, B., S. Sharma, J.C. Schippers and K. Shordt (2007). Arsenic in Drinking Water, Thematic Overview Paper 1, International Water and Sanitation Centre, The Hague, Netherlands.

Available at: <http://www.irc.nl/page/33113>

Parts 7, 8 and 9 of this Thematic Overview Paper provide detailed information about:

- Arsenic removal technologies: precipitation processes, adsorption processes, ion exchange and membrane filtration
- Arsenic removal systems: centralized arsenic removal systems, and household level point-of-use (POU) treatment systems
- Mitigating the arsenic problem: social and institutional aspects: awareness, sharing arsenic-free point sources, arsenic removal at household level, communal plant and institutional aspects

CATEGORY 2 – HIGH QUALITY UNPUBLISHED PAPERS**4 Week Daily Study on Total Coliform Removal of the KAF**

Reference: Sharma, D. (2005) Bachelor of Science Thesis, Kathmandu University, Nepal.

Available at: http://web.mit.edu/watsan/worldbank_summary.htm

- Installed 5 KAF (plastic Gem505 version) in the village of Kasiya of Nawalparasi districts of Nepal
 - 40 L of tube well water poured into each filter per day
 - Tested total coliform removal over a 4-week period using membrane filtration
 - 4 of the 5 filters achieved 96-100% total coliforms removal within 3 weeks since installation, of which one filter achieved 100% total coliform removal in just 9 days
 - The remaining one filter showed unsatisfactory total coliform removal, believed to be related to insufficient sand cleaning
 - The use of a clean storage container and good hygiene practice was found to improve filtered water quality
-

Can Iron and Arsenic Particles Migrate through the KAF Sand Layer?

Reference: Ghimire, B. (2005). Masters Thesis, Kathmandu University, Nepal

Available at: http://web.mit.edu/watsan/worldbank_summary.htm

- Two older concrete filters (12-months of operation) and two newer concrete filters (5-months of operation) in the Terai region of Nepal were studied
 - Sand samples were collected at every 4 cm interval from the top to the bottom of the sand layer
 - Arsenic and iron concentrations on these sand samples were tested using laboratory AAS method
 - Iron and arsenic appear to be effectively trapped on top of the fine sand
 - The iron and arsenic found in the region 5 cm or lower appear to be background concentration
 - The significantly lower arsenic-to-iron ratio at 5 cm depth or lower further confirms that arsenic-loaded iron particles are NOT migrating down through the sand media
 - The similarity in the profiles of older (12-months) and newer (5-months) filters suggest that the profiles may not change over time
-

Arsenic, Iron and Coliform Removal Efficiency of KAF (2004)

Prem Krishna Shrestha

Source: Masters Thesis, Tribhuvan University, Nepal

Available at: http://web.mit.edu/watsan/worldbank_summary.htm

- Tested arsenic, iron, and coliforms removal of the KAF Gem505 version through 3 rounds of study.
- Phase I laboratory study used groundwater from Kathmandu spiked with arsenic
- Phase II laboratory study used tap water from Kathmandu spiked with arsenic
- Phase III field study used naturally occurring arsenic-contaminated water in the Terai region of Nepal.
- Phase I study found that arsenic removal is less than 50% because of phosphate interference. Phosphate in the Kathmandu groundwater was 31 ppm.
- Phase II study found that arsenic removal is 85%. Phosphate concentration in Kathmandu tap water is only 0.4 ppm.
- Phase III study found that for naturally-occurring groundwater contaminated by arsenic, the arsenic removal is the best, at 91%.
- Laboratory study shows 94% removal of total coliform.

KAF Study on Effect of Air Space between the Resting Water and the Diffuser Basin

Pandey, S. (2004) Bachelors Thesis, Kathmandu University, Nepal

Available at: http://web.mit.edu/watsan/worldbank_summary.htm

- 4 KAF Hilltake versions located in a rural village of Nawalparasi district were studied
- Raw water of 250 ppb arsenic was poured into the filter for 4 cycles
- Filtered water was continually collected and monitored (one sample for every 2 L filtered)
- Found that there is no fluctuation in arsenic concentration within short timeframe
- The arsenic concentration is either non-detect or 10 ppb in majority of the filtered samples
- Research suggests that arsenic removal is happening at two locations – adsorption on iron nails in the diffuser box, and adsorption on iron particles accumulated on the fine sand

Performance Evaluation of the Arsenic Biosand Filter for Mitigation of Arsenic Contamination

Reference: Odell, N. (2004); US Peace Corps Volunteer, Parasi, Nepal.

Available at: http://web.mit.edu/watsan/worldbank_summary.htm

- Two concrete version of the KAF were studied in the rural town of Parasi
- One filter had 2.5 kg of iron nails, one filter had 5.0 kg of iron nails
- Over 95% of arsenic can be removed in the KAF with 5.0 kg of iron nails
- Study recommended the use of 5.0 kg of iron nails for effective arsenic removal
- 4-months is too short a time to observe any noticeable decrease in iron nails' arsenic adsorption capacity

Arsenic Biosand Filter: Design of an Appropriate Household Drinking Water Filter

Reference: Ngai, T. and S. Walewijk (2003). Final Report Submitted to Massachusetts Institute of Technology.

Available at: http://web.mit.edu/watsan/worldbank_summary.htm

- Pilot study -16 concrete filters in 4 rural villages (Nawalparasi and Rupendehi districts) installed in Oct 2002
- Evaluation conducted in Jan 2003 showed the following results:

Technical Indicator	Range	Average Results
Arsenic removal	87 to 96%	93%
Total coliform removal	0 to >99%	58%
<i>E. Coli</i> removal	0 to >99%	64%
Iron removal	>90 to >99%	>93%
Flow rate	4 to 23 L/hr	14 L/hr

Report on a Four-Month Performance Evaluation of the Cement Arsenic Biosand Filter (ABF) for Mitigation of Arsenic Contamination

Reference: Odell, N. (2004) Water Supply and Sanitation Division, Department of Water Supply and Sewerage, Ministry of Physical Planning and Works, Nepal.

The goal was to test the capacity, efficacy and lifetime of the ABF components. Two ABF were tested for 4 months in Nepal. The filters differed in characteristic: one had 2.5 kg of arsenic removal material (rusted iron nails) and the other had 5 kg of nails. The arsenic concentrations were charted of the tube well water against filtered water. Two different sources of water were use for each of the filters but their arsenic concentrations were close. Results show that the filter containing 5 kg of nails was more efficient to remove arsenic than the one containing 2.5 kg of nails.

CATEGORY 3 – INFORMAL REPORTS**Assessment of Five Technologies for Mitigating Arsenic in Bangladesh Well Water**

Reference: Ontario Centre for Environmental Technology Advancement. Environmental Technology Verification-Arsenic Mitigation, Arsenic Mitigation Based on an Agreement between the Governments of Canada and Bangladesh.

Available at:

www.physics.harvard.edu/~wilson/arsenic/remediation/ETVAM%20Poster.ppt

This presentation is a summary of a study done in Bangladesh on five arsenic removal technologies: MAGC/ALCAN, READ-F, SONO 45-25, TETRATREAT and AdsorpAs®-SIDKO. Five hydrogeologically different water sources were treated and arsenic concentrations in effluent and influent were tested. Results show that:

- All technologies removed arsenic to <50 ppb, providing at least 45 L in a 12 hour day
 - Most technologies did not meet their stated performance claims for media life
 - Groundwater composition (e.g. phosphate concentration) had a significant effect on the media life of a given technology.
 - None of the spent filter media can be classified as hazardous waste according to the US-EPA guideline
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PART 4: SUMMARY OF PUBLICATIONS**Table 1: Arsenic, Occurrence and Chemical Specifications**

Country	Author(s)	Organization(s)	Year	Category	Key Findings
-	-	World Bank	2005	Published Paper	<ul style="list-style-type: none"> • Distribution of arsenic contamination • Mechanisms of arsenic mobilization
-	Hitchon, B. Perkins, E.H. Gunter, W.D.	Geoscience Publishing Ltd	1999	Published Paper	<ul style="list-style-type: none"> • General geochemistry • Aqueous geochemistry
-	Smedley P.L. Kinniburgh, D.G.	WHO	2001	Published Paper	<ul style="list-style-type: none"> • Arsenic concentrations in different types of water • Distribution of arsenic • Arsenic redox and kinetic • Sources of arsenic • Mineral interactions • Global occurrence of arsenic in groundwater
-	Rasmussen, L. Andersen, K.J.	WHO	2001	Published Paper	<ul style="list-style-type: none"> • Most toxic forms of arsenic are inorganic (dominant in surface and groundwater) • Organic forms are much less toxic (common in fish products)
-	Petrusevski, B. Sharma, S. Schippers, J.C. Shordt, K.	IRC	2007	Published Paper	<ul style="list-style-type: none"> • Global arsenic occurrence • Sources of arsenic • Arsenic chemistry and specifications

Table 2: Arsenic Health Impacts

Country	Author(s)	Organization(s)	Year	Category	Key Findings
-	-	World Bank	2005	Published Paper	<ul style="list-style-type: none"> • 60 million people are at risk from high levels of naturally occurring arsenic in groundwater and 700,000 have been affected by arsenicosis • Arsenic removal measures should be considered within the wider context of safe water supply as waterborne diseases are as well a serious health issue
-	Abernathy, C. Morgan, A.	WHO	2005	Published Paper	<ul style="list-style-type: none"> • Review of arsenic health effects
-	Petrusevski, B., Sharma, S. Schippers, J.C. Shordt, K.	IRC	2007	Published Paper	<ul style="list-style-type: none"> • Exposure, effects, forms and symptoms

Table 3: Arsenic Removal Technologies

Country	Author(s)	Organization(s)	Year	Category	Key Findings
Nepal	Ngai, T. Dangol, B. Murcott, S.	Massachusetts Institute of Technology (MIT) ENPHO World Bank	2005	Published Paper	<ul style="list-style-type: none"> 95% of 966 filters met the Nepali arsenic interim standard Average arsenic and iron removal efficiency was in the range of 90-95% 85.3% of households used the filter after 1 year
Bangladesh	Sutherland D.	Water Aid Bangladesh	2001	Published Paper	<ul style="list-style-type: none"> 3 of the 7 technologies tested on 63 wells reduced arsenic below the Bangladesh Drinking Water Standard (BDWS) of 0.05 mg/L: Alcan, BUET and Sono
-	Lien, H.-L. Wilkin, R.T.	ELSEVIER, Chemosphere 59 (2005) 337-386	2004	Published Paper	<ul style="list-style-type: none"> Arsenic removal is a two-step reaction with fast initial disappearance of arsenite followed by a slow subsequent removal process Arsenic removal capacity of zero-valent iron was determined to be approximately 7.5 mg As/g Fe
Bangladesh	Roberts, L.C. Hug, S.J. Ruettimann, T. Billah, MD.M. Khan, A.W. Rahman, M.T.	Environmental Science & Technology	2003	Published Paper	<ul style="list-style-type: none"> Application of Fe(II) instead of the usually applied Fe(III) is advantageous to remove arsenic Field study with 22 tubewells shows that passive treatment (by iron) efficiently removed phosphate, but iron concentration was generally too low for efficient arsenic removal
Bangladesh	Al Rmalli, S.W. Harrington, C.F. Ayub, M. Haris, P.I.	The Royal Society of Chemistry	2005	Published Paper	<ul style="list-style-type: none"> Quantitative removal of arsenate from a solution at pH 6.0 was achieved in 60 minutes, using 30 mg/ml of dried root material leaving solutions of 200 µg/l of arsenate with 9.50µg/l As(III) and 7.85µg/l As(v)
-	-	Pureflow© Filtration Systems Bulletin A2.9432.4	-	Published Paper	<ul style="list-style-type: none"> General information on reverse osmosis, granular ferric hydroxide (GFH), ion exchange, activated alumina, lime softening, coagulation-filtration, electrodialysis (ED), electrodialysis reversal (EDR), nano-filtration and coagulation assisted membrane process (CAMP)
-	-	World Bank	2005	Published Paper	<ul style="list-style-type: none"> Different ways to mitigate arsenic in drinking water Mitigation in the context of the overall water supply sector and incentives to different stakeholders Explanation and comparison of the following: <ul style="list-style-type: none"> Oxidation-sedimentation

Country	Author(s)	Organization(s)	Year	Category	Key Findings
					<ul style="list-style-type: none"> - Coagulation-Sedimentation-Filtration - Sorptive filtration - Membrane techniques
Several	Feroze, A. Ashraf, A. Adeel, Z.	Bangladesh University of Engineering and Technology	2001	Published Paper	<ul style="list-style-type: none"> • Compilation of papers presented at the International Workshop on Technologies for Arsenic Removal from Drinking Water
Vietnam	Berg, M., S. Luzi, P.T. K. Trang, P.H. Viet, W. Giger and D. Stuben.	Center for Environmental Technology and Sustainable Development	2006	Published Paper	<ul style="list-style-type: none"> • Efficiency of sand filters to remove arsenic by co-precipitation with hydrous ferric iron
-	Petrusevski, B., Sharma, S. Schippers, J.C. Shordt, K.	IRC	2007	Published Paper	<ul style="list-style-type: none"> • Arsenic removal technologies • Arsenic removal systems • Mitigating the arsenic problem
Nepal	Sharma, D.	Kathmandu University	2005	Unpublished Paper	<ul style="list-style-type: none"> • Removal of total coliforms in 5 filters showed 4 out of 5 filters removed 96-100%
Nepal	Ghimire, B.	Kathmandu University	2005	Unpublished Paper	<ul style="list-style-type: none"> • Iron and arsenic appear to be effectively trapped on top of the fine sand in 4 filters (2 old, 2 new)
Nepal	Shrestha, PK	Kathmandu University	2004	Unpublished Paper	<ul style="list-style-type: none"> • Arsenic removal is the best for naturally-occurring groundwater contaminated with arsenic at 91% • Laboratory study shows 94% removal of total coliform
Nepal	Pandey, S.	Kathmandu University	2004	Unpublished Paper	<ul style="list-style-type: none"> • Arsenic removal is occurring at two locations – adsorption on iron nails and on iron particles accumulated on the fine sand
Nepal	Odell, N.	US Peace Corps	2004	Unpublished Paper	<ul style="list-style-type: none"> • Over 95% of arsenic can be removed in the KAF with 5.0 kg of iron nails • Recommend use of 5.0 kg iron nails
Nepal	Ngai, T. Walewijk, S.	MIT	2003	Unpublished Paper	<ul style="list-style-type: none"> • Arsenic removal on average 93% in 16 pilot filters • Iron removal - >93% on average
Bangladesh	-	Ontario Centre for Environmental Technology Advancement	-	Informal Report	<ul style="list-style-type: none"> • MAGC/ALCAN, READ-F, SONO 45-25, TETRATREAT and AdsorpAs@-SIDKO • All technologies removed arsenic to < 50 ppb, providing at least 45 L in a 12 hour day