



ARSENIC PRIMER

Guidance on the Investigation &
Mitigation of Arsenic Contamination



World Health
Organization



for every child

ARSENIC PRIMER¹

Guidance on the Investigation &
Mitigation of Arsenic Contamination





ACKNOWLEDGMENTS

The 2018 update to the 2008 version of the UNICEF Arsenic Primer has been a collaborative effort by the Water and Environmental Section of UNICEF Programme Division and the Water, Sanitation, Hygiene Division of WHO.

The authors from UNICEF and WHO responsible for the updating of the Primer:

Cecilia Scharp - Water, Sanitation and Hygiene Section, UNICEF Headquarters
Hrachya Sargsyan - Water, Sanitation and Hygiene Section, UNICEF Headquarters
Fiorella Polo - Water, Sanitation and Hygiene Section, UNICEF Headquarters
Richard Johnston - Technical Officer, Water, Sanitation, Hygiene and Health Unit, WHO
Jennifer De France - Technical Officer, Water, Sanitation, Hygiene and Health Unit, WHO

Overall Guidance & Direction:

Sanjay Wijesekera - Associate Director, WASH, UNICEF Programme Division.

Contributors:

The contribution of Peter Ravenscroft - Water Quality Consultant in the drafting the document and Mark Ellery- Water & Sanitation Consultant, Fiona Baker - Knowledge Management Consultant in the finalising of the document are gratefully acknowledged.

Consultations with sector experts in the development of the document included:

UNICEF Headquarters:

Tom Slaymaker– Senior Statistics & Monitoring Specialist,
Robert Bain–Statistics & Monitoring Specialist

UNICEF Country Offices:

Dara Johnston–Chief WASH, UNICEF Bangladesh,
Andrew Trevett–Chief WASH, UNICEF Kenya,
Michael Forson–WASH Specialist, UNICEF Sudan,
Aidan Cronin–Chief WASH, UNICEF Indonesia,
Peter Harvey–Chief WASH, Supply Division

Special Thanks

Feedback on drafts of this document were gratefully received from Robert Bain–Statistics & Monitoring Specialist, UNICEF Research and Policy Division; Manish Wasuja–WASH Specialist, UNICEF India; Omar El Hattab–WASH Regional Advisor, UNICEF MENA; Kitka Goyol–Chief WASH, UNICEF Pakistan; Boluwaji Onabolu-WASH Specialist, UNICEF Bangladesh, Angella Rinehold–WSH/PHE, WHO, John Fawell, Cranfield University.

¹ The term “primer” refers to an elementary textbook or manual that serves provides a base layer of information for a particular subject of study

CONTENTS

A	Preface	
	Ted Chaiban Director of Programme Division, UNICEF	7
	Introduction	8
B	Understanding the Problem – Sources and Consequences of Arsenic Exposure	
	B1 Health Impact of Arsenic Exposure	13
	B2 Occurrence of Arsenic in Groundwater and Surface Water	19
	B3 Food and Other Sources of Arsenic Exposure	23
C	Bringing about Solutions - Reducing Exposure to Arsenic in Drinking Water	
	C4 Frameworks for Safe Water and Risk Prioritization	27
	C5 Assessing and Managing Arsenic Hazard Information	35
	C6 Measuring Arsenic in Drinking Water	41
	C7 Selecting Barriers (Provision of Safe Water)	47
	C8 Communications and Behaviour Change	53
	C9 Operational Monitoring and Surveillance	57
	C10 Water Resources Management and Sustainability	60
D	Bringing About Solutions - Multi-Sectoral Responses To Arsenic Contamination	
	D11 Health Sector - Palliative Treatment	63
	D12 Food, Agriculture and Nutrition	65



Ted Chaiban

Director of Programme Division, UNICEF



The Sustainable Development Goals for water prioritize universal access to drinking water and the sustainable management of water resources to ensure that no one is left behind. In particular SDG 6.1 represents greater focus on the safety of drinking water in seeking “by 2030, achieve universal and equitable access to safe and affordable drinking water for all.” The recognition that an improved water source may not always ensure a safe drinking-water service has resulted in the establishment of indicators for measuring access to ‘safely managed drinking-water services.’ These include safety, as measured by compliance with microbiological and priority chemical standards. Amongst the most harmful chemicals are arsenic and fluoride, because of their serious health impacts and the large populations exposed. A safely managed drinking-water service is not only free from contamination but is also set within an institutional framework where the demand, supply and regulation of drinking water ensure the mitigation of any potential risks to safe human consumption. Given the various routes through which arsenic in the ground water may be mediated, a failure to safely manage water resources can potentially compromise the achievement of food security (SDG 2) contributing to a failure to ensure healthy lives (SDG 3).

The ‘*Framework for Safe Drinking-water*’ described in the WHO *Guidelines for Drinking-water Quality* provides a means for integrating the implications of arsenic exposure beyond the water sector into the management of the consequences of arsenic exposure within the health sector. These guidelines promote the establishment of national health-based targets; the development of water safety plans by water suppliers to ensure that all potential risks to drinking-water safety are identified and mitigated; and the independent surveillance to ensure that standards are being met; being adapted to local priorities, environmental conditions, economic status and institutional capacities. This provides the conceptual basis for the management of arsenic risks within the water sector and beyond.

The Arsenic Primer originally published by UNICEF in 2008 has been updated to reflect the changes associated with the Sustainable Development Goals, the framework for safe drinking water and the experience over the last decade in the implementation of arsenic mitigation programmes. This revised primer has been developed by UNICEF in collaboration with WHO to provide practical advice for the staff of UN agencies but is also applicable for government counterparts and development workers responding to the challenge of arsenic contamination of the drinking water.

A1

Background

In the 1980s, it came to light that groundwater in the state of West Bengal in India was contaminated with naturally occurring arsenic at concentrations that were causing illness and death and threatening the health of millions of people. In the 1990s, it became clear that groundwater in other parts of India and Bangladesh were similarly or even more severely affected. Testing programmes showed that tens of millions of people were at risk in the region, leading to the abandonment of the assumption that groundwater was generally “safe” for human consumption. As the testing for arsenic was expanded into other countries it became apparent that arsenic contamination extended across large parts of South, Southeast and East Asia. It was also recognized that the discovery of arsenic in the groundwater in Taiwan, Hungary, Chile and Argentina potentially contributed to the underlying health

problems that occurred in these countries. Arsenic at concentrations exceeding the World Health Organization (WHO) guideline value have now been detected in the groundwater in many countries throughout the world, with new discoveries still coming to light in many areas that have never been properly tested.

In 2009, over 140 million people around the world were estimated to be exposed to arsenic in drinking water at concentrations above the WHO guideline value of 10 ppb (Ravenscroft, 2009). This number may be an underestimation as some countries have not screened for arsenic or have only measured the population exposed to more than 50 ppb, the former WHO guideline value. These people are at risk of the serious long-term health impacts of chronic arsenic poisoning that may continue to increase even as their exposure is reduced, since some of the health effects are non-reversible and have long latency periods.

While the mitigation of exposure to arsenic contamination is progressing, particularly in Bangladesh, India, China and some South and Southeast Asian countries, the experiences (positive and negative) offer considerable lessons for future mitigation efforts. While some countries have considerable experience in arsenic mitigation, other countries are only now discovering the presence of arsenic contamination in groundwater. This Primer draws on the experience gained from ongoing mitigation programmes and is intended as a guide for countries either unaware of arsenic contamination or at earlier stages in the mitigation process. It can also serve as an updated resource for countries in a later stage of mitigation.

About the Primer, Target Audience and Scope

The first edition of the Arsenic Primer was published by UNICEF in 2008 to assist country offices in responding to an emerging awareness of the global arsenic contamination issue. Over the last decade much has been learned about the extent, consequences and options for mitigating arsenic contamination in the drinking water. In this new edition, UNICEF and

Chapter Summary:

- Arsenic is a notorious poison that causes many illnesses and can be fatal.
- An estimated 140 million people in at least 70 countries are exposed to arsenic in drinking water above WHO's guideline value.
- The Primer is designed for UN agencies, governments and partners in responding to the discovery of arsenic in drinking water.
- The primer is designed to mitigate and help balance the risks of arsenic contamination versus other potential contaminants.



WHO have collaborated to update the previous document to reflect the experience over the last decade and to meet the needs of a broader audience.

This Arsenic Primer provides information on arsenic contamination and advice to support mitigation, from testing methods to the treatment of arsenic patients, from the water sector to the health and agriculture sectors. It is intended primarily for the staff of UN agencies but is also applicable for government counterparts and field workers responding to the problem of arsenic contamination in the drinking water. The Primer seeks to provide a basic understanding of all aspects of arsenic contamination and its mitigation to assist water sector professionals to develop country-specific arsenic monitoring and mitigation programmes.

Three aspects of arsenic contamination deserve a special mention at the outset and will be further detailed within the Primer.

- *The first is latency:* the effects of arsenic on health take years or even decades to develop and even longer until the impacts on health are detected. So even if the risks of arsenic exposure were detected and completely mitigated, the health impacts in the form of skin conditions, cancers and cardiovascular diseases might continue for decades requiring ongoing, if declining, health care and social welfare.
- *The second is communication:* the discovery of natural arsenic poisoning comes as a shock to society and is frequently met with disbelief and denial. Managing information, raising knowledge and changing individual behaviours and social norms at all levels is essential to mitigate arsenic-contamination risks.
- *The third is food:* wherever there is risk of arsenic exposure from water there is an increased risk of arsenic exposure from the environment primarily via food. This means that action on drinking water alone may not be sufficient to reduce people's arsenic exposure to safe levels.

Box 1

Units, Guidelines and Standards

Arsenic concentrations are reported in different units. Here we use ppb (parts per billion), which is equivalent to $\mu\text{g/L}$ (micrograms per litre). Sometimes, arsenic is reported as ppm (parts per million) or mg/L (milligrams per litre). The numbers are simply a thousand times smaller so that 10 and 50 ppb or $\mu\text{g/L}$ become 0.01 and 0.05 ppm or mg/L.

The World Health Organization's *Guidelines for Drinking-water Quality* include guideline values (GVs) for a range of drinking-water contaminants including arsenic. GV is a type of health-based target defined using risk factor analysis. These GV is intended to assist countries to set their own standards for drinking-water contaminants. This means that national standards may differ from the GV of WHO to account for local circumstances.

In 1991, the 50 ppb (parts per billion) arsenic GV was provisionally lowered to 10 ppb. This GV is still provisional because of uncertainties of health impacts at low exposure as well as practical limitations regarding detection and removal.

National standards for arsenic vary with many countries adopting the WHO GV while others such as Bangladesh have adopted a standard of 50 ppb. While India has adopted a standard of 10 ppb it does permit a relaxation to 50 ppb in the absence of any alternate source.

Predicting the Extent of Arsenic in Groundwater

In 2008, UNICEF commissioned a study to predict the likely global extent of arsenic contamination of groundwater as a companion to the original Primer. In 2011, researchers at the EAWAG (in Switzerland) published global risk maps based on a different algorithm. Both models predict potential occurrence of arsenic in groundwater and correctly identified areas where arsenic contamination has subsequently been found. Both sets of predictions are publicly

accessible at www.gapmaps.org which is an ideal starting point for those concerned about the possibility of arsenic contamination in a particular country or region.

Framework for Safe Drinking Water and Use of the Arsenic Primer

The framework for safe drinking-water (FSW; WHO, 2017) advocates for a preventive, risk-based 'catchment to consumer' approach to ensure drinking-water safety. This Primer seeks to ensure that a response to arsenic contamination is dealt with in a way that respects the contamination risks associated with the safe management of drinking water (and sanitation). At the heart of this approach is an attempt to quantify both microbial and chemical risks to strike an optimum balance given the available resources in managing these risks.

The initial discovery of an arsenic contamination problem has often initially led to short-term intensive arsenic-specific mitigation programs. Over time and with experience, many countries have moved towards balancing the risk of arsenic exposure with other chemical as well as microbial risks to ensure that sectoral goals are met and that the most important risks are addressed. Of note is the possibility of risk substitution, where options to reduce exposure to arsenic contamination can increase the exposure to microbial contamination.

The framework for safe drinking water proposes: the establishing of health-based targets (i.e. the parameters and limits included in drinking-water standards); the identifying and managing of risks within water-supply systems (i.e. water safety plans); and the independent surveillance of the effectiveness of these risk-management measures in achieving health-based targets. This broad framework seeks to enable the chemical and bacterial drinking-water safety risks to be managed and balanced against other potential routes of exposure that undermine public health. This version of the Primer prioritizes the framework for safe drinking water in assessing and managing the risks of arsenic in drinking water.

Primer structure

The primer is structured into four modules organized as follows:

- **Module A:** *Introduction* offers the context and background to arsenic contamination for updating the 2008 Arsenic Primer.
- **Module B:** *Understanding the problem* (chapters B1-B3) provides a foundation to understand the science of arsenic; describes the effects of prolonged exposure on human health; and details how arsenic exposure can occur from water, food and even airborne sources.
- **Module C:** *Reducing exposure to arsenic in drinking water* (chapters C4-C10) is the core of the Primer detailing the formulation of a response to quantify and mitigate the effects of arsenic exposure in drinking water. This commences with the framework for safe drinking water (C4) to establish health-based targets, water safety plans and surveillance. The identification of risks is detailed in the chapters on hazard-mapping investigations to establish the extent of arsenic contamination (C5) and a description of the options for measuring arsenic in drinking water (C6). The mitigation of those risks includes a description of appropriate technology options that provide protection against arsenic contamination (C7) and the communications necessary to promote the behaviour change measures to ensure that technology options are meaningfully adopted (C8). The monitoring by water suppliers and surveillance agencies necessary to ensure that actions in mitigating arsenic deliver the intended results (C9) is followed by a description of potential impact on the sustainability of water resources and the need for institutional coordination (C10).
- **Module D:** *Multi-sectoral responses to arsenic contamination* (chapters D11-D12) extends the scope of the original Primer to explain how responses to contaminated drinking water need to be integrated with actions by the health sector, as well as the agriculture and nutrition sectors.

General Resources on Arsenic

The following publications and websites are recommended as general resources on arsenic contamination and mitigation. They have been regarded as resources for most of the chapters that follow and therefore will not always be specifically cited.

Publications:

Bhattacharya, P., D.A. Polya and D. Jovanovich Eds. (2017) Best Practice Guide on the Control of Arsenic in Drinking Water. IWA. <https://www.iwapublishing.com/books/9781843393856/best-practice-guide-control-arsenic-drinking-water>

IRC (2007) Thematic Overview Paper 17 'Arsenic in Drinking Water'. <http://www.ircwash.org/resources/arsenic-drinking-water-0>

Johnson, C.A. and A. Breitzler Eds. (2015). Geogenic Contamination Handbook. Swiss federal Institute of Aquatic Science and Technology (EAWAG). <http://www.eawag.ch/en/research/humanwelfare/drinkingwater/wrq>

Joint FAO/WHO Expert Committee on Food Additives (2011). Safety evaluation of certain contaminants in food. WHO Food Additives Series No. 63, 2011. http://apps.who.int/iris/bitstream/10665/44520/1/9789241660631_eng.pdf

Ravenscroft, P., H. Brammer and K.S. Richards (2009) Arsenic Pollution: A Global Synthesis. Wiley-Blackwell. <http://onlinelibrary.wiley.com/book/10.1002/9781444308785>

United Nations ACC Sub-Committee on Water Resources (2001) United Nations Synthesis Report on Arsenic in Drinking Water, New York, WHO <https://www.ircwash.org/resources/united-nations-synthesis-report-arsenic-drinking-water>

UNICEF (2008) Water Quality Handbook http://www.unicef.org/wash/files/WQ_Handbook_final_signed_16_April_2008.pdf.

World Bank/WSP (2005) Arsenic Contamination of Groundwater in South and East Asia: Towards a More Operational Response. Volume 1: Policy Report and Volume 2: Technical Report. Washington: World Bank http://siteresources.worldbank.org/INTSAREGTOPWATRES/Resources/ArsenicVolII_PaperI.pdf http://siteresources.worldbank.org/INTSAREGTOPWATRES/Resources/ArsenicVolII_WholeReport.pdf

WHO (2017) Guidelines for Drinking Water (4th edition incorporating the first addendum) http://www.who.int/water_sanitation_health/publications/drinking-water-quality-guidelines-4-including-1st-addendum/en

Websites:

Groundwater Assessment Platform (GAP) <http://www.gapmaps.org>

Wilson, Richard et al. (2008). Chronic Arsenic Poisoning: History, Study and Remediation (Harvard University arsenic project website) http://www.physics.harvard.edu/~wilson/arsenic/arsenic_project_introduction.html

Arsenic Crisis Information Centre <http://bicn.com/acic> World Health Organization (WHO) http://www.who.int/water_sanitation_health/water-quality/en



UNDERSTANDING THE PROBLEM

Sources and Consequences of Arsenic Exposure

B1

Health Impact of Arsenic Exposure

Introduction

Arsenic is a systemic poison, the continued ingestion of which can lead to a wide range of diseases and premature death. Symptoms of arsenic exposure include skin lesions; cancers of the skin, lung and bladder; and gastro-intestinal, cardio-vascular and pulmonary conditions. Chronic arsenic poisoning also inhibits the cognitive development of children. Arsenic exposure is remarkable for the long latency before exhibiting symptoms potentially even occurring decades after exposure has ceased (e.g. symptoms have even been known to emerge in adults due to exposure *in utero* or during early childhood). As there is no cure for chronic arsenic poisoning and because the effects of poisoning are dose-dependent and continue to develop over time, reducing exposure as soon as possible is the most important measure to protect health.

Chapter Summary:

- The effects of arsenicosis include skin lesions, cardiovascular disease, various cancers, stillbirths and negative impacts on cognitive development in children.
- Arsenic patients are often subject to gross discrimination: children may be excluded from education, women may be excluded from marriage or forced to divorce and may be prevented from working.
- Arsenic exposure is remarkable for its long latency period, sometimes decades after exposure, before symptoms of arsenicosis appear.
- The risk of detrimental arsenic health effects increases with arsenic concentration and earlier age of exposure potential and contaminants.



Box 2 Myths and Misconceptions about Arsenic

Myth 1: Skin lesions are indicative of those affected by arsenic poisoning. Most clinical victims of arsenic poisoning do not develop skin lesions or arsenicosis. This may mean that they do not associate their current or future health condition with arsenic poisoning.

Myth 2: Arsenic in food is less harmful. This is partially true, especially in fish and seafood which contain arsenic primarily in its organic form, which is much less toxic than the inorganic form which dominates in ground water. However, arsenic in staple foods like rice is typically 70-90% inorganic and may contribute higher amounts of harmful arsenic to human diets than water.

Myth 3: National water quality standards are safe. The WHO guideline value of 10 ppb is based on practical considerations rather than health implications and is considered provisional. National standards should reflect an acceptable

level of risk to the local conditions and capacities but do not guarantee complete safety (see Box 3 for more information).

Myth 4: Safe wells will remain safe. Although many wells in arsenic-contaminated areas do remain safe, a minority can become contaminated over a period of months to a few years. Periodic re-testing is essential as it also enables testing errors to be identified.

Myth 5: Providing safe water will end arsenic poisoning and arsenic-related disease.

Drinking or cooking water is usually the primary source of exposure to inorganic arsenic but arsenic from irrigation water can remain in the soil and be transferred into crops and food. Due to long latency periods associated with arsenic, cancers and other health problems can still occur many years after exposure has ceased.

The term *arsenicosis* is widely used to refer to any kind of arsenic-related disease but it has a specific clinical definition that can lead to confusion and serious underestimation of the significance of chronic arsenic poisoning. In the public mind, “arsenicosis” is a catch-all term for the effects of arsenic, but for clinicians in South Asia “arsenicosis” is a diagnostic term associated with a combination of specific skin conditions and water analysis. This means that the number of “arsenicosis patients” will be significantly less than the number of people suffering from chronic arsenic poisoning. As Ahsan and Steinmaus state “the vast majority of diseases and deaths among exposed populations do not show classic dermatological manifestations” (Ahsan, 2013). This means that arsenic-induced cardiovascular and cancer related morbidity and mortality are often not attributed to arsenic poisoning.



Picture 1: Arsenicosis Patient in Bangladesh

Source: UNICEF Bangladesh (2012)

Not everyone exposed to excess arsenic will develop an arsenic-related disease. Arsenic is a *hazard* (i.e. something that can cause harm) and the likelihood that this exposure will lead to health effects and the severity of the health effects is the *risk*. The *risk* of detrimental arsenic health effects increases with arsenic concentration and earlier age of exposure. There are also natural contributory factors such as genetic susceptibility, in addition to modifiable factors such as diet and smoking that increase the susceptibility to detrimental health effects.

Box 3

Setting the Guideline Value for Arsenic²

Since 1993 WHO has set a provisional guideline value of 10 parts per billion (ppb) for arsenic in drinking water.

Health-based values for genotoxic carcinogens are conventionally set at a benchmark of 1 in 100,000 excess cancer cases given a lifetime exposure. The cancer risk estimate for low-dose exposure to genotoxic carcinogens apply a conservative model, assuming a linear, non-threshold approach and incorporating a number of other usually conservative assumptions, because of the practical epidemiological difficulty of quantifying thresholds or non-linear responses. Based on this approach, the maximum likelihood estimates for bladder and lung cancer for populations in the USA exposed to 10 ppb arsenic in drinking water are, respectively, 12 and 18 per 10,000 population for females and 23 and 14 per 10,000 population for males. The actual risk of cancer would be significantly lower if there is a threshold or arsenic exhibits a non-linear dose response at low doses.

The cancer risk model would suggest a health-based value below 10 ppb. However there remains considerable uncertainty over the actual risks at low concentrations and available data on mode of action do not provide a biological basis for using either linear or non-linear extrapolation. Further, the removal of arsenic to concentrations below 10 ppb is difficult in many circumstances and the practical quantification limit for arsenic is in the region of 1–10 ppb. In view of the practical difficulties in removing arsenic from drinking water, particularly from small supplies, and the practical quantification limit for arsenic, the guideline value of 10 ppb is designated as provisional. However, given the possibility of adverse health impacts at low exposures, every effort should be made to keep concentrations as low as reasonably practicable and below the guideline value when resources are available.

²See http://who.int/water_sanitation_health/water-quality/guidelines/chemicals/arsenic.pdf?ua=1

Setting a standard for arsenic in drinking water involves *risk management*: choosing a point on a spectrum of risk. Water-quality standards and regulations for arsenic issued by governments do not necessarily represent a threshold between safe and unsafe water, but rather what is considered an acceptable level of exposure given the socio-economic scenario of the country (see Box 3). This means that the public-health priority should be to reduce exposure for the millions of people around the world who are still exposed to excessive arsenic concentrations (e.g. 100 ppb or more). Where it is difficult to achieve the guideline value, Member States may set higher limits or interim values as part of an overall strategy to progressively reduce risks considering local circumstances, available resources and the risks from low arsenic sources that are microbiologically contaminated.

Skin Lesions

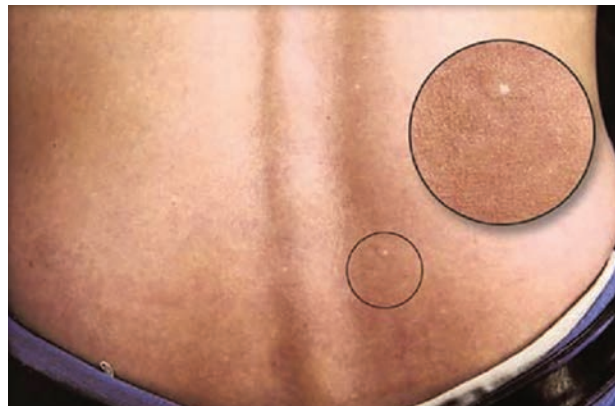
The most widely recognized signs of chronic arsenic poisoning are *melanosis* (changes in skin colour) and *keratosis* (hardening and thickening of skin into nodules).

Melanosis: occurs mainly on unexposed parts of the body such as the chest, abdomen, back, arms, legs, hands and feet. Small patches of skin, from the size of a pinhead to the size of a grain of corn, either become darker (hyper-pigmentation) or lighter (hypo-pigmentation or leucomelanosis) than the surrounding skin. Raindrop pigmentation patterns are generally characteristic of very high levels of exposure to arsenic.

Keratosis: and the more advanced form hyperkeratosis, occurs mainly on the palms of the hands and the soles of the feet and is approximately half as common as melanosis. Keratosis initially presents as small nodules that can be felt when touched, that can grow and coalesce into wart-like bumps in the latter hyperkeratosis. As the nodules thicken, the skin can become cracked causing pain and increasing the vulnerability to secondary infections and potentially debilitation.

The risk of skin lesions increases with the duration and concentration of arsenic exposure, with melanosis generally preceding keratosis. At high exposure levels, melanosis and keratosis can develop in a few years but in most cases skin lesions take 10 to 20 years to exhibit. However, lesions can develop in small children, reflecting their greater susceptibility to exposure *in utero* and early life. While skin lesions have been reported at concentrations below 50 ppb (though this may be due to an incomplete exposure history) the prevalence rises sharply at exposures above levels of 300 ppb.

In any given situation, men are more likely than women to develop skin lesions. Skin lesions tend to appear in clusters of people within a village, potentially reflecting localized hot spots (i.e. a highly contaminated well shared by a single household) or genetic factors or nutritional factors (i.e. malnourished people are estimated to be twice as likely to develop skin lesions).



Picture 2: Melanosis and Leucomelanosis on Back

Source: Endemic Arsenicosis in China



Picture 3: Hyperkeratosis on the Palm

Source: Endemic Arsenicosis in China

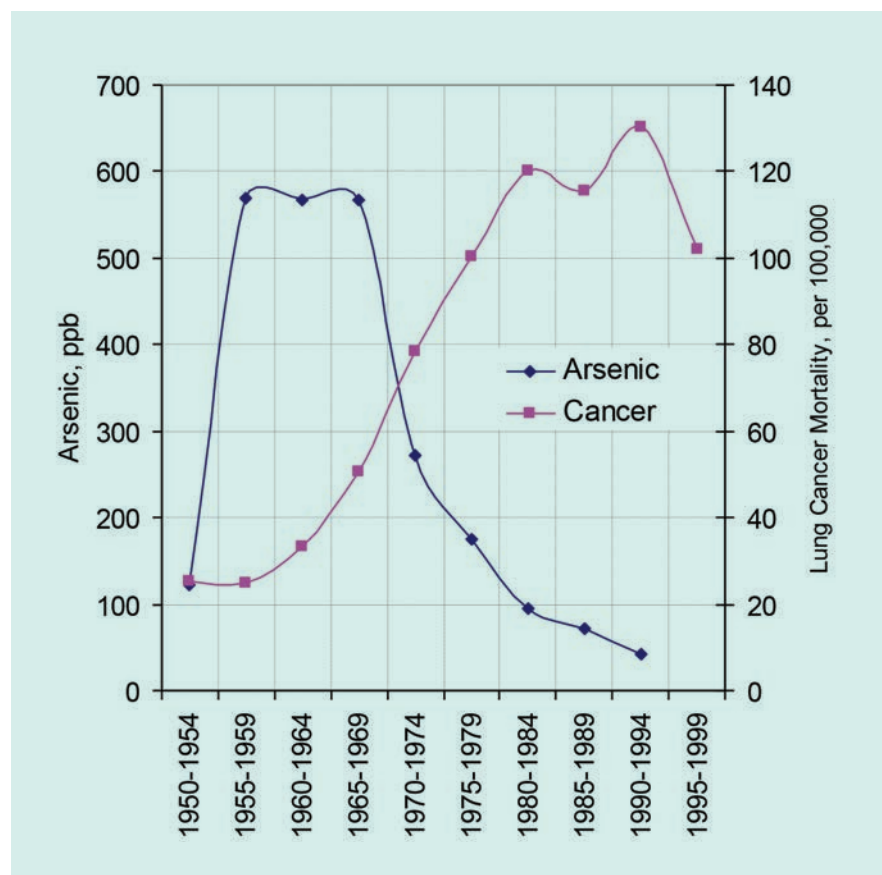


Figure 1:
Arsenic exposure and
male lung cancer mortality
in Chile

Source: (Marshall, 2007)

Cardiovascular Diseases

While skin lesions are the most commonly recognized symptom of arsenic poisoning, other arsenic-related diseases pose a greater mortality risk. Cardiovascular disease is the leading cause of death worldwide and the risk of cardiovascular disease is significantly increased by exposure to arsenic. This increase in mortality has been documented in Taiwan, Chile and Bangladesh. For instance, 30% of deaths due to cardiovascular disease were attributed to arsenic concentrations exceeding 12 ppb in a severely contaminated region of Bangladesh (Chen, 2011). Studies in Chile have shown that mortality due to heart disease has a long latency and the peak death toll can occur more than a decade after exposure stops. There is also a markedly increased risk of cardiovascular disease among smokers who are exposed to arsenic in drinking water.

Cancer

Arsenic is a known carcinogen and cancer poses the greatest threat to human health from excessive arsenic exposure. Skin cancers can be readily identified as resulting from arsenic exposure, but lung and bladder cancer constitute the greatest burden of disease and often occur without skin lesions (Ahsan, 2013). This means that just relying on the visible symptoms of arsenic poisoning will grossly underestimate the burden of disease.

Arsenic-induced cancer is known to have particularly long latency periods with arsenic-induced cancers exhibiting up to 40 years after the end of exposure. In the city of Antofagasta in northern of Chile, the entire population was exposed to high concentrations of arsenic (average 570 ppb) for more than 12 years before arsenic removal plants were commissioned. The cancer burden continued to increase after

exposure ceased and peaked more than 20 years later (see Figure 1). At the peak, arsenic-induced cancers were responsible for the deaths of 1 in 20 adult females and nearly 1 in 10 adult males.

The lung cancer risk of drinking water having 500 ppb arsenic is comparable to regularly smoking cigarettes. The cancer risk of consuming arsenic at 50 ppb is comparable to that posed by exposure to second-hand smoke, although this does not account for the risk of other arsenic-related diseases.

The US National Research Council has estimated that as many as 1 in 100 additional cancer deaths could be expected from a lifetime exposure to drinking water containing 50 ppb (NRC, 2001). A study in a highly-affected area of Bangladesh attributed 21.4% of all deaths in the area to arsenic >10 ppb. Similar results were found in other parts of Bangladesh, and an analysis of national survey data estimated an annual death toll of 43,000 (Flanagan, 2012).

Early Life Exposure

One of the significant features of arsenic poisoning, is that exposure *in utero* significantly increases the risks of stillbirth (Shih, 2017) and exposure in early childhood significantly increases mortality risks in young adults from multiple forms of cancer, lung disease, heart attacks and kidney failure -(Smith, 2006; Farzan, 2013). Early childhood exposure to arsenic also has significant negative impacts on cognitive development, intelligence, and memory (Tolins, 2014; Wasserman, 2011). This little-known fact could potentially increase the effectiveness of behavioural change programmes if included in awareness-raising activities.

Other Effects

Besides skin lesions and cancers, arsenic has been linked to a wide range of other health problems. One symptom is peripheral neuropathy or a tingling sensation in the fingers and toes. Another frequently reported symptom is gastrointestinal disturbance. In southwest Taiwan, a form of gangrene called “black-foot disease” is associated with arsenic but this has rarely been reported elsewhere and it

is possible that malnutrition contributes to its development.

Pulmonary effects are common and range from mild bronchitis to potentially fatal bronchiectasis and chronic obstructive pulmonary disease. Arsenic-exposed populations have been reported to be at higher risk of developing diabetes, hypertension, hepatomegaly (abnormal enlargement of the liver) and conjunctivitis.

The stigma of arsenicosis significantly impacts the lives of those with obvious symptoms and especially women. In some areas, those suffering from arsenicosis have been shunned by spouses, community members and potential suitors due to a mistaken belief that arsenicosis is contagious. A fear of ostracism can cause families to isolate their own members from engagement in society which has major inter-generational consequences on households.

Additional Resources

Ahsan, H. and C. Steinmaus (2013). “Invited Commentary: Use of Arsenical Skin Lesions to Predict Risk of Internal Cancer—Implications for Prevention and Future Research.” *American Journal of Epidemiology* 177(3): 213-216. <https://www.ncbi.nlm.nih.gov/pmc/articles/PMC3555485/>

Chen, Y., J. H. Graziano, F. Parvez, M. Liu, V. Slavkovich, T. Kalra, M. Argos, T. Islam, A. Ahmed, M. Rakibuz-Zaman, R. Hasan, G. Sarwar, D. Levy, A. van Geen and H. Ahsan (2011). “Arsenic exposure from drinking water and mortality from cardiovascular disease in Bangladesh: prospective cohort study.” *BMJ* 342. <https://www.ncbi.nlm.nih.gov/pubmed/21546419>

Flanagan, S. V., R. B. Johnston and Y. Zheng (2012). “Arsenic in tube well water in Bangladesh: health and economic impacts and implications for arsenic mitigation.” *Bulletin of the World Health Organization* 90: 839-846. <http://www.who.int/bulletin/volumes/90/11/11-101253/en/>

FAO and WHO (2011). Evaluation of certain contaminants in food: Seventy-second report of the Joint FAO/WHO Expert Committee on Food Additives (JECFA). Geneva, FAO and WHO. http://apps.who.int/iris/bitstream/10665/44520/1/9789241660631_eng.pdf

Farzan, S. F., M. R. Karagas and Y. Chen (2013). "In utero and early life arsenic exposure in relation to long-term health and disease." *Toxicol Appl Pharmacol* 272(2): 384-390. <https://www.ncbi.nlm.nih.gov/pubmed/23859881>

Marshall, G., C. Ferreccio, Y. Yuan, M. N. Bates, C. Steinmaus, S. Selvin, J. Liaw and A. H. Smith (2007). "Fifty-Year Study of Lung and Bladder Cancer Mortality in Chile Related to Arsenic in Drinking Water." *JNCI Journal of the National Cancer Institute* 99(12): 920-928. <https://www.ncbi.nlm.nih.gov/pubmed/17565158>

National Research Council (2001). *Arsenic in Drinking Water. 2001 Update*. Washington (DC): National Academies Press (US); <https://doi.org/10.17226/10194>

Shih, Y.-H., T. Islam, S. K. Hore, G. Sarwar, M. H. Shahriar, M. Yunus, J. H. Graziano, J. Harjes, J. A. Baron, F. Parvez, H. Ahsan and M. Argos (2017). "Associations between prenatal arsenic exposure with adverse pregnancy outcome and child mortality." *Environmental Research* 158: 456-461. <https://www.ncbi.nlm.nih.gov/pubmed/28692928>

Smith A. H., E. O. Lingas and M. Rahman (2000). "Contamination of drinking-water by arsenic in Bangladesh: A public health emergency." *Bulletin of the World Health Organization* 78(9): 1093-1103. <https://www.ncbi.nlm.nih.gov/pmc/articles/PMC2560840/>

Smith, A. H., G. Marshall, Y. Yuan, C. Ferreccio, J. Liaw, O. von Ehrenstein, C. Steinmaus, M. N. Bates and S. Selvin (2006). "Increased mortality from lung cancer and bronchiectasis in young adults after exposure to arsenic in utero and in early childhood." *Environmental Health Perspectives* 114(8): 1293-1296. <https://www.ncbi.nlm.nih.gov/pubmed/16882542>

Tolins, M., M. Ruchirawat and P. Landrigan (2014). "The developmental neurotoxicity of arsenic: cognitive and behavioral consequences of early life exposure." *Ann Glob Health* 80(4): 303-314. <https://www.ncbi.nlm.nih.gov/pmc/articles/PMC3783578/>

Ministry of Health People's Republic of China, UNICEF East Asia and Pacific Regional Office, China Medical University Shenyang (October 2004) "Endemic Arsenicosis: A Clinical Diagnostic Manual with Photo Illustrations" https://www.unicef.org/eapro/Endemic_arsenicosis.pdf

Wasserman, G. A., X. Liu, F. Parvez, P. Factor-Litvak, H. Ahsan, D. Levy, J. Kline, A. van Geen, J. Mey, V. Slavkovich, A. B. Siddique, T. Islam and

J. H. Graziano (2011). "Arsenic and manganese exposure and children's intellectual function." *Neurotoxicology* 32(4): 450-457. <https://www.ncbi.nlm.nih.gov/pubmed/21453724>

Websites:

University of California, Berkeley Arsenic Health Effects Research Program (many papers can be downloaded here) <http://asrg.berkeley.edu/>

U.S. Agency for Toxic Substances and Disease Registry (ATSDR) <https://www.atsdr.cdc.gov/substances/toxsubstance.asp?toxid=3>

World Health Organization (WHO)
South East Asia Region

WHO Technical Publication 30: Field Guide for Detection, Management & Surveillance of Arsenicosis in the South-East Asia Region http://www.searo.who.int/entity/water_sanitation/documents/arsenicosis2006/en/

WHO Technical Publication 38: Participant Handbook: Detection, Management and Surveillance of Arsenicosis in South -East Asia Region http://apps.searo.who.int/PDS_DOCS/B0303.pdf

UNDERSTANDING THE PROBLEM

Sources and Consequences of Arsenic Exposure

B2

Occurrence of Arsenic in Groundwater and Surface Water

Introduction

This section focuses on how water resources can become contaminated with arsenic. Arsenic in groundwater is predominantly the result of natural geochemical processes with the Ganges-Meghna-Brahmaputra basin in South Asia being the most significant example of this type of contamination. Surface water can become contaminated by arsenic arising from either human activity (e.g. mining) or natural sources with Antofagasta in Northern Chile being the most notable example of this type of contamination. Airborne particles containing arsenic from coal burning and mineral smelting could contaminate surface water or even rainwater, which is otherwise usually free from contaminants. Diffuse anthropogenic sources (e.g. arsenical pesticides and wood preservatives) are not known to have contaminated groundwater or surface-water but can cause extensive soil pollution. Point sources of arsenic pollution such as industrial spills, landfills and mining wastes have also been known to have severe, if only local, health impacts.

Sources of Arsenic

Some arsenic is naturally present in most rocks and sediments that form aquifers. Even natural background levels of a few mg/kg along with certain geochemical conditions can be sufficient to yield concentrations in groundwater that are above the WHO guideline value. Although arsenic contamination has been reported from most aquifer types, it is much more common in some types of aquifers. In terms of human exposure, the most important are alluvial aquifers adjacent to young mountain ranges (e.g. the Himalayas, the Alps and the Andes) and fluvio-glacial aquifers in general. All areas of recent volcanic or geothermal activity and sulfide mineralization should be considered to pose a risk, including that of wind-blown volcanic sediment (such as in Argentina).

Chapter Summary:

- Arsenic can occur naturally in groundwater.
- Natural geological processes can release arsenic from rocks and sediments into groundwater.
- Understanding the hydrogeological environment and the geochemical processes that lead to elevated arsenic levels in groundwater are crucial to tackling any arsenic problem.
- There are four main geochemical processes which trigger the natural release of arsenic into groundwater: reductive desorption, alkali dissolution, sulphide oxidation and geothermal activity.



For a public-health risk to occur, arsenic must be released from the aquifer rock or sediment into the groundwater and then consumed (ingested or inhaled) by humans in one form or another. In most cases, the arsenic in rock and sediment is immobile with only trace levels of arsenic found in the groundwater. However, certain natural hydrogeochemical conditions can trigger the rocks and sediments to release naturally present arsenic, leading to high concentrations of arsenic entering the groundwater.

There are four main geochemical processes that trigger the natural release of arsenic from aquifer materials into the groundwater (see Box 4). These processes occur in a wide range of geological and climatic environments. Where reductive dissolution tends to occur in unconsolidated sediments in humid climates; alkali desorption and sulfide oxidation tend to occur in hard rocks in drier climates; and geothermal occurs in specific volcanic settings.

Box 4 Natural Geochemical Processes that Release Arsenic into Groundwater

Process	Characteristic geochemical conditions	Generalized geological environment	Countries where this process is known to operate	Additional information
Reductive dissolution	Anoxic groundwater; low levels of dissolved oxygen, nitrate (NO ₃) and sulfate (SO ₄); pH~7; high iron (Fe); also high ammonium (NH ₄) and bicarbonate (HCO ₃).	Holocene floodplains of rivers draining young mountain chains; glacial deposits.	Bangladesh, India, Vietnam, China, Myanmar, Cambodia, Laos, Nepal, Pakistan, Taiwan, Japan, Italy, Hungary, USA, Botswana, Cameroon	Affects large areas, and accounts for the majority of known arsenic occurrences. Manganese may affect adjacent aquifers.
Alkali desorption	Oxic groundwater; pH ~ 8; low levels of iron. Possible elevated levels of other toxic ions such as F, B, Mo, Se.	Alluvium and bedrock aquifers.	Argentina, USA, Spain, China	May affect large areas.
Sulfide oxidation	Oxic groundwater; pH < 7 (sometimes extremely acidic); high levels of sulfate.	Areas of ancient sulfide mineralization, often associated with rare metals such as gold and tin.	Ghana, Burkina Faso, Thailand, India, Turkey, Finland, Mexico, Canada, USA	Usually localized, may be associated with lowering of water table.
Geothermal	High temperature groundwater; high chloride (Cl).	Areas of geothermal activity; often recent volcanic activity.	Chile, China, New Zealand, Italy, Bolivia, Peru, Ecuador	Usually localized.

The most important of these is reductive dissolution which is the dominant process along the river basins on the fringes of the Alpine-Himalayan mountain belt (see Figure 2)³.

Understanding the Geological Environment

Understanding the hydrogeological environment and the geochemical processes that lead to elevated arsenic in groundwater is crucial to tackling any arsenic problem. Each process responsible for the occurrence of arsenic will have different implications.

For example, while reductive dissolution gives rise to elevated levels of arsenic in the shallow Holocene sediments in the floodplains of the Ganges-Brahmaputra-Meghna basin, the deeper aquifers and geologically older terraces are mostly free from arsenic contamination (see Figure 3).

Alkali desorption is mostly found in sedimentary rocks like sandstone or semi-arid alluvial basins. The process tends to give rise to elevated arsenic levels at greater depths and after considerable distances along flow paths.

³The theory that arsenic pollution in India and Bangladesh was caused by sulfide oxidation induced by the pumping of groundwater has been broadly rejected, however the pumping of groundwater can lead to the sub-surface movement of dissolved organic carbon and arsenic which can potentially exacerbate the problem posed by arsenic in specific wells.

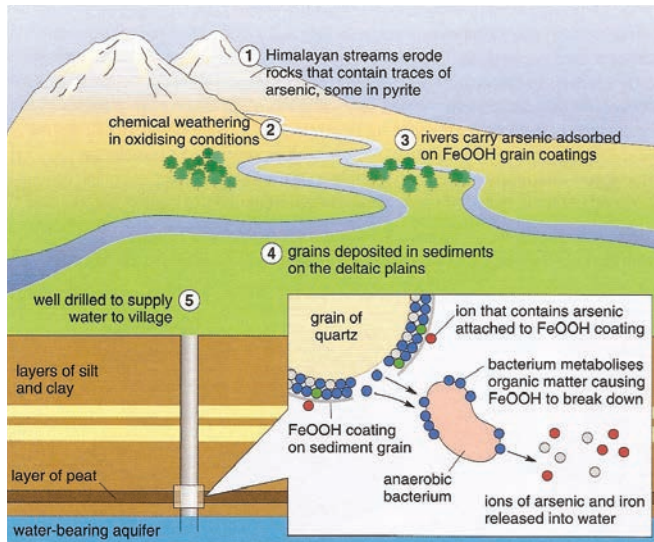


Figure 2: Reductive dissolution process in alluvial basins

Source: OU, 2006

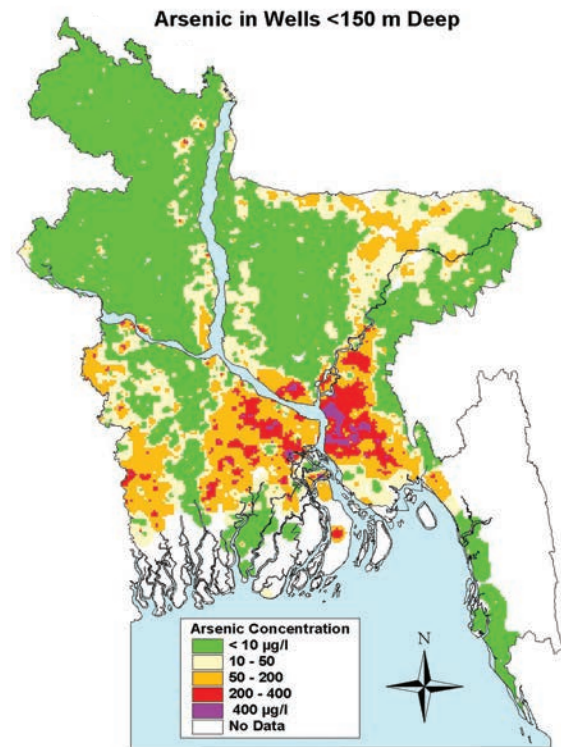


Figure 3: Distribution of arsenic in wells less than 150m deep in Bangladesh

© Peter Ravenscroft

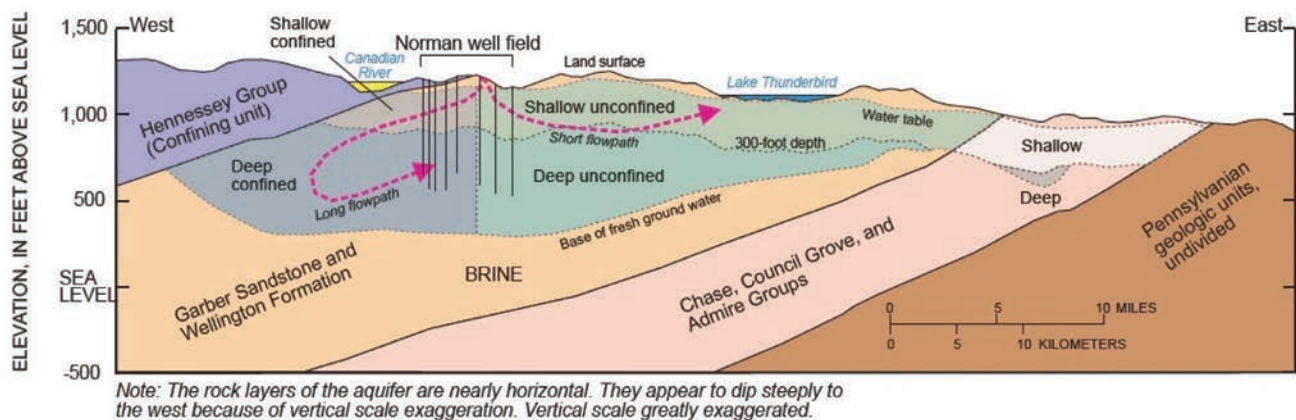


Figure 4: Arsenic mobilization by alkali desorption in Oklahoma (USA)

Source: Schlottman 1998

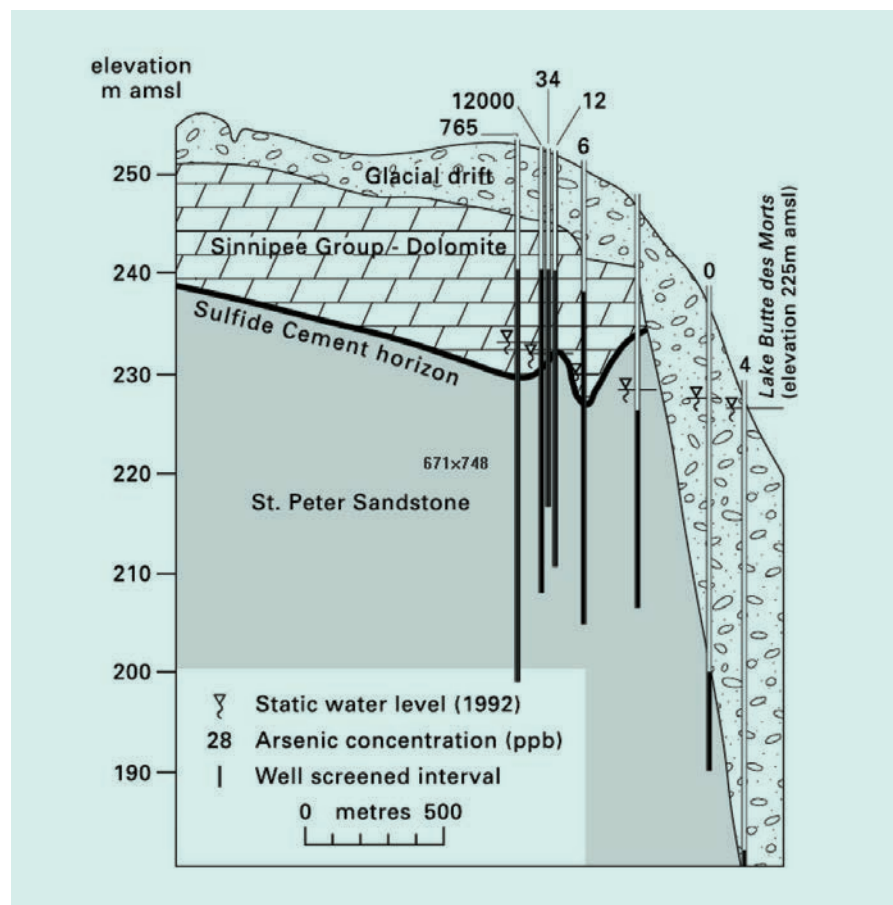


Figure 5:
Arsenic mobilization
by sulfide oxidation
in Wisconsin (USA)
© Peter Ravenscroft

A well-documented example of alkali desorption occurs in the deeper and confined sections of the Garber Sandstone aquifer in Oklahoma (USA) where arsenic concentrations of up to 232 ppb are accompanied by naturally elevated concentrations of chromium, selenium and uranium (see Figure 4).

Arsenic released by sulfide oxidation almost always occurs in hard rock aquifers that have enriched in sulfide minerals by ancient geological processes, which can be either volcanic or sedimentary. The arsenic-rich sulfide minerals tend to be associated with specific layers and seasonal or pumping induced water table changes (see Figure 5) leading to contamination which is extreme but very localized.

A good example in an ancient dolomite aquifer in Wisconsin (USA), where high arsenic and high sulfate concentrations occur in wells where the water table fluctuates seasonally across the so-called Sulfide Cement Horizon (SCH).

When these wells were installed, the water was not polluted but increases in pumping lowered the water table which allowed oxygen from the atmosphere to react with sulfide minerals in the SCH releasing arsenic into the groundwater. In contrast, arsenic mobilization by reductive dissolution or alkali desorption typically happens over geologic timescales, rather than in response to any changes to aquifer chemistry caused by installation of wells and abstraction of groundwater.

Additional Resources

DPHE. 2001. Arsenic contamination of groundwater in Bangladesh. Department of Public Health Engineering, British Geological Survey BGS Technical Report WC/00/19. <http://www.bgs.ac.uk/arsenic/>

OU. 2006. Water and well-being: arsenic in Bangladesh. S250 Science in Context, topic 3. The Open University, UK.

UNDERSTANDING THE PROBLEM

Sources and Consequences of Arsenic Exposure

B3

Food and Other Sources of Arsenic Exposure

Introduction

While arsenic contamination of the drinking water is the major focus of this primer, there are other significant routes of arsenic exposure. Exposure to arsenic from food poses a major risk and food can take up arsenic through the soil, irrigation water or cooking water. Arsenic can be transmitted through the air with occupational exposure to airborne arsenic being significant for mining and smelter workers, but it is not discussed here. As arsenic is also toxic to plants (phytotoxicity), arsenic-contaminated irrigation water also hampers food security. As arsenic absorption through the skin is minimal, handling arsenic-contaminated water is not considered dangerous.

Arsenic in Agriculture

Arsenic can build up in the soil when arsenic-contaminated groundwater is used for irrigation. This is more pronounced with water that is rich in iron, soils that are rich in clay and land that is not subject to flooding. Arsenic uptake by plants is complex, but there is usually a correlation between the arsenic content of the soil, the arsenic content of the shoots and grain up to a maximum or limiting value where further uptake stops. While arsenic in water is $\geq 99\%$ present in the more toxic inorganic form, arsenic in plants may be present in both the inorganic and less toxic organic forms.

While most plants accumulate arsenic, rice accumulates up to 10 times more arsenic than any other major food crop under the same soil conditions. Different strains of rice show differences in arsenic uptake, which is also dependent on the composition of the irrigation water and the type of soil. The anaerobic conditions in rice paddy soils are favourable for the uptake of arsenic by rice. Arsenic moves from the soil solution through the roots and shoots to accumulate in the leaves and grains.

Chapter Summary:

- Whenever arsenic occurs in water it may be found in soil and irrigation water, from where it may enter the food chain.
- Rice crops and baby food contaminated with arsenic pose a serious threat for poisoning.
- Rice accumulates up to 10 times more arsenic than any other major food crop under the same soil conditions.
- The long-term build-up of arsenic in the soil not only increases the uptake in grains but is also toxic to crops, which leads to decreased food security.



Where irrigated rice crops alternate with a rain-fed rice crops in monsoonal climates, the accumulation of arsenic in the irrigated crops will tend to be accompanied by arsenic accumulation in the non-irrigated crops, albeit at slightly lower concentrations. In South Asia, arsenic in rice is typically about 80% inorganic with a median concentration of 0.1 mg/kg but in highly affected areas this may exceed 0.2 mg/kg. Though some vegetables have higher levels of arsenic than rice on a dry-weight basis, the daily intake of rice in the Asian countries most prone to arsenic contamination means that rice is the principal form of arsenic exposure through food.

The long-term build-up of arsenic in the soil not only increases the uptake in the grains but it also becomes toxic to the crops. Observations in Bangladesh (see Figure 6), have shown a strong relationship between increasing arsenic in the soil and decreasing crop yield (phytotoxicity). This has reached a point where rice production has been abandoned in some areas due to a loss of yield (rather than a concern over the

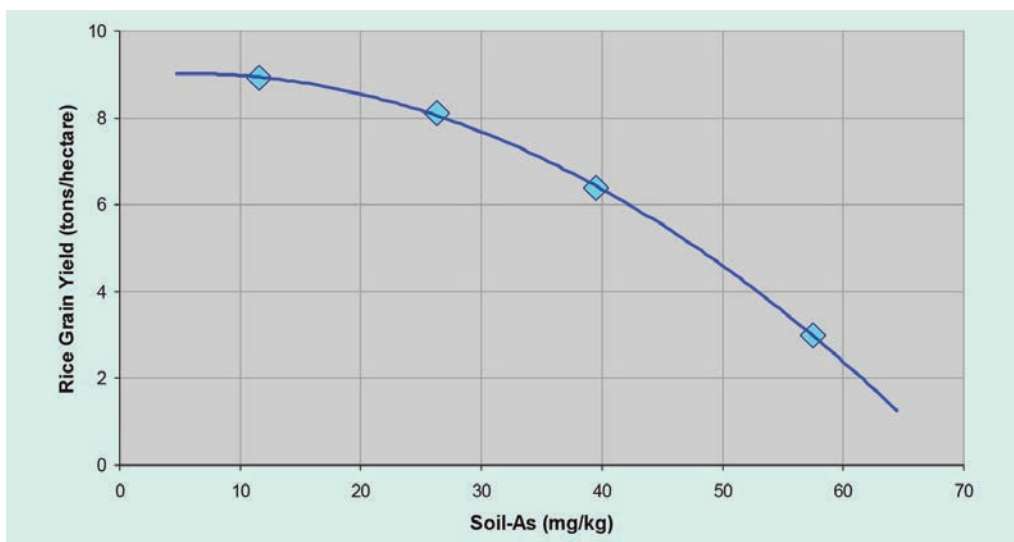


Figure 6: Rice yield reductions due to arsenic in the soil
© Peter Ravenscroft

arsenic content of the grain) from a condition known as Straighthead Disease in which the rice panicles are sterile. The rate at which arsenic accumulates will depend on the nature of the soil, but where arsenic continues to accumulate continued production of rice and other crops may be unsustainable.

Domestic animals may also be fed crop residues (e.g. rice straw) containing elevated levels of arsenic. Though little information is available, arsenic is not thought to accumulate to dangerous levels in meat or milk. However animal dung which contains high levels of partially digested plant matter can contain high levels of arsenic. When dung or crop residues are used as a domestic fuel, arsenic can be released into the air, posing an exposure risk via inhalation.

Health Significance of Arsenic in Food

There are few studies that differentiate the impacts of food and water on arsenic exposure. One cross-sectional study in six villages in West Bengal observed that on average persons with arsenic skin manifestations received over half their total arsenic intake from food (Uchino, 2006).

Three surveys over ten years at the Matlab research site in Bangladesh documented that while the median levels of arsenic in the drinking water decreased from 23 ppb to <2 ppb, the median urinary arsenic concentrations in a cohort of a thousand women and children only decreased from 82 to 58 ppb (Kippler, 2016). This modest decline being attributed to ongoing exposure through food, principally rice.

Arsenic in Coal

Coal can contain very high levels of arsenic constituting up to 3.5% arsenic by weight. Millions of households around the world burn coal in unventilated stoves for heating as well as for drying food. In southwest China, arsenic-rich coal is used to dry chili peppers and corn, which has resulted in the exposure of people to arsenic both through inhalation and food contamination. Coal-drying can also release high levels of fluoride, selenium or other toxins to food and air. Thousands of cases of arsenicosis and millions of cases of fluorosis have been linked to coal-burning.

Additional Resources

- An, D., Li, D., Liang, Y., & Jing, Z. (2007). Unventilated Indoor Coal-Fired Stoves in Guizhou Province, China: Reduction of Arsenic Exposure through Behavior Changes Resulting from Mitigation and Health Education in Populations with Arsenicosis. *Environmental Health Perspectives*, 115(4), 659–662. <http://doi.org/10.1289/ehp.9273>
- Brammer, H. and P. Ravenscroft. (2009). Arsenic in groundwater: A threat to sustainable agriculture in South and South-east Asia. *Environ. Int.*; 35(3): 647–654. <https://www.ncbi.nlm.nih.gov/pubmed/19110310>
- Duxbury, J. and G. Panaullah. (2007). Remediation of arsenic for agriculture sustainability, food security and health in Bangladesh. *FAO Working Paper*. <https://www.ircwash.org/resources/remediation-arsenic-agriculture-sustainability-food-security-and-health-bangladesh>
- FAO and WHO (2011). Evaluation of certain contaminants in food: Seventy-second report of the Joint FAO/WHO Expert Committee on Food Additives (JECFA). Geneva, FAO and WHO. http://apps.who.int/iris/bitstream/10665/44520/1/9789241660631_eng.pdf
- Heikens, A. (2006) Arsenic contamination of irrigation water, soil and crops in Bangladesh: Risk implications for sustainable agriculture and food safety in Asia. RAP 2006/20, Bangkok, FAO. <http://www.fao.org/3/a-ag105e.pdf>
- Kippler, M., H. Schröder, S. M. Rahman, F. Tofail and M. Vahter (2016). Elevated childhood exposure to arsenic despite reduced drinking water concentrations — A longitudinal cohort study in rural Bangladesh. *Environment International* 86: 119-125. <https://www.sciencedirect.com/science/article/pii/S0160412015300830>
- Liu, J., Zheng, B., Aposhian, H. V., Zhou, Y., Chen, M.-L., Zhang, A., & Waalkes, M. P. (2002). Chronic arsenic poisoning from burning high-arsenic-containing coal in Guizhou, China. *Environmental Health Perspectives*, 110(2), 119–122. <https://www.ncbi.nlm.nih.gov/pmc/articles/PMC1240722/>
- Senanayake, N. and A. Mukherji (2014). Irrigating with arsenic contaminated groundwater in West Bengal and Bangladesh: A review of interventions for mitigating adverse health and crop outcomes. *Agricultural Water Management*, 135: 90-99. <https://doi.org/10.1016/j.agwat.2013.12.015>
- Williams PN, Price AH, Raab A, Hossain SA, Feldmann J, Meharg AA. (2005). Variation in arsenic speciation and concentration in paddy rice related to dietary exposure. *Environ. Sci. Technol.* 39 (15): 5531-5540. <https://www.ncbi.nlm.nih.gov/pubmed/16124284>
- Williams PN1, Islam MR, Adomako EE, Raab A, Hossain SA, Zhu YG, Feldmann J, Meharg AA. (2006). Increase in rice grain arsenic for regions of Bangladesh irrigating paddies with elevated arsenic in groundwaters. *Environ. Sci. Technol.* 40: 4903-4908. <https://www.ncbi.nlm.nih.gov/pubmed/16955884>



C BRINGING ABOUT SOLUTIONS

Reducing Exposure to Arsenic in Drinking Water

C4

Frameworks for Safe Water and Risk Prioritization

Framework for safe drinking water

National drinking-water regulations and standards are necessary for ensuring access to safe drinking water and safeguarding public health. The term “standard” is commonly used to describe a mandatory numerical value in a table of parameters with limits (such as 10 ppb for arsenic). Regulations are requirements that can include or refer to a table of parameters and limits. Regardless of how a country defines “standards” or “regulations,” both are interdependent.

The framework for safe drinking water described in the WHO *Guidelines for Drinking-water Quality* (GDWQ) provides the basis for national regulations and standards to be adapted to local priorities, environmental conditions, economic status and institutional capacities (see Figure 7). This framework provides a means for integrating the implications of arsenic exposure beyond the water sector into the management of the consequences of arsenic exposure within the health sector.

Figure 7: WHO Framework for safe drinking water



Source: WHO (2011) *Guidelines for Drinking-water Quality* (Fourth Edition)

Chapter Summary:

- National frameworks for safe drinking water can guide arsenic mitigation programmes.
- Framework for Safe Drinking-water as described in the WHO *Guidance for Drinking-water Quality* has three key components:
 - Establishment of health-based targets, including water-quality standards
 - Development of risk-assessment and management plans (i.e. water safety plans - WSP)
 - Independent surveillance
- The objective of arsenic-specific risk mitigation plans is to reduce the duration and the intensity of exposure to arsenic.
- Preventing arsenic exposure requires assessing and managing risks at both national and local levels.



The framework for safe drinking water is comprised of three core components: (i) the establishment of health-based targets including water quality standards; (ii) the development of water-safety plans (WSPs) by water suppliers; and (iii) the independent surveillance of compliance.

Health-Based Targets

Health-based targets are measurable health, water quality or performance objectives that are established based on a judgement of safety and on risk assessments. The GDWQ describes four types of health-based targets: health outcome, water quality, performance and specified technology targets.

Health-outcome targets: These targets, generally established at a national level, represent a tolerable burden of disease, which is often defined in disability life adjusted years (DALYs). Health outcome targets need to be translated into water quality, performance or specified technology targets in drinking-water regulations

or standards, as a benchmark to confirm the adequacy of water supply systems and the need for improvement. In establishing health outcome targets (and the other targets), a consideration should be given to exposure through other routes. For arsenic, this is principally via food and possibly via airborne routes. Arsenic in food is particularly important where arsenic is present in irrigation water or where arsenic is present in the water used to cook absorbent foods. This is vital in places where rice is the staple diet as rice accumulates arsenic from the soil, from irrigation water and from boiled water far more than any other crop. While the average per capita consumption of water varies relatively little around the world, the average per capita consumption of rice varies enormously between cultures, from almost zero to more than 400 grams per day among South Asian agricultural workers. For infants in South Asia, rice comprises a significant component of their diets and the major arsenic exposure risk path (see Chapter D12).

Water-quality targets: Water-quality targets are the most common form of health-based target applied to chemicals. This includes the provisional guideline value for arsenic in the GDWQ. Arsenic should be included in national drinking-water standards along with all other priority microbial, chemical and radiological contaminants that are important in the country. Priority contaminants are those that frequently occur at concentrations that can impact on health, and so arsenic will be a high priority in many countries and vital for achieving SDG 6.1. Where no national standard exists, the WHO guideline value for the contaminant should be the point of departure for developing such standards. The current WHO guideline value for arsenic of 10 ppb, established in 1993, is classified as provisional because of the constraints of treatment performance and analytical accuracy rather than health effects. The concentration of arsenic in drinking water below which no effects can be observed is still to be determined and so every effort should be made to keep concentrations as low as reasonably possible.

In some settings it may be feasible to achieve lower levels of arsenic – in the Netherlands the

national standard is 10 ppb, but water companies have adopted a new guideline of 1 ppb, based on the results of a cost-benefit analysis and a health-impact model (van der Wens, 2016). In other settings, local considerations could result in developing a national standard for arsenic that is higher than the WHO guideline value. This may be particularly relevant in places where a high percentage of the population is exposed to very high concentrations of arsenic (e.g. 100 ppb) and it is difficult to achieve the guideline value. The principle that should be followed is the risk-based prioritization of mitigation where arsenic concentrations are highest. In such situations however, it is advised that the WHO guideline value (or a value that is lower) be retained as a long-term goal. Accordingly, development of interim standards or permitting derogations that allow exceedances of the desired standard for a specified time should be considered. An alternative approach is to establish separate mandatory and desired arsenic concentration targets, giving water suppliers time to continue operation before achieving the desired standard by a particular point in time.

The need for transitional strategies may be widespread. Many countries adopted an arsenic standard before the WHO guideline value was lowered from 50 to 10 ppb and before widespread arsenic contamination was recognised. While there will be pressure to immediately adopt the current guideline as a standard, this may pose a public relations challenge for governments, potentially doubling the officially exposed population. In such situations, a transitional approach to implementing a new standard that prioritises mitigation interventions might be adopted and should be comprehensible to the general public.

Performance and specified technology targets: The framework for safe drinking water proposes the establishment of targets for the performance of water-treatment processes and technologies (i.e. arsenic removal systems although these are most commonly established for microbial hazards). This needs to be done with a deep understanding of local circumstances because the specification of minimum performance targets will shape the selection of technologies,

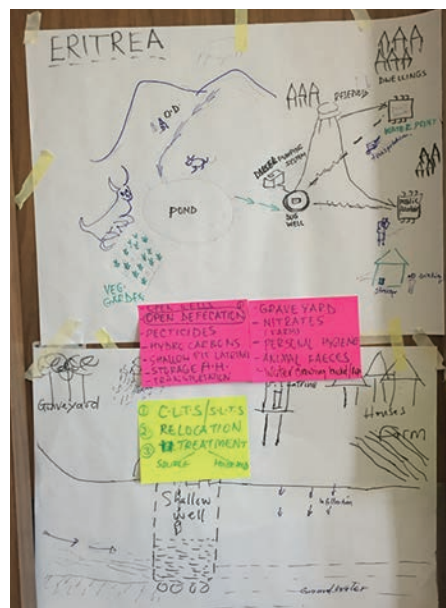
and hence the cost and time scale for implementing potential mitigation options. Setting performance targets for systems and technologies should be approached through a consultative process involving health specialists, treatment experts and WASH practitioners. This should include an adequate means of verification of performance particularly for community- or household-managed water treatment systems or technologies that may perform well in laboratory conditions but suffer from poor maintenance when deployed in the field.

Arsenic Standards for Food

The FAO and WHO formerly recommended a Provisional Tolerable Weekly Intake of 15 µg/kg body weight for inorganic arsenic (equivalent to 2.1 µg/kg/day, or 130 µg/day for a person weighing 60 kg). This recommendation previously supported the provisional guideline value of 10 ppb for arsenic in drinking water. However, the recommendation was withdrawn in 2011 because the 2.1 µg/kg/day limit was considered too close to levels where the risk of lung cancer incidence exceeded 0.5% (at 3.0 µg/kg/day).

Assessments of the total intake of arsenic needs to consider exposure from both food and water, including water used in food preparation and to irrigate crops. While assessments of exposure through water are relatively straightforward (i.e. consuming 1.5 litres of drinking water per day containing 100 ppb will exceed 130 µg/day), exposure through food varies enormously depending on dietary habits: in highly contaminated rice-growing areas of South Asia the combined exposure can exceed 1,000 µg/d (Uchino, 2016).

Unlike water, where arsenic is usually $\geq 99\%$ inorganic, the more toxic inorganic and less toxic organic concentrations of arsenic in food vary significantly. South Asian rice typically contains about 80% inorganic arsenic with a median concentration of 0.1 mg/kg (but in highly affected areas this may exceed 0.2mg/kg potentially reaching 0.4 mg/kg). While Bangladesh has no standard for arsenic in food, China recently set a standard of 0.2 mg/kg inorganic arsenic in rice. The EU advises a lower concentration of 0.1 mg/kg of inorganic



© Fiona Eloise Baker

arsenic for the consumption by infants and in baby food.

Water-Safety Plans

Water safety plans (WSPs) are a systematic risk assessment and management approach to ensure drinking water safety that encompass all stages in the delivery chain (from 'catchment to consumer'). Water safety plans are widely recognized as a reliable and effective way to manage drinking-water supplies to protect public health. Water safety plans provide a tool for the day-to-day management of water-supply systems (in contrast to spot checks through surveillance) and are applicable to all system types, sizes and resource level.

While end-point testing regimes are effective in assessing water safety at the point of delivery to consumers, this approach will only detect problems after consumers have been exposed. Water safety plans were introduced to complement end-point testing as a means of predicting and managing potential water contamination risks – though their application to arsenic risk management is relatively new. Water safety plans emphasize the prevention of contamination where possible (i.e. prioritising alternative drinking-water sources with lower arsenic concentrations where practical) while managing the potential of risk substitution (i.e. increased risk to consumers due to increased microbial contamination).

While national standards establish water quality parameters and limits, water safety plans ensure those standards can be achieved by defining the processes through which water safety will be safeguarded. Ideally drinking-water quality regulations should recommend or require water safety plans to complement the national standards. Binding instruments that define the process for the management of water safety risks are dependent on the context which enables the major contamination risks and the practicality of the means for ensuring compliance to be determined.

The process for developing and implementing a water safety plan in piped urban systems is similar to the process for small community water supplies, which is summarized in Box 5. In countries where there are millions of privately installed water sources, this water safety planning approach of identifying and managing drinking water contamination risks may need to be adapted to foster compliance by the households that are the water service providers, as well as drinking-water consumers.

More information on introduction and scale up of water safety plans can be found in the references below and the WHO website.

Surveillance

Institutional accountability to ensure drinking-water safety generally requires the separation of the roles of service provision from that of the authority responsible for independent oversight to safeguard public health (i.e. drinking-water supply surveillance). Surveillance is a public-health assessment of the safety and acceptability of drinking-water supplies. Ideally it contributes to the protection of public health by not only promoting the improvement of the quality of drinking water, but also the quantity, accessibility, coverage, affordability and continuity of drinking-water supplies (i.e. indicators of service). The surveillance authority must have the authority to determine whether a water supplier is fulfilling its obligations and the means of enforcing those obligations.

The surveillance function provides an independent check that water safety plans are appropriate, being implemented and effective and that the water quality standards are

Box 5

Water Safety Plan Steps

The six steps in developing and implementing a community water safety plan are to:

1. Assemble the water safety plan team
2. Describe the water supply system
3. Assess risks considering hazards, hazardous events and existing control measures
4. Develop and implement an incremental improvement programme
5. Monitor control measures and verify the effectiveness of water safety plans
6. Document, review and improve all aspects of water safety plan implementation

being met. The findings from the surveillance function should feed back into the revision of water safety policies, regulations, standards and supporting programmes. This is discussed further in Chapter C9.

Developing a Risk-Based Mitigation Plan

Protecting people from arsenic poisoning through access to arsenic-safe water will either entail the switching to an alternate existing safe water source; constructing a new water source; or removing arsenic from the contaminated water source. Where the discovery of arsenic contamination was relatively recent there will be a degree of uncertainty as to the best course of action. Where the extent of arsenic contamination is large or unknown, the capacity of the institutions to offer mitigation options will probably be exceeded in the short term.

In such situations, a risk management plan can enable the scale and the means of arsenic mitigation to be prioritized to maximize the reduction in arsenic-related morbidity and mortality. The starting point for drawing up an arsenic risk-management plan is to consider the full range of factors that influence the risk of contracting arsenic-related diseases. An arsenic risk-management plan will therefore need to prioritize actions based on:

- The concentration of arsenic in water (assuming that health impacts follow a roughly linear dose-response curve)
- The duration of exposure to arsenic in drinking water
- Exposure to other inorganic sources of arsenic such as food (often acquired from the use of arsenic-contaminated water for irrigation or cooking)
- The vulnerability of individuals and groups to the consequences of arsenic exposure (i.e. the health impacts based on nutritional and genetic factors)
- The vulnerability of individuals and groups to the consequences of mitigation efforts. This can potentially be reduced to two components:
 - the average distance to the nearest safe source or the average number of people sharing each safe source⁴
 - poverty as a proxy for the affordability of households to mitigate their arsenic-exposure risks
- Operability and maintainability: must be appropriate to the socio-economic conditions and the institutional capacities of the operators and the service industry.
- Monitoring: which is generally easier for public water-supply systems (government and community owned) as compared to private water supply systems (private and household owned).
- Regulation: this can be very valuable where there is an effective regulator to monitor the quality of mitigation provided by public, community and privately operated systems.

Many of these factors involve trade-offs. For instance, placing higher value on the speed of delivery could justify accepting a shorter working life or paying a higher cost in the short term. Where necessary, such arguments should be justified in terms of the costs of health care and the reduction in negative health impacts, often expressed in DALYs⁵.

Blanket screening (i.e. the testing and marking all water sources) is usually required to develop a comprehensive risk management plan and should ideally include the GPS location of all safe and unsafe water points and household locations (if this is not already known). Further detailed information can be established through more in-depth surveys and analysis considering the factors that influence the selection of mitigation options. Such analysis should consider:

- Technical effectiveness: in avoiding or removing arsenic while avoiding the potential of risk substitution (e.g. increased faecal contamination risks).
- Cost: considering the challenge of scale versus effectiveness, and the balance between capital and operating costs, and who pays each.
- Implementation time: all other things being equal, the arsenic response versus exposure time relationship means that faster mitigation options will be preferable.
- Acceptability: to provide an adequate quantity of water of a satisfactory aesthetic quality (e.g. high levels of iron or manganese or taste or odour can cause otherwise effective mitigation options to be rejected by consumers).

Water Supply Options and Relative Risk Assessment

Due to the spatial variability of arsenic in groundwater there is almost always some arsenic-safe sources even in the most contaminated areas. These sources can be identified through blanket testing and should be marked accordingly (e.g. by painting the spouts of arsenic-safe water sources green and either sealing or painting red all the arsenic-contaminated water sources)⁶. In communities where there are sufficient existing arsenic-safe supplies to meet minimum service standards, the construction of new water sources or the introduction of arsenic removal systems can be given a lower priority. In such situations, people can be encouraged to share the arsenic-safe water sources, at least in the short term. This approach, known in South Asia as “well switching” is most viable when most water sources are tested and clearly marked safe or unsafe, and when people are properly informed through a communication programme (see Chapter C8) and when people agree to share these safe water sources.

⁴This is a good measure of vulnerability in the early stages of mitigation but an increasingly poor measure later in the mitigation programme.

⁵Disability Adjusted Life Years. See for example Howard et al. (2006).

⁶The testing and marking of safe and unsafe drinking water sources is referred to as “screening.”

It should be recognised that “well switching” is easiest to implement where the percentage of contaminated wells is low. Potential inequities should also be appreciated with peoples’ ability to access water from a safe water source often inversely proportional to their social capital. The choice on whether to mark or to seal arsenic-contaminated sources is one which also deserves careful consideration of the various pros and cons. Such considerations need to be carefully weighted and explicitly addressed in the design of the communications programmes.

If a blanket arsenic-screening programme reveals that there are insufficient arsenic-safe sources in a community, experience suggests that the next best option is to develop alternative sources of arsenic-safe water exploring different depths of groundwater or surface water options. The identification of alternate arsenic-safe⁷ water sources will necessarily depend largely on the water resources and the technologies already available. Alternative water-supply facilities need to be chosen to ensure that the contamination risks from the new source do not exceed the contamination risks from the old source. This is not always as obvious as it sounds, particularly where there is a trade-off between fast-acting faecal contamination and slow-acting arsenic.



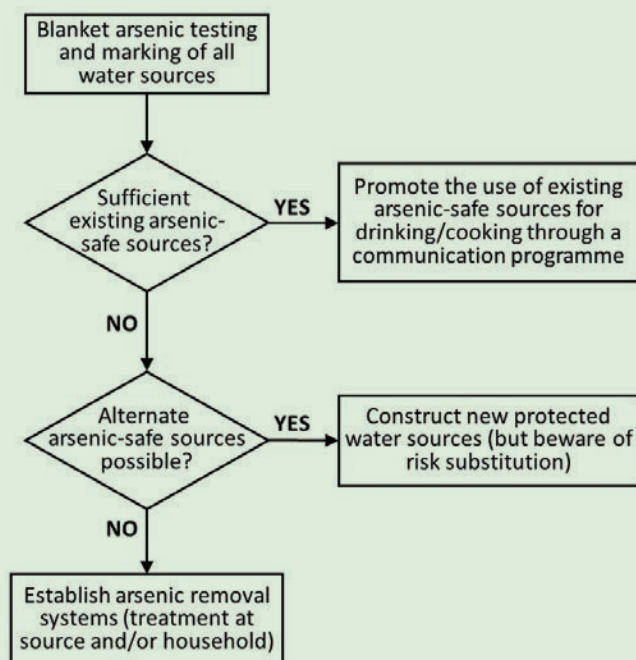
Picture 4: Social map identifying priority households for arsenic mitigation

© Silke Fock-Kutsch; 2012

⁷This document uses the term arsenic-safe water to mean water that complies with health-based targets. Please note, that the guideline value was established based on practical grounds, rather than health.

⁸Note: This empirical comparison of risk undertaken by Howard G et al (2006) did not include the cost or user preference for alternate water supply options

Figure 8: Water in Arsenic Contaminated Areas



For instance, a rigorous assessment of alternate water-supply options in Bangladesh used DALYs (disability adjusted life years) to combine and compare the health risks of arsenic contamination (slow-acting but long-lasting) and microbial contamination (fast-acting and severe) during the wet and dry seasons. This analysis identified the consequence of failure to meet water-quality standards to be greater for microbial contamination, identifying two drinking-water sources (i.e. arsenic-safe deep aquifers and rainwater harvesting) as having a significantly lower combined burden of disease than all the other options (i.e. dug wells, filtered surface water, shallow tubewells and arsenic-removal devices)⁸.

Experience also suggests providing new arsenic-safe water sources is generally a better option than removing arsenic from contaminated water sources. The treatment of arsenic-contaminated water in small systems or in the household should only be considered when all other options have been exhausted because of the cost, the maintenance requirements, the complexity and the potential increase in bacterial risks often associated with greater complexity.

Box 6

To Mark or to Seal Arsenic Contaminated Sources?

Arsenic-contaminated water sources may be safely used for bathing, washing and cleaning if appropriately marked and if people are appropriately informed.

- **However**, allowing arsenic-contaminated water sources to remain open increases the risk that people will continue to drink or cook with the water in spite of their awareness and the clear marking of the source.
- **But**, this risk must be weighed against the health risks posed by the closing of water sources because the collection of water from more distant sources will probably mean less water to sustain sanitation and hygiene practices. The additional workload of collecting water is most likely to disproportionately fall on women and children.
- **Alternatively**, it may be prudent to close highly contaminated water sources (e.g. above 200 ppb) because of the greater risk they pose and clearly mark yet maintain open all other water sources that exceed the drinking-water standard. The ultimate decision on whether to close or mark a water source will reside with the asset owner, unless otherwise stipulated by the Law.



These Bangladeshi women know the red spout means the water is arsenic-contaminated and cannot be used for drinking or cooking – but that it can be used for other purposes.

© UNICEF/UNI33033/Noorani

Additional Resources

Howard, G., Ahmed, M. F., Shamsuddin, A. J., Mahmud, S. G., & Deere, D. (2006). Risk Assessment of Arsenic Mitigation Options in Bangladesh. *Journal of Health, Population, and Nutrition*, 24(3), 346–355. <https://www.ncbi.nlm.nih.gov/pmc/articles/PMC3013255/>

Uchino, T., T. Roychowdhury, M. Ando and H. Tokunaga (2006). Intake of arsenic from water, food composites and excretion through urine, hair from a studied population in West Bengal, India. *Food and Chemical Toxicology* 44(4): 455-461. <https://www.sciencedirect.com/science/article/pii/S0278691505002619>

UNICEF (2008) Handbook on Water Quality New York, UNICEF https://www.unicef.org/wash/files/WQ_Handbook_final_signed_16_April_2008.pdf

van der Wens, P., K. Baken and M. Schriks (2016). Arsenic at low concentrations in Dutch drinking water: assessment of removal costs and health benefits. 6th International Congress on Arsenic in

the Environment. P. Bhattacharya. Stockholm, Sweden, CRC Press. <https://www.taylorfrancis.com/books/9781315629438>

WHO (2017). Guidelines for Drinking-Water Quality. Fourth edition, incorporating the first addendum. Geneva: WHO. http://who.int/water_sanitation_health/publications/drinking-water-quality-guidelines-4-including-1st-addendum/en/

WHO (2011) Arsenic in Drinking-water. Background document for development of WHO Guidelines for Drinking-water Quality http://www.who.int/water_sanitation_health/water-quality/guidelines/chemicals/arsenic.pdf?ua=1

WHO, IWA (2010). Think Big, Start Small, Scale Up: A Road Map to support country level implementation of Water Safety Plans. http://www.who.int/water_sanitation_health/dwq/WSP/en/.

Websites:

WHO Water safety planning resources http://www.who.int/water_sanitation_health/water-quality/safety-planning/wsp-publications/en/



C5

Assessing and Managing Arsenic-Hazard Information**Introduction**

This module describes how to respond to initial reports or suspicions of arsenic contamination, which may arise from newspapers, research, international agencies, or the discovery of arsenic in neighbouring countries. The generation and the management of information on the extent of arsenic contamination is extremely important and has been divided into assessment and management phases in this chapter.

Assessment Phase Arsenic Testing

Experience suggests that initial reports of arsenic contamination of the groundwater may be treated with disbelief and denial. Managing the initial assessment of a suspicion of arsenic contamination is extremely important to avoid panic while the extent of any contamination is identified. At the same time, it is imperative to avoid unnecessary delays or denial that will increase the burden of disease if arsenic contamination is confirmed.

The first verification actions should be to consult the arsenic-contamination risk maps and establish a small group of experts encompassing water supply, hydrogeology, analytical chemistry, public health and dermatology. This group of experts should determine whether there are sufficient grounds for commissioning priority research to verify the presence of an arsenic contamination risk and develop an assessment programme. Once the need for further investigation has been established, the multi-disciplinary research group will initiate a phased programme of investigation. Such an investigation will require various dimensions including hydrological, medical and behavioural studies with the core objective of determining which people are exposed, to what levels of contamination and through which media.

Chapter Summary:

- Assessing the risks of exposure to arsenic can be done through geological models or through field surveys. Medical reports of symptoms compatible with arsenicosis can also be the first indication of possible contamination risk.
- When there is suspicion of arsenic contamination, managing the initial assessment phase is extremely important so as to avoid panic while the extent of any contamination is identified.
- When arsenic contamination is confirmed it must be quickly followed up with rapid reconnaissance surveys and possibly blanket testing of water sources in the affected areas.
- Blanket testing and marking of all safe water points enables consumers to identify opportunities to switch to lower-risk water sources.



As soon as there is credible evidence of arsenic contamination, an appropriate system for coordination should be established between water, health and agriculture sectors which would ideally include public and private agencies, academic and implementing organizations, and national and international actors. Actions should be stepped up progressively to verify the nature and scale of the problem, backed up by a multi-agency risk management plan that includes a communications component designed to manage a transparent and measured response to the scale of the risks.

The capacity of the monitoring services including the relative roles of laboratory and field testing need to be defined. This should establish whether surveys will conduct testing on site with field kits or transport samples back to laboratories, whether laboratory cross-checks will serve as a quality control measure for field kit analyses, whether laboratories need upgrades and/or expansion, and the extent to which this can be managed and financed by the public- or private-service providers.

Box 7**Global Arsenic Prediction Maps**

Over the last 30 years there has been an escalation in the number of countries where arsenic contamination has been identified (totalling over 70 countries). In most cases, the water had never been tested for arsenic or other toxic chemicals. This experience suggests that new cases of arsenic contamination will continue to be identified. Two global risk maps freely available from the Groundwater Assessment Platform website (www.gapmaps.org) have been developed to assist in predicting the risk of arsenic contamination.

The first is based on a global study commissioned by UNICEF in 2007 to predict where arsenic contamination might occur (*see inside back cover image*) while the second is based on modelling developed by EAWAG in Switzerland in 2008. The two approaches have many similarities and a few key differences:

- The UNICEF model predicts mobilization processes based on the geological and climatic setting, while the EAWAG applied a geostatistical model to geochemical, geological and climatic data.
- The EAWAG model estimates the probability of contamination but no estimate of population, while the UNICEF model produces an absolute (yes/no) risk assessment and an estimate of the population at risk.

Both models involve considerable simplification and uncertainty but are complementary in nature. Those involved in the use of groundwater for drinking purposes are recommended to consult both sets of maps, taking follow-up action if either map predicts a risk of arsenic contamination⁹.

⁹ The absence of identified arsenic-contamination risks from these maps in no way reduces the need to undertake hydrochemical baseline surveys in all countries and regions if they have not been undertaken previously

¹⁰ Prioritizing GPS mapping in all surveys and monitoring will enable essential data from the initial assessment phase to be incorporated into latter management phase alternate water supply options

Management Phase Arsenic Testing

Priority arsenic mitigation activities should commence parallel to the ongoing investigation during the assessment phase. Once assessment phase arsenic testing is complete, and the extent of the risk broadly established, initial surveys (reconnaissance and detailed surveys) and priority mitigation efforts will tend to be replaced by a series of monitoring and surveillance activities, integrated with mitigation options targeted based on risk considering water technology, behavioural change and health-assessment systems. The different combinations of surveys (see Box 8) and testing technologies (see Chapter C6) will need to be deployed as the requirements shift from the assessment to the management phases.¹⁰

The management phase of arsenic testing will tend to be defined by the strengthening of third party verification of test results and the move to ensure that all new groundwater sources are tested for arsenic after drilling. This requires the establishment of protocols and procedures for the arsenic testing and equipping of all new groundwater sources, in addition to the protocols and procedures for the routine arsenic testing of existing water sources. Where significant numbers of private groundwater sources are being installed, this will probably require some form of approval process for private water-asset owners and some form of certification for private providers of drilling and testing services.

Another significant element of the management phase is the blanket testing and marking of all water sources in those areas where arsenic contamination risks have been established. Blanket testing and marking of all water sources is financially and logistically demanding especially but extremely important. The testing and marking of all sources within an area has been considered the first step in the mitigation ladder, enabling consumers to identify opportunities to switch to lower-risk water sources. Due to the cost there is an

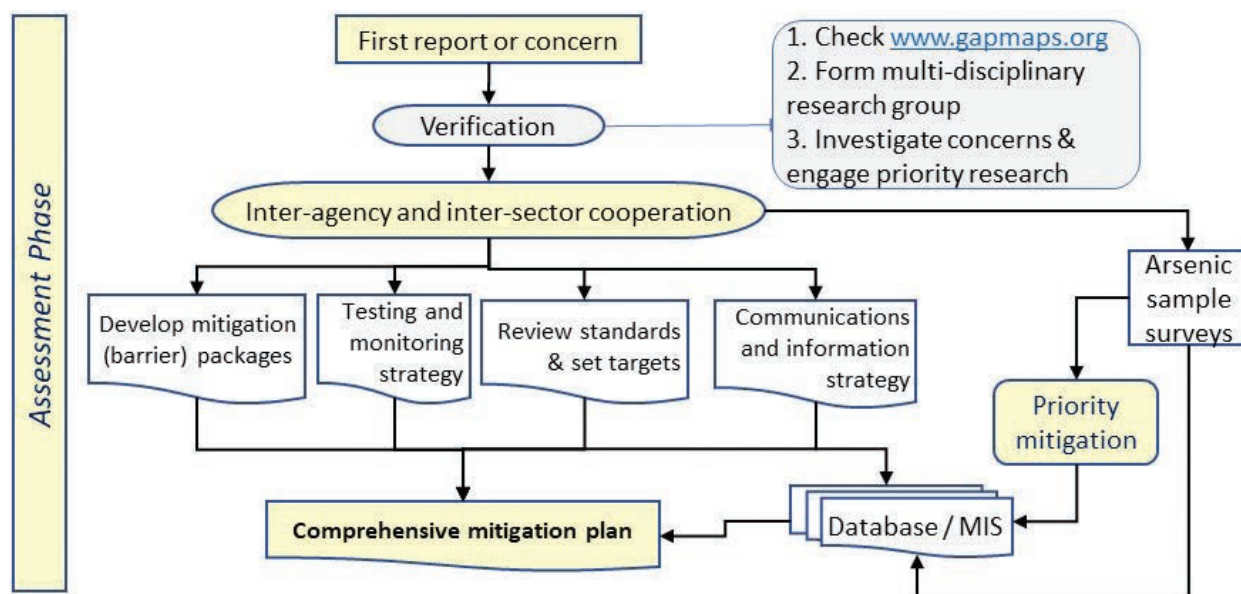


Figure 9: Assessment phase testing to ascertain the extent of arsenic risks to drinking water

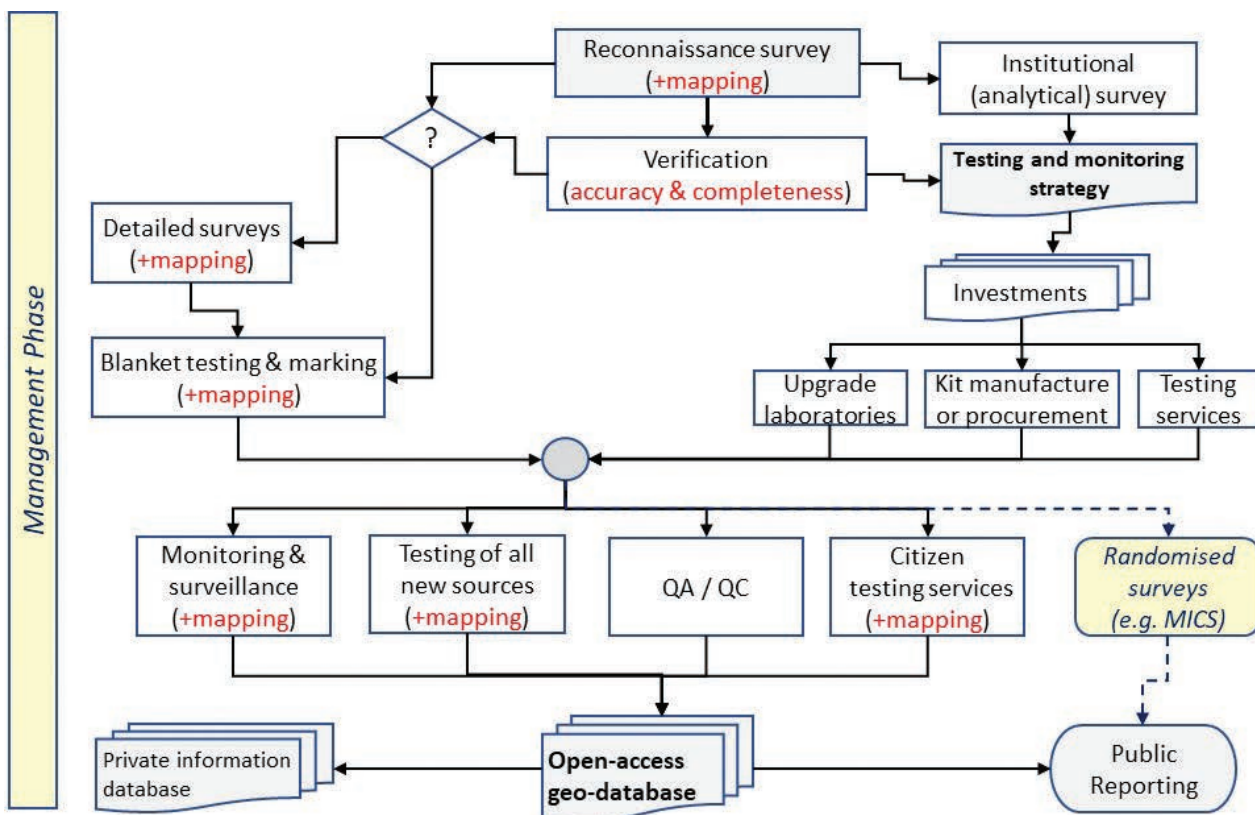


Figure 10: Management phase testing to manage arsenic contamination risks to drinking water

Box 8

Types of Surveys and Monitoring

Arsenic levels in water sources can be assessed through a variety of survey and monitoring tools. Whether testing is done with field kits or in laboratories, by specialists or by field teams with only a short training, quality assurance and control measures are essential to ensure that the results are reliable and credible.

Reconnaissance Surveys: aim to identify arsenic affected and unaffected regions, the range of concentrations present (including any other chemical contaminants) and to support planning for blanket testing and marking. They are conducted rapidly, generally by experts, in the Assessment Phase of a response. Ideally samples should be tested in well-respected laboratories, with or without field testing, and if there is any doubt, duplicate samples should be sent abroad for verification.

Detailed Surveys: are an optional extension of reconnaissance surveys, following the same principles and procedures. They are conducted in regions where arsenic contamination is known, but there has not been a decision to implement blanket testing and marking. Where the informal private sector installs household wells, these follow-up surveys may continue until locally accessible arsenic monitoring systems are operational.

Blanket Testing and Marking: aims to test all water sources in an area and is conducted by specially trained teams from line departments, NGOs or contractors. Blanket testing and marking usually focuses on a single parameter (arsenic) using field kits and should include a public health education programme providing immediate communication of relevant information to the users and owners of contaminated water sources.

Commissioning Tests: should be a mandatory requirement for every agency installing new water sources in arsenic-affected areas prior to equipping the bores to ensure that contaminated sources are not put into use. Given the high incentives for drillers to drill safe boreholes the weight of experience suggests that commissioning tests should be subject to additional levels of quality assurance and quality control.

Operational Monitoring: is routine monitoring (water quality testing and/or visual observations) undertaken by a water supplier, which does not measure the parameter of ultimate concern (in this case arsenic), but rather confirms that control measures are working properly. Examples of operational monitoring are: testing chlorine residuals, or (in the case of arsenic) checking that sources marked as unsafe are not used for drinking. This is further described in Chapter C9.

Compliance Monitoring: is undertaken to confirm compliance with drinking-water quality standards (in this case for arsenic). Compliance monitoring may be undertaken by a water supplier or the surveillance agency and is described further in Chapter C9.

Surveillance: is an independent public-health assessment of the safety and acceptability of drinking-water supplies. Surveillance is described further in Chapter C9.

Citizen Monitoring: is testing which is initiated by citizen consumers rather than agencies. There are two basic types of citizen monitoring: (i) where individuals or community-based organisations (CBOs) undertake their own testing campaigns, or (ii) where citizens engage professional testing services by public or private providers to provide either laboratory or field-based testing services.

Randomized Surveys: are like the Detailed Surveys and may be part of multipurpose national surveys but belong to the management of the operational phase. Their purpose is to provide a representative snapshot of the levels of exposure in a region or country. Randomized surveys are particularly valuable in providing an overview of the levels of exposure where surveillance programmes are poorly developed and the prevalence of arsenic exposure is reasonably high.

Water Resource Monitoring: complements the testing described above and concentrates on the state of water resources to identify bulk changes in water quality or quantity particularly with a view to warn of the possible migration of contaminants towards safe sources. These are typically conducted by specialist water resource or environmental agencies as part of groundwater mapping and future water resource planning processes.

Box 9**Setting Up a Blanket Arsenic Testing and Marking Campaign**

In establishing a blanket arsenic testing and marking programme the following should be considered:

- (i) Blanket testing and marking for arsenic should be preceded by one or more reconnaissance surveys to identify the approximate extent of arsenic contamination and range of arsenic concentrations.
- (ii) Blanket testing and marking is most effectively conducted with field kits supplemented by laboratory testing for quality control purposes.
- (iii) If not already existing, a unique well identification code should be introduced and physically recorded at the well or its surrounding area.
- (iv) Prioritizing a GPS referenced database for all wells will improve monitoring, enable mapping and planning, and facilitate the provision of feedback from water users.
- (v) Quality assurance should go beyond simple quality control of field kit test results, to include refresher training, supervision and surveillance of the testing programmes.
- (vi) It is imperative that blanket testing and marking is accompanied by the dissemination of information about arsenic and water safety, with messages tailored to suit the result of each test.

understandable reluctance to repeat blanket testing and marking. However, with good planning and robust systems to test all new water sources the need to repeat blanket testing and marking processes can be avoided.

In the Management Phase, testing should be decentralised and accessible to all managers of drinking-water sources (as well as users of the water supplies) through some combination of line departments and local government, NGOs and the private sector. Developing information systems to collate information from both public and private tubewells against screen depth is extremely important to improve the understanding and mapping of arsenic risks. Access to this information by water resource planning organisations as well as drillers will improve the efficiency of public and private investments.

Randomised surveys that include water quality testing (i.e. the Multiple Indicator Cluster Survey conducted by National Statistics Organisations

with UNICEF) are valuable in providing periodic evaluations of the overall level of exposure but they are no substitute for permanent monitoring systems as they do not provide knowledge of the status of individual water sources in a manner that enables the providers and consumers to manage their risks of exposure.

Additional Resources

Ravenscroft, P. (2008) Predicting the global extent of arsenic pollution of groundwater and its potential impact on human health. UNICEF, New York. http://users.physics.harvard.edu/~wilson/arsenic/references/Ravenscroft_Prediction.pdf

Groundwater Assessment Platform (GAP): Groundwater quality information management system on geogenic contaminants, EAWAG

<http://www.eawag.ch/en/research/humanwelfare/drinkingwater/gap/>

<http://www.gapmaps.org/>



C6

Measuring Arsenic in Drinking Water**Introduction**

Testing for arsenic is central to any arsenic-mitigation programme. Testing is carried out both to assess the extent of the arsenic problem on a large scale (reconnaissance surveys) and to ascertain and mark which sources within individual communities are contaminated. Testing is not a one-off activity and, following the undertaking of any blanket testing and marking programme, it should be institutionalized to test all new water points that continue to be installed; to understand changes in arsenic contamination; and to assess the effectiveness of mitigation efforts on arsenic exposure.

While testing water for arsenic is more difficult than testing for most other chemical contaminants, the methods available have improved significantly in recent years. A combination of field and laboratory testing methods with appropriate quality assurance and capacity building measures will be required within any arsenic-mitigation programme.

The methods described below focus on measuring the inorganic arsenic concentrations in water. Concentrations of organic arsenic having significance for health are exceptionally rare in drinking water and are therefore not measured for public health surveillance purposes. Analysis of arsenic in food, crops, body tissue or fluids, soils and rock is beyond the scope of this document.

Field Testing for Arsenic

In the past, arsenic field tests were semi-quantitative at best, but the accuracy and precision of field test methods have improved dramatically. The most commonly used field test methods rely on the reduction of arsenic to arsine gas (Gutzeit method) which reacts with chemicals in a test paper or indicator tube to produce a colour change. Comparison with a colour chart then enables the arsenic concentration to be estimated either manually

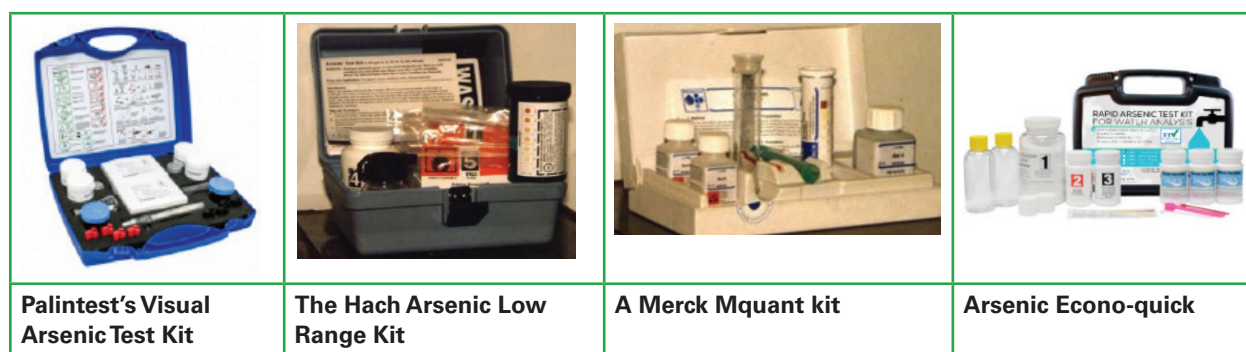
Chapter Summary:

- Testing should not be a one-off activity. It should be carried out to assess the extent of the arsenic problem, to understand changes in contamination, and to assess the effectiveness of mitigation efforts.
- Lab testing would historically yield more reliable results than field tests. However, the accuracy of arsenic field tests has improved dramatically, giving an opportunity to carry out large-scale testing and providing immediate feedback.
- It is important to balance the mobilization of resources in the initial intense phases of a mitigation programme with long-term investments in developing national water surveillance systems.



or electronically using a digital photometer. As colour changes are subject to interference by sulfide, modern kits include a reagent to prevent sulfide reaching the test paper.

Most field test kits have colour charts graduated to read in broad divisions such as 10, 25, 50, 100 and 200 ppb where the tester records the closest match. This relatively coarse banding of field kit charts can raise procedural issues however testers should not attempt to interpolate between readings – as this is a false accuracy. For example, if the national standard is 50 ppb and the result from a reliable field test is also 50 ppb, then the sample can be classified as compliant even though the actual result could have been anywhere between 37.5 and 75 ppb (the midpoints between 25 and 50, and 50 and 100 ppb, assuming that these common values are shown on the colour chart).



Picture 5: Examples of arsenic field-testing equipment

Experience shows that for most natural waters where laboratory tests indicate an arsenic value of 50 ppb, most field kit results will fall slightly below 50 ppb, however some test results could exceed 50 ppb. Deciding whether to accept or reject border values or alternatively retest such waters in a laboratory is an important procedural issue that needs to be determined by the relevant authorities.

The quality of field test results is dependent on the quality of training and strict adherence to defined procedures in the field. Field kits available in the 1990s were initially not very reliable, producing too many false negative results at the 50 ppb threshold, but reliability has improved to the point that they are now reliable at even the 10 ppb level, though it can be difficult to consistently distinguish very light colour changes. This has enabled field kits to be deployed to identify the risks of consuming water below, above and within the 10- 50 ppb range allowing the introduction of a three-colour painting scheme classifying arsenic concentrations: >50 ppb as red, 10-50 ppb as green, and ≤10 ppb as blue (van Geen et al. 2014).

Laboratory Testing for Arsenic

There are various methods available for the laboratory testing for arsenic. In order of increasing sophistication (and cost) these range from the Silver Diethyl-dithio-carbamate (SDDC) colorimetric method, using a photometer or spectrophotometer; Anodic Stripping Voltammetry (ASV); Graphite Furnace Atomic Absorption Spectrophotometry (GF-AAS); Flame AAS with Hydride Generation apparatus (HG-AAS); to Inductively Coupled Plasma

Optical Emission Spectrometry (ICP-OES) and Inductively Coupled Plasma Mass Spectrometry (ICP-MS). In well managed laboratories, AAS techniques will achieve sufficiently accurate results at concentrations of 1 ppb or less while ICP techniques offer similar detection limits, along with the ability to analyse for many other metals and metalloids at the same time as arsenic.

Sampling Procedure

It is important that correct sampling procedures are followed for both field and laboratory testing of arsenic. The first choice is to decide whether the water is to be sampled at the point of consumption (usually within the household) or at the point of collection (e.g. a borehole). Normally the chemical quality of water at these two points is very similar, but household water can contain less arsenic due to the co-precipitation of iron and arsenic during storage. Initial surveys should sample water at the point of collection to seek



Picture 6: Econoquick Test Kit Colour Chart
© UNICEF/UNI142282/Haque

Picture 7: Laboratory Test Procedures



The SDDC colorimetric method



An HG-AAS machine

©UNICEF/2005/Nickson

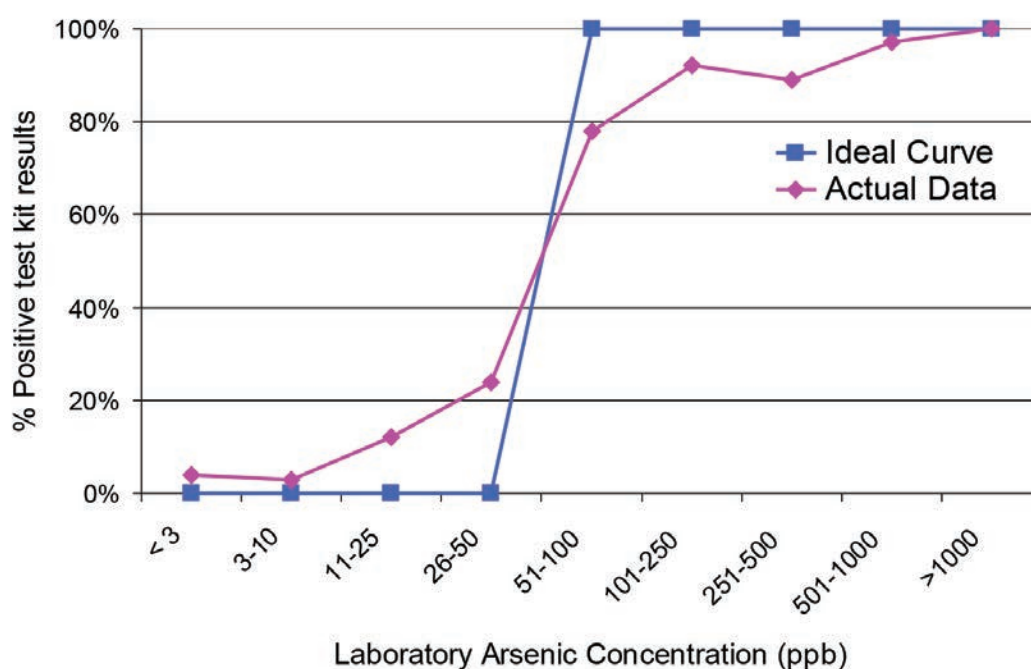


Figure 11: Merck 'Sensitiv' test kit survey results in Bangladesh

Source: (Rosenboom, 2004)

to ascertain the probable public health risk at the various points of use¹¹. Ideally water samples tested should be representative of the water that users take to their homes. Hydrogeological and other surveys will require different sampling strategies. Operational wells should be sampled during a period of sustained use as this negates the need for flushing, however, if this is not possible, at least one well-volume of water should be removed before taking a sample. For piezometers and inactive wells, the convention of removing three well-volumes of water should

apply unless dedicated in-situ sampling devices have been installed.

Field tests should be conducted immediately after collecting the water sample. If samples are to be transported to a laboratory for analysis, the sample is normally acidified to a pH of <2 by adding a small quantity of concentrated reagent-grade nitric or hydrochloric acid at the time of sample collection. Alternatively, acidification can take place later in the laboratory provided the samples can settle for a few days for any

¹¹ Hydrogeological and other purpose surveys will obviously require different sampling strategies.

Box 10 Field versus laboratory testing

	Field Testing	Laboratory Testing
Strengths	• Rapid – large numbers of samples can be tested in a short period of time. • Simple – field testers require less education and skill than laboratory staff. • Low cost. • Results obtained, recorded and shared immediately with locals to begin raising awareness. • Less chance of misreporting of results. • Potential to engage those from arsenic affected areas that are highly motivated.	• Inherently more precise and, when properly conducted, more accurate than field testing. • Conducted by professional scientists with more analytical understanding of the context. • Can build longer term capacity for general water quality monitoring and surveillance. • Laboratory provides a focus and a base for water-quality work. • Procedures are more auditable.
Weaknesses	• Overall accuracy and precision are lower than properly conducted laboratory testing. • Difficult to distinguish light colour changes particularly at values around 10 ppb. • Interpretation of results can be ambiguous particularly at the border value limits (i.e. 50 ppb or 10 ppb). • More potential for human error as more people are carrying out the testing. • Requires more quality control and field supervision. • Difficult to investigate systemic problems associated with temporary survey staff.	• Requires sophisticated equipment, trained staff and long-term support systems. • Requires good chain of custody systems to transport samples from field to lab. • Correct sample collection, labeling and handling required. • More expensive. • Equipment requires maintenance, calibration and spare parts. • More difficult to communicate results back to users, possibility of potential delays or errors.

precipitate of iron oxyhydroxide (orange colour commonly seen in groundwater containing iron) to redissolve. This reduces the risks associated with having field teams carrying acids but is best planned with the laboratory supplying the bottles and any preservatives required.

Relative Strengths and Weaknesses of Field and Laboratory Testing

The advantages and disadvantages of field and laboratory approaches are summarized in Box 10. While laboratory equipment will produce more accurate and precise results, field testing offers the ability to provide immediate feedback to providers and users on the condition of water sources. Although the dependence on field versus laboratory testing regimes will vary depending on local capabilities and constraints,

most water quality surveillance systems are comprised of a combination of bulk testing using field kits and quality control using laboratories.

While field kits are inferior to laboratory methods for the precise and accurate measurement of arsenic concentration, the advantage of field kits is that they are a practical, rapid and cost-effective means of both assessing and providing immediate feedback on the quality of water to providers and users in the context of a potential public health crisis. Field kits are practical in enabling the maximum number of people to be removed from the most dangerous levels of arsenic exposure in the minimum time, enabling technically superior measurement systems to be established in the medium to long term.

During the early 2000s, field test kits results in India and Bangladesh were used in a semi-quantitative manner to classify wells as above or below the national standard of 50 ppb. While field test kits are reliable when arsenic levels are well above or well below the 50 ppb threshold value, false positives and negatives when they do occur rarely result in an error by more than one colour band (i.e. 50 ppb tested as <25ppb or >100 ppb). Figure 11 shows that field kits in Bangladesh were most likely to have errors in the 25-100 ppb range. As the test methods and the accuracy of the test kits improve, it is likely that transcription errors will become a greater relative source of error.

In the longer term, national water-quality testing capacity needs to be strengthened, optimizing the use of field and laboratory methods, and decentralising testing to the maximum extent that quality can be assured. In parallel, attention should be given to promoting the two-way flow of information on arsenic contamination through mobile technologies and web-based applications.

The reference list at the end of this chapter includes case histories of some successes

Box 11

Water-Quality Testing Regime in Uttar Pradesh, India

Faced with the prospect of testing a huge number of public and private tubewells in Uttar Pradesh in the late 2000s, UNICEF supported the government in implementing a combination of field and laboratory testing. Fourteen zonal laboratories were equipped with either the SDDC method with a photometer or a field kit with a colorimeter. Field testing was conducted with simple field kits and where testing indicated >40 ppb, confirmatory samples were sent to the zonal laboratory for retesting. An additional 5% of sources (i.e. 1 in 20) were also randomly sampled and tested in the laboratory for quality control purposes.

and failures of field testing campaigns and Box 12 provides information on some of the widely used arsenic-detection field kits. While some kits have distinct advantages, there is no single best kit that is independent of considerations of cost, accuracy, ease of use, robustness and institutional setting. Moreover, the improvements over the last 15 years show that recommendations can soon be outdated and therefore those responsible for procurement should reassess the best option for a particular context paying attention to emerging technologies such as electrochemical methods and biosensors.

Health and Safety Issues in Field Testing

While laboratory personnel will already have a high degree of sensitivity to the hazards of handling chemicals and equipment, this will not necessarily be the case for most people engaged in field testing for arsenic. It is the responsibility of those organising the field testing to ensure safe working practices through proper training, documentation and supervision. Trainers should consult the kit manufacturer's literature when designing any training course however essential control procedures should include:

- Hand washing before and after testing.
- No consumption of food or water, or smoking, during testing.
- The reagents may include toxic or hazardous substances such as acid. Direct contact with the skin should be avoided and any contact should be washed off the skin immediately.
- Most kits generate small quantities of highly toxic arsine gas. Although this gas is normally absorbed by the test paper, the risk that some may escape to the atmosphere requires that testing must always be conducted in a well-ventilated location.
- The test paper is impregnated with highly toxic mercury bromide. Used test papers should never be left on site but placed in a plastic bag and disposed of as a hazardous waste.
- All chemicals that are carried into a village or house should be taken away with any unused or waste chemicals disposed of through the nearest laboratory.

Box 12 Commercially Available Arsenic Field Test Kits¹²

- Acustrip Inc. (www.acustrip.com) markets five different arsenic test kits. The main product, the Arsenic Check test (#481396) has a range of 5-500 ppb, while the lower-priced, less sensitive version (#481298) has a range of 10-1,000 ppb. The company also markets a low-range kit (#481297) with a range of 2-160 ppb and two “individual” kits for household use. The Acustrip kits have a reported reaction time of only 12 minutes.
- Hach (www.hach.com) produces two arsenic test kits. The EZ Arsenic Kit (# 2822800) has a range up to 4,000 ppb, takes fewer steps, and is more economical. The Low Range Kit (# 2800000) has a range up to 500 ppb and is best for samples containing sulfide or arsenic-iron particles.
- Industrial Testing Services (www.sensafe.com) produce the Quick™ range of kits that can detect down to 0.3 ppb but all kits detect concentrations below 5 ppb and report results within 14 minutes.
- Merck (www.merckmillipore.com) has produced arsenic test kits for many years and markets two colorimetric kits: the standard MQuant™ arsenic test kit (#117917) with a reported detection range of 20-3000 ppb, and the newer, more sensitive kit (#117927) with a reported detection range of 5-500 ppb. Merck also produces a digital optical photometer Spectroquant® arsenic kit (#101747) with a reported range of 1-100 ppb for more accurate measurement of colour. These photometers are typically used in laboratories but the Nova 60A (# 1.09751.0001) has a battery pack and can be used as a “portable field station”.
- Palintest Water Analysis Technologies (<https://www.palintest.com>) produces the Digital Arsenic Test Kit (PT 981) which uses an optical photometer to measure the colour change on mercuric bromide paper. It is portable and detects arsenic in a reported range of 2-100 ppb. Palintest also produce a Visual Arsenic Detection Kit (VCDK) with a reported range of 10-500 ppb that is cheaper but less precise. As a result, the Digital Kit has been used for quality control of manual testing in some large programmes.

Additional Resources

American Public Health Association (2005) Standard Methods for the Examination of Water and Wastewater, 21st Edition, APHA/AWWA/WEF. <https://www.standardmethods.org/>

George, C. M., Zheng, Y., Graziano, J. H., Rasul, S. B., Hossain, Z., Mey, J. L., & van Geen, A. (2012). Evaluation of an Arsenic Test Kit for Rapid Well Screening in Bangladesh. *Environmental Science & Technology*, 46(20), 11213–11219. <http://doi.org/10.1021/es300253p>

Jakariya, Md. et al. (2007) Screening of arsenic in tubewell water with field test kits: Evaluation of the method from public health perspective, *Sci. Tot. Env.*; 379, 2-3: 167-175. <https://pdfs.semanticscholar.org/152f/0b722ba1308de73d098e307cc891226af60c.pdf>

Rosenboom, J. W. (2004). Not Just Red or Green: An Analysis of Arsenic Data from 15 Upazilas in Bangladesh. Dhaka, DPHE/APSU/ UNICEF. <http://citeseerx.ist.psu.edu/viewdoc/download?doi=10.1.1.160.9978&rep=rep1&type=pdf>

Steinmaus, C. M., George C.M., Kalman D.A, Smith A.H., (2006) Evaluation of Two New Arsenic Field Test Kits Capable of Detecting Arsenic Water Concentrations Close to 10 µg/L, *Environ. Sci. Technol.*, 40 (10), 3362 -3366. <https://pubs.acs.org/doi/abs/10.1021/es060015i>

Van Geen, A., Sumon, E. B. A., Pitcher, L., Mey, J. L., Ahsan, H., Graziano, J. H., & Ahmed, K. M. (2014). Comparison of two blanket surveys of arsenic in tubewells conducted 12 years apart in a 25 km² area of Bangladesh. *The Science of the Total Environment*, 0, 484–492. <http://doi.org/10.1016/j.scitotenv.2013.12.049>

¹² This list does not include all available kits and it is not an endorsement of the companies or products listed.

C7

Selecting Barriers (Provision of Safe Water)

Introduction

This chapter concentrates on the provision of arsenic-safe water supply options with the caveat that any technical solutions must be combined with behavioural change communications and systems support (covered in the following chapters). The decision tree in Figure 8 and the associated text in chapter C4 is particularly relevant to this notion of introducing control measures to safeguard against arsenic contamination risks. In selecting mitigation options (or introducing control measures), it is vital to appreciate the importance of time in reducing exposure. Delay in mitigation increases the levels of exposure and the associated risks of disease. This means that staging of a response is often extremely effective in reducing the overall levels of exposure. For instance, while well sharing might be socially unsustainable in the long-term it can reduce arsenic exposure levels very cheaply in the short term while more sustainable options such as piped water networks are being designed, funded and constructed.

Control Measures – Catchment Management

Catchment management is a conventional part of Water Safety Plans aimed at the control of anthropogenic hazards (usually within a multiple barrier approach). Though it is relevant to all water supplies it has limited application to reducing arsenic exposure because the source of contamination is usually the aquifer itself. Nevertheless, a detailed conceptual understanding of the distribution of arsenic and the capture zones of groundwater sources can help to avoid or reduce arsenic contamination of boreholes. In some cases, this may enable groundwater abstraction to be planned to promote long-term natural attenuation of arsenic contamination in-situ.

Chapter Summary:

- When selecting mitigation options, it is vital to appreciate the importance of time in reducing exposure, as any delay in mitigation increases the level of exposure and the associated risk of disease.
- To control arsenic poisoning, people must access arsenic-safe water by: switching to an existing safe source, blending water from sources that have different levels of risk, constructing a new source or removing arsenic from contaminated water.
- Removing arsenic from water is generally more technically challenging, more difficult to maintain and operate and cost prohibitive for poorer communities and households.
- Whatever option is chosen the new source must be protected from faecal contamination.



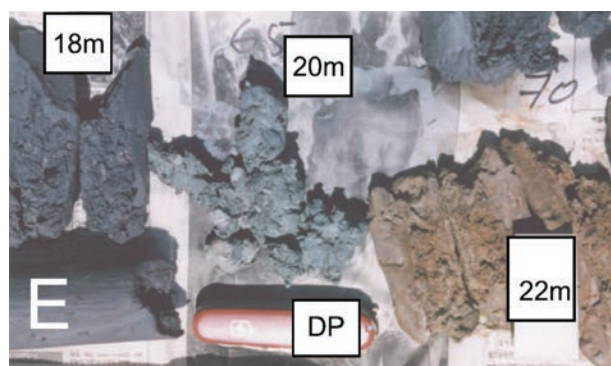
A special case of catchment management applies to cases of sulfide oxidation where it is highly desirable to minimise fluctuation of the water table across critical arsenic-rich horizons (see Chapter B2). While the arsenic-rich sulphide layers can be relatively harmless when permanently immersed, they can be sources of serious arsenic pollution if exposed to the atmosphere. Preventing this form of exposure to arsenic contamination requires: (i) knowledge of the location of these arsenic rich sulphide layers; (ii) reliable monitoring of the water table depth; and (iii) the regulatory ability to manage aquifer levels through preventing over abstraction.

Control Measures – Source Substitution

While developing new water supplies is beyond the scope of this chapter (see e.g. IRC, 2002) the following offers an overview of the issues affecting the most probable alternate water sources (i.e. groundwater, surface water and rainwater) in arsenic-affected areas.

Groundwater

Not all aquifers will be contaminated in the alluvial areas, where arsenic is commonly found. Typically, “very shallow” aquifers (often tapped by dug wells) are likely to be relatively low in arsenic, while the ‘middle’ aquifers are more likely to be contaminated, and the “deep” aquifers are usually very low in arsenic. The depths of the arsenic-contaminated aquifers can vary widely and need to be determined locally.



Picture 12: The palaeosol horizon at 22m on the DP site in West Bengal is a natural barrier to arsenic migration.

© UNICEF/2008/McArthur

Aquifers formed of older (Pleistocene) alluvium are usually very low in arsenic and can often be identified by their brown (oxidized) colour. These older arsenic-safe sediments are often found at depths of a few tens of metres beneath a protective reddish-brown palaeosol (“old soil”) clay (see Picture 12). In such situations, the detailed mapping of arsenic concentrations against well depths can provide guidance on the likely safe depth for well installation and offer a baseline against which arsenic contamination levels may be evaluated.

Where shallow arsenic-safe groundwater is available, it is more likely to be proximate to the point of use and less prone to faecal contamination as compared to surface water but more prone to faecal contamination than deeper aquifers. Where deeper arsenic-safe aquifers are available, they can be tapped by drilling boreholes and installing handpumps or

motorized pumps. In alluvial formations, it is possible to manually drill boreholes to depths of 200 m or more. Mechanized drilling rigs enable the installation of high capacity pumps for larger communities or drilling in areas with difficult formations (i.e. gravel).

Surface Water

Surface water is used throughout the world as a source of domestic water supply for both large piped systems and smaller rural systems. Surface water is more susceptible than groundwater to seasonal variations, bacterial contamination (both human and animal) and anthropogenic chemical contamination (i.e. industry, agrochemicals). The necessity to treat surface water increases the complexity and the cost and the possible rejection by consumers because of the taste of chlorine resulting in lower levels of sustainability, especially in rural and poorer areas.

Rainwater

Rainwater is usually very pure when it reaches the earth, notwithstanding the deposition of atmospheric pollutants around some urban areas. The safe harvesting of rainwater is subject to challenges posed by the collection and storage of a sufficient quantity of water. The safety challenge is primarily because the surfaces used to collect rainwater are often not clean and must be flushed before water is collected. Maintaining a sufficient quantity of rainwater means that it must be stored for long periods of time increasing the cost and the susceptibility to microbial contamination.

In countries where there is a long and successful tradition of household rainwater harvesting and storage this should be considered a viable arsenic mitigation option. On the other hand, the performance of rainwater harvesting systems has been poor when it has been introduced primarily as an arsenic mitigation option. This suggests a need for greater institutional support if rainwater harvesting is to be introduced as an effective arsenic mitigation option.

Other Alternatives

In many cases, the optimal solution (at least in the short term) will be a combination of sources

and technologies that could include rainwater harvesting in the wet season, sharing boreholes during the dry season, using surface water for cooking and arsenic-contaminated wells for bathing. In some situations, the required quantity of water may be achieved by blending contaminated groundwater with rainwater or treated surface water to meet the national water-quality standards. In coastal and saline areas, reverse osmosis treatment may be employed to desalinate brackish groundwater but the cost to build and operate means that it should be considered one of the options of last resort.

Control Measures – Arsenic Removal

Removing arsenic from water is generally more technically challenging, more difficult to operate and maintain, and often too expensive for poor communities and households.

Removing arsenic from drinking water can be technically challenging because the treatment target is so low (i.e. reducing concentrations to 10 ppb or 50 ppb can mean target reduction rates of over 90%). Identifying the target concentration reduction is extremely important because while many of the methods can reduce arsenic to 50 ppb or below, some methods struggle to achieve levels below 10 ppb.

The most common low-cost removal techniques are co-precipitation and adsorption using iron oxyhydroxides or activated alumina. Here the chemistry of the local groundwater is extremely important in choosing an arsenic removal method. Where arsenic has been mobilised by reductive dissolution (see Chapter B2) the waters are reducing and therefore rich in iron (and sometimes manganese). High levels of iron in drinking water need to be removed (because it is aesthetically objectionable) but this is also an asset because the oxidation of iron using aeration will also remove arsenic. Removal of arsenic with natural iron works best where the iron to arsenic mass ratio is >20:1 and preferably >40:1 (Hug, 2008). Where arsenic is mobilised by sulfide oxidation, alkali desorption or geothermal activity, the water will usually be toxic and low in iron requiring more complex arsenic removal technologies such as synthetic adsorbents.



Picture 13: Nirmal combined arsenic and iron removal filter used in India

© UNICEF/2003/Keast

As arsenic removal efficiency depends strongly on the composition of water, it should be considered essential to test the water and desirable to conduct trials before deployment of any treatment technology. High levels of phosphate and other competing ions can significantly reduce the efficiency of arsenic removal systems.

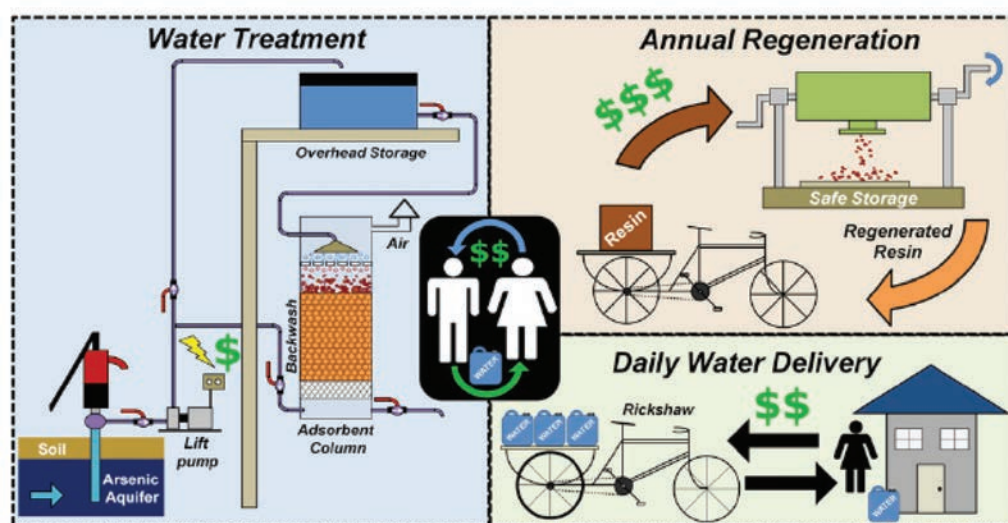
Different types of arsenic removal units are available for municipal water systems; large rural piped systems; small community systems attached to handpumps; and household containers using hand-carried water.

- Large urban supplies are the most likely to have the technical and financial resources needed to design, install and maintain arsenic removal systems. Smaller municipal systems, especially those that don't already include treatment steps, may struggle to provide the long-term institutional support necessary for efficient operation and maintenance.
- In rural areas where there are many small supplies, conventional treatment methods may be too complex. Community arsenic-removal systems, often relying on adsorption or ion exchange, appear to offer a fair compromise between technical complexity, collective motivation and the provision of institutional support. While these community arsenic-removal systems can be managed by social businesses (German, 2013) the financial and technical resources for long-term sustainability may be all too limited.
- While household arsenic-removal filters are the easiest to procure and distribute quickly, there are few examples of long-term sustainable use and lots of anecdotal evidence of abandonment. By and large, household filtration systems have not received the

necessary institutional support from vendors to sustain operation and maintenance, beyond pilot studies where the cost and effort is disproportionate to the scale.

In Bangladesh, the government implemented a comprehensive assessment programme to certify household arsenic removal filters prior to their deployment. While this was effective in preventing ineffective arsenic removal devices from entering the market, experience suggests that the technical efficiency was less significant than the ease of operation and the quality of support in determining the effectiveness and sustainability of these technologies.

Though household arsenic-removal devices appear to be a rapid and effective mitigation option, the validation of long-term performance under 'normal' operating conditions are relatively rare. For instance, controlled studies of an approved arsenic removal device (SONO filter) in Bangladesh indicated that it could remove arsenic for eight years, but actual field observations indicated a much shorter life period (Neumann, 2013). Follow-up studies on another approved arsenic removal device (Read-F filter) in Bangladesh indicate that arsenic removal efficiency alone is an insufficient indicator of performance, given the extent to which the application in the field influences effectiveness.



Overview of holistic arsenic treatment in operation: water treatment, daily water delivery, and annual resin regeneration.

Figure 12: Community Filter with social business development

(German, 2013)

Six hundred approved units were monitored monthly for the first six months, and then again after another year without any support. Monitoring of the efficiency of the device from water-quality samples and effectiveness on reducing arsenic exposure from biomarkers (urinary arsenic, uAs) initially showed excellent results. The arsenic contamination levels reduced to <10 ppb and the median uAs reduced from 117 to 51 ppb in a single week. However, after six months the median uAs had returned to 126 ppb and after another year 95% of the units had been abandoned with inconvenience being cited as the main reason for their abandonment (Sanchez, 2016).

Despite all the efforts and the widespread availability of relatively effective low-cost units in the end, arsenic-removal devices have had limited impact on overall mitigation efforts. In Bangladesh, the successful mitigation of arsenic risks for most people living in arsenic-affected areas has been achieved through either well-switching or the provision of deep boreholes. Nevertheless, arsenic removal remains an important mitigation option where those options are not feasible.

Arsenic Wastes

Arsenic removal inevitably produces an arsenic-rich waste or sludge that needs to be disposed of in a responsible manner. While some regard this as a critical obstacle most commentators see this as a tolerable risk because the benefits of arsenic-safe water outweigh the risks of the disposal of arsenic-rich sludge. In any case, a quantitative assessment of the risks posed by the available arsenic sludge disposal options should be undertaken. Depending on national regulations and the availability of safe landfills, every arsenic removal device provider should be expected to submit arsenic sludge disposal solutions for approval. Innovative options for disposal have been known to include the mixing of the sludge with clay for brick-making to immobilize the arsenic, mixing into aggregate used for paving of roads, and blending with cow dung to methylate the arsenic sludge.

¹³ It must be clearly communicated that the boiling of drinking water does not reduce arsenic contamination risks.

Household Water Treatment for Faecal Contamination

Most small-scale technologies offered as alternatives to arsenic contaminated boreholes tend to be more prone to faecal contamination. As a result, the household treatment of drinking water to reduce faecal contamination is often promoted in regions impacted by arsenic across the developing world. By far the most common and accessible protection against faecal contamination is the boiling of drinking water¹³.

Other technologies for household water treatment for protection against faecal contamination are filtration with ceramic filters; chlorination using liquid or tablets; solar disinfection in clear bottles; thermal disinfection (pasteurization) in opaque vessels and combination systems employing chemical coagulation-flocculation, sedimentation, filtration and chlorination. While national regulations will often determine what products can be made available, since 2014, WHO has been evaluating the microbiological performance of household water-treatment products through an International Scheme to Evaluate Household Water Treatment Technologies.

Verifying the Effectiveness of Control Measures

An important part of the Framework for Safe Drinking-water is verifying the effectiveness of arsenic control measures. This verification process entails the routine assessment of mitigation performance against health-based targets (i.e. national arsenic standards and health outcomes).

This may be complemented by periodic surveys assessing the effectiveness of mitigation measures. For instance, Figure 13, shows an example of a national survey in Bangladesh of government-installed water technologies within the previous one to six years. This reveals that although the arsenic compliance was better than the average baseline survey level of 13%, the level of non-compliance was still unacceptably high. Combining the arsenic monitoring information with data on functionality, usage, cost and exposure to other

Waterpoint Type	Number Surveyed	Non-functional	As > 50 ppb	Fe >1.0 ppm	Mn > 0.4 ppm	E coli >0 (source)	Av. HH's served	Nominal Cost (\$)
Deep Tubewells	57,025	7%	7%	50%	12%	31%	47	950
Shallow Tubewells	38,940	10%	9%	47%	49%	32%	10	220
Ring Wells	12,500	23%	4%	42%	40%	72%	9	750
Rainwater Harvesters	1,280	24%	0%	0%	0%	96%	1	320
Pond Sand Filters	2,138	46%	0%	0%	0%	89%	25	1500

Figure 13: Performance of government installed water technologies in Bangladesh Source Ravenscroft, 2014

NB: The figures for shallow tubewells apply only to those with suction-mode ('Nr 6') pumps. Only random samples of the surveyed waterpoints were tested in the laboratory for Fe, Mn and E. coli.

contaminants, demonstrates the importance of a holistic risk assessment to the selection of safe water technologies (Ogata, 2015). This suggests that while deep tubewells pose greater risk of arsenic contamination they continue to serve the greatest number of people, have the highest functionality, the lowest levels of bacterial contamination at the lowest cost per household served.

Additional Resources

German, M., H. Seingheng and A. K. SenGupta (2014). Mitigating arsenic crisis in the developing world: Role of robust, reusable and selective hybrid anion exchanger (HAIX). *Science of The Total Environment* 488-489: 547-553. <https://doi.org/10.1016/j.scitotenv.2013.10.092>

Howard, G., Ahmed, M. F., Shamsuddin, A. J., Mahmud, S. G., & Deere, D. (2006). Risk Assessment of Arsenic Mitigation Options in Bangladesh. *Journal of Health, Population, and Nutrition*, 24(3), 346–355. <https://www.ncbi.nlm.nih.gov/pmc/articles/PMC3013255/>

Hug, S. J., O. X. Leupin and M. Berg (2008). Bangladesh and Vietnam: Different groundwater compositions require different approaches to arsenic mitigation. *Environmental Science and Technology* 42(17): 6318-6323. <https://pubs.acs.org/doi/full/10.1021/es7028284>

Smet, Jo; van Wijk, Christine (eds.) (2002). *Small Community Water Supplies: Technology,*

People and Partnership. Delft, the Netherlands. IRC International Water and Sanitation Centre. (Technical paper Series 40). https://www.ircwash.org/sites/default/files/Smet-2002-Small_TP40.pdf

McArthur, J. M., P. Ravenscroft, D. M. Banerjee, J. Milsom, K. A. Hudson-Edwards, S. Sengupta, C. Bristow, A. Sarkar, S. Tonkin and R. Purohit (2008). How paleosols influence groundwater flow and arsenic pollution: A model from the Bengal Basin and its worldwide implication. *Water Resources Research* 44(11). <http://onlinelibrary.wiley.com/doi/10.1029/2007WR006552/pdf>

Neumann, A., R. Kaegi, A. Voegelin, A. Hussam, A. K. M. Munir and S. J. Hug (2013). "Arsenic Removal with Composite Iron Matrix Filters in Bangladesh: A Field and Laboratory Study." *Environmental Science & Technology* 47(9): 4544-4554. <https://www.ncbi.nlm.nih.gov/pubmed/23647491>

Sanchez, T. R., D. Levy, M. H. Shahriar, M. N. Uddin, A. B. Siddique, J. H. Graziano, A. Lomax-Luu, A. van Geen and M. V. Gamble (2016). Provision of well-water treatment units to 600 households in Bangladesh: A longitudinal analysis of urinary arsenic indicates fading utility. *Science of The Total Environment* 563-564: 131-137. <https://www.ncbi.nlm.nih.gov/pubmed/27135575>

Websites:
WHO International Scheme to Evaluate Household Water Treatment Technologies. http://www.who.int/water_sanitation_health/water-quality/household/scheme-household-water-treatment/en/

C8

Communications and Behaviour Change**Introduction**

Communications should be at the centre of any arsenic response. Access to information on arsenic contamination is extremely important both in facilitating behavioural change and minimizing the perverse negative consequences (i.e. risk substitution) associated with uninformed action. Core components of an effective arsenic communications strategy include:

1. Assessments of existing knowledge, attitudes and practices of consumers in household members' use of water for drinking, food preparation, cooking and other purposes in the arsenic-affected areas. This forms the basis for identifying priority messages to the primary water users to increase understanding of the harmful health effects of arsenic and to motivate households to identify effective strategies to reduce their own exposure to arsenic.
2. Assessments at the project and programme level to understand the existing knowledge, attitudes and practices of the drinking-water providers in the installation, testing, operation and maintenance of water supplies. These assessments should additionally be extended to health and agricultural surveillance services. This forms the basis for communications to providers to modify their systems to identify arsenic exposure risks and manage the provision of alternate water services, as well as the development of systems for managing arsenic exposure through food and the provision of health services to exposed populations.
3. Assessments of the existing knowledge, attitudes and practices of national politicians, technocrats and civil society that dictate the policy and practices towards arsenic mitigation. This forms the basis for advocacy on the allocation of funding, the amending of laws, regulations and standards, the changing of the allocation of roles and the modification of systems and processes without creating fear or necessarily associating themselves with failure.

Chapter Summary:

- To develop effective barriers to arsenic contamination technology options and institutional support must be coupled with behaviour change and social norms interventions.
- Promoting behavioural change can be especially challenging for arsenic mitigation, as arsenic in water is invisible and tasteless, and the consequences of ingestion are not visible in the short term.
- Behaviour and social norm change programmes can promote the uptake and sustained use of alternative safe water sources or household arsenic removal options.
- By conducting collaborative technological and social assessments of the knowledge, attitudes and practices of users, providers and policymakers at the outset it is possible to design sustainable packages of social, technical and support actions.



These communication assessments and communications delivery need to be viewed as two-way processes of understanding and testing the means of changing the behaviour of consumers, service providers and policy-makers to respond to the risks of arsenic contamination to ensure safe water for all (i.e. an adequate, accessible and affordable quantity of water free of chemical and microbial contamination for all).

Communication Challenges

Promoting behavioural change is always challenging and especially so for arsenic mitigation. Because arsenic in water is invisible and tasteless and the consequences of ingestion are not visible in the short term the first challenge is simply convincing people that arsenic is present and that it poses a health risk. Establishing the link between consuming arsenic and developing skin diseases has proven to be quite practical but convincing some people that their apparently clean water source may pose serious health problems (including cancer) many years in the future is very difficult. This difficulty

is often compounded by solutions that generally involve giving up the most convenient drinking-water sources that entail a loss of privacy or create an extra burden in carrying water. Due to the long-term nature of the problem, modified patterns of behaviour need to be sustained for many years even though there may be no visible benefits of doing so.

Behavioural Studies in the Assessment Phase

Choosing a good technology is a necessary but not sufficient condition for mitigating arsenic contamination. Technically robust interventions have often failed because of a lack of motivation to sustain their operation or just being technically inappropriate to the context. Most often this is underpinned by a failure to understand the perspective of the end users and the operators. Typically, the technical design and construction elements are undertaken first, with the training and motivation activities added later stage.

By conducting collaborative technical and social assessments of the knowledge, attitudes and practices of the users, providers and policy-makers at the outset it should be possible to design sustainable packages of social, technical and support actions. Such assessments are likely to include techniques ranging from simple questionnaires and interviews, to narrative ethnography and methods based on the Theory of Planned Behaviour (see, e.g. Inauen 2013 and Mosler 2010) and should include:

- a) People's understanding (beliefs) about (i) the nature of arsenic poisoning and its victims; (ii) the benefits of mitigation in relation to other threats to life and livelihood; and (iii) willingness to seek mitigation and whether this is achievable (i.e. self-efficacy in relation to bureaucratic obstacles) and whether their peers will support or oppose such action (social norms).
- b) Preferences between individual and community systems.
- c) The desirability of arsenic mitigation versus alternate community priorities such as electrification, roads and schools. This is particularly important where only part of a community is affected by arsenic contamination while other alternatives benefit the whole community.

- d) The acceptability of technological options in terms of palatability, quantity produced, accessibility, and user expectations of upfront payments, and their willingness and ability to pay in cash and/or kind for O&M.

Maintaining Momentum and Longer-Term Challenges

Experience suggests that the instinctive response to arsenic contamination is one of disbelief and denial. Disbelief as people struggle to believe that existing water management practices might be harmful and denial of the need to change often reinforced by the social and economic costs of that change. Understanding the reasons for disbelief and denial is extremely important because they can be remarkably persistent. For instance, while the effects of arsenic contamination in the drinking water in South Asia have been accepted for almost 20 years there is still widespread disbelief that arsenic can contaminate rice and an almost complete denial of the arsenic-related imperative to change rice growing, cooking and eating practices in some areas.

The establishment of a consensus on the problem and the initiation of an arsenic mitigation programme is often followed by a period of stagnation. Where arsenic mitigation is conducted by multiple government and non-government agencies and private initiatives it is difficult to track the progress in mitigation activities and the reduction in exposure levels. As a result, arsenic mitigation interventions are prone to elite capture and overstated optimism on the expected versus the actual performance of mitigation options (partially because of the invisible and tasteless nature of arsenic contamination and partially because of the emotive nature of the arsenic issue). Thus, while periodic sample surveys may reveal that mitigation is not reducing exposure, there is a tendency to persist with ineffective investments in the face of not knowing what else to do.

Preventing stagnation requires the early establishment of robust monitoring and surveillance systems for all government, NGO, private sector and household wells with transparent and accountable public reporting

mechanisms. Establishing a system for clearly marking all water sources to show which source is safe, which source is not safe and which source has not been tested is vital right from the start. This must be accompanied by a parallel communications campaign ensuring that everyone understands (i) the marking system; and (ii) the dangers of arsenic poisoning beyond skin diseases. Access to accurate and meaningfully compiled and displayed information has proven to be the most promising means of maintaining the momentum and continuously correcting the direction of arsenic mitigation activities.

Communications for Reducing Arsenic Exposure

Barriers to arsenic exposure are constructed through packages of technology, behaviours and institutional support systems. In some cases, the technology can be extremely simple (i.e. the blanket testing and marking of wells) and the cost very low (i.e. the switching to safe sources owned by neighbours) but effectiveness depends on the desire to collect safe water and is determined by social constructs (i.e. the willingness to share a safe source). In Bangladesh, blanket testing accompanied by effective communication campaigns and a cultural willingness to share water sources enabled millions of people to switch to arsenic-safe sources.

In other cases, more complex technologies need to be associated with a detailed understanding of behaviour and incentives. A failure to fully comprehend the associations that people have with convenience can lead to surprising results. For instance, while research of arsenic-contaminated areas in Bangladesh revealed a strong willingness to pay for the convenience of piped drinking water that is also safe (World Bank, 2002), however arsenic mitigation via rural piped drinking-water systems has not proven to be successful. Similarly, while numerous low-cost arsenic removal technologies have been developed and promoted within Bangladesh, failures in the O&M of these filters has resulted in limited sustainable deployment of these technologies.

¹⁴ Note in other countries, arsenic-safe wells may be painted green.

Figure 14: India Arsenic Programme Key Messages

© UNICEF



Ask for testing and mark the spout red or blue depending on the result.



Avoid water from a red-spout tubewell



Do drink water from a blue-spout¹⁴ tubewell



Drink only safe water even if it means carrying it back from a far-away blue-spout source

Changing beliefs, attitudes and norms

Regardless of what is done to support specific solutions, some form of behaviour change communications is required to change the knowledge, attitude and practices of the population living in affected regions (including both those exposed and those not exposed).

The stratification of target groups, the development of messages and the choices of media and methodologies form an essential part of the development of communication campaigns. Once communication materials and methods are developed they still need to be field tested and modified accordingly prior to their release. Effective communication campaigns are an invaluable investment in mitigating the risks of arsenic exposure. Ensuring the effectiveness of communication campaigns requires the allocation of sufficient resources to their monitoring and evaluation.

Communication campaign design principles

Key principles to consider when designing an arsenic communication programme are:

- Levels of knowledge can be raised, but knowledge may have little effect on behaviour.
- Beliefs and values influence how people behave.
- A behaviour is more likely to be repeated if the experience is rewarding (i.e. improved symptoms) and less likely if the experience is punishing or unpleasant (i.e. greater ostracism).
- Individuals are not passive responders but can take a proactive role in behaviour change.
- Social relations and norms have a critical and persistent influence on how people behave.
- Behaviour is not independent of context. People influence, and are influenced, by their physical and social environments.
- Focus should be on interpersonal communication techniques as much as possible

National policy and advocacy

At the national level, initially there is likely to be great interest in the issue of arsenic and the response from the public institutions and civil society. During the Assessment Phase, agencies should give greatest attention to providing accurate information, supporting local researchers, and facilitating the access

of exposed populations to mitigation activities. Raising awareness and changing behaviours can be facilitated by skilful mass media campaigns (i.e. television and radio messaging).

Countries may develop Arsenic Policies which can be effective in mobilizing and coordinating activities across different sectors but care should be taken not to be over-prescriptive in identifying the means rather than the objectives of mitigation. In the Management Phase, the most important action is the promotion of transparency and accountability through clear public reporting. In some cases, an annual “State of Arsenic” report may provide a summary on the progress and the challenges but in other cases this may not be politically tenable.

Additional Resources

Arsenic communication packages available with the UNICEF offices in India and Bangladesh.

Inauen, J., M. M. Hossain, R. B. Johnston and H.-J. Mosler (2013). “Acceptance and Use of Eight Arsenic-Safe Drinking Water Options in Bangladesh.” *PLoS One* 8(1): e53640. <https://www.ncbi.nlm.nih.gov/pubmed/23326477>

Mosler, H.-J., O. R. Blöchliger and J. Inauen (2010). “Personal, social, and situational factors influencing the consumption of drinking water from arsenic-safe deep tubewells in Bangladesh.” *Journal of Environmental Management* 91(6): 1316-1323. <https://www.dora.lib4ri.ch/eawag/islandora/object/eawag:6324>

United Nations ACC Sub-Committee on Water Resources (2002). United Nations synthesis report on arsenic in drinking water. Chapter 7: Communication for Development (Michael Galway). WHO <https://www.ircwash.org/resources/united-nations-synthesis-report-arsenic-drinking-water>

World Bank (2002). Willingness to pay for arsenic-free, safe drinking water in rural Bangladesh - methodology and results (English). Water and Sanitation Program field note. Washington DC <http://documents.worldbank.org/curated/en/422221468013803608/pdf/multi0page.pdf>

C9

Operation Monitoring and Surveillance**Operational Monitoring**

Operational monitoring is routine monitoring conducted by a water supplier to confirm that control measures are working to protect water safety at key steps along the water-supply chain. Operational monitoring includes water-quality testing as well as visual observations. Note that arsenic testing is covered under compliance monitoring.

Wherever arsenic removal (or dilution) technologies are applied, operational monitoring should be carried out regularly to confirm that systems are functioning as expected. Appropriate operational monitoring parameters, locations and frequency will vary by treatment technology and resources available for testing. As an example, in an arsenic-removal system relying on adsorption onto granular media, the turbidity of the treated water should be routinely tested to confirm optimal treatment conditions. Or, where source blending is applied to dilute arsenic concentrations, flow meters should be routinely checked to confirm the appropriate ratio of source waters. There may also be cases where operational monitoring should be carried out at the catchment level. For example, where control measures are in place to protect against anthropogenic sources of arsenic contamination (e.g. mining activities) the water supplier may need to liaise periodically with the catchment management authority to ensure that source protection controls are being effectively implemented.

Compliance Monitoring

Compliance monitoring is monitoring undertaken to confirm that drinking-water quality standards are being met (e.g. that the arsenic limit established is not exceeded). Compliance monitoring should be done both by the water supplier and an independent surveillance agency. Where undertaken by the water supplier, compliance monitoring may be done through internal processes or under contract,

Chapter Summary:

- Wherever arsenic removal technologies are applied, operational monitoring should be carried out regularly to confirm that systems are functioning as expected.
- Water-quality surveillance should then be carried out to confirm that systems are delivering water to expected quality standards.
- Determining whether the improvements in drinking water have been effective on health requires the measurement of biomarkers of arsenic exposure.



with a summary of results generally required to be submitted to the policymaker, or an independent regulator, or made public under their customer service obligations. Failures to report accurate data can be met with sanctions that include criminal proceedings, public blacklisting, fines denial of access to finance, or the exclusion from tendering opportunities.

If not dictated by national standards, the frequency of compliance monitoring for arsenic should reflect the risk of arsenic limit exceedance. If source waters are known to contain arsenic levels that exceed established limits such that arsenic removal or blending is applied, compliance monitoring should be carried out more frequently than if source waters are naturally low in arsenic and where arsenic concentrations are stable, such as in deep groundwater. This is based on the premise that arsenic in groundwater moves relatively slowly and that the risk of exposure to arsenic accumulates with time.

Surveillance

Surveillance refers to the independent audit of the drinking-water suppliers to confirm the safety and acceptability of drinking-water supplies. Within the framework for safe drinking water, the role of surveillance is to check that water safety plans are both appropriate and being implemented effectively, and to check that drinking-water quality standards are being met. This is achieved through water safety plan auditing and through water-quality testing. Where compliance monitoring of water quality (see Compliance Monitoring) is carried out by the water supplier, additional testing should be carried out by the surveillance agency or a third party for independent verification. Surveillance should provide feedback on the state of the water supply system and should be an instrument to identify potential improvements at the local, regional and national levels.

National regulations should establish the requirements for surveillance by an agency that is independent of the drinking-water service provider. This surveillance function can potentially be performed by multiple agencies if there is the ability to link the health outcomes/ impact to the drinking-water surveillance results. Where independent surveillance is constrained by a lack of resources, sample surveys (e.g. MICS) can provide a snapshot of the effectiveness of the service providers in managing water safety risks but this should not be a substitute for routine surveillance.

Sustainable Arsenic Testing

Once discovered, arsenic will remain a hazard for both new and existing water supplies. While arsenic can be avoided, the risk cannot be permanently eliminated. In the long run, arsenic may migrate or be mobilized in aquifers where it is currently not a hazard. Many countries will commence a mitigation programme with a target of eliminating exposure above 50 ppb but later seek to reduce this target to 10 ppb or lower. In arsenic-prone areas, the testing of all new sources at the time of installation and regular retesting of existing wells and piped water-supply systems requires considerable resources to be dedicated to the testing, marking and management of the data.

Regular blanket testing is not a practical solution in the long run and must be replaced by a system that enables arsenic-testing services to be accessible and accountable to local water-service providers and water users. This requires a shift from externally engaged surveys in the Assessment Phase to a permanent system of local testing and surveillance services in the Management Phase. The premier challenge faced here has been the capacity and viability of private providers offering pay-for-use arsenic water testing services where governments cannot meet the demand or need for testing. Pay-for-use arsenic testing services depend on the willingness to pay by drinking water users and providers based on their perceptions of the risk and self-efficacy of doing so.

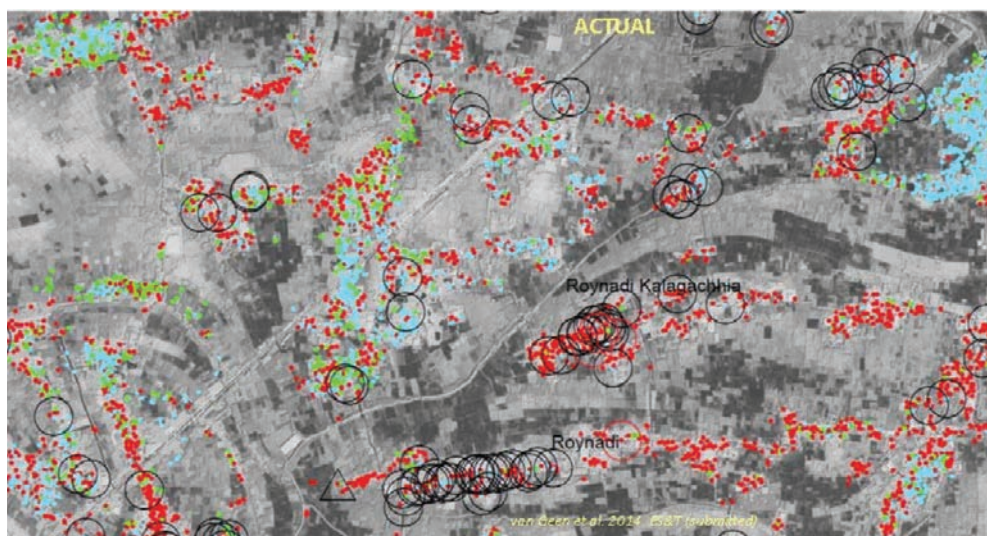
Previous trials have struggled to find successful business models though this could be improved if subsidized by electronic payments for supplying verifiable data into regional or national databases; by developments in testing technology; or through penalties for service providers who fail to submit test results. The establishment of a sustainable pay-for-use arsenic testing for drinking water is highly dependent on government establishing a suitable enabling environment and a strong regulatory system with penalties for failure.

In arsenic-affected areas, pay-for-use testing services should be complemented by ensuring or requiring testing in facilities such as health clinics and private organizations such as well drillers and water-treatment vendors.

Equitable and Efficient Siting of Water Sources

Monitoring can provide information on the performance of individual water points but does not necessarily measure the overall effectiveness of programmes, especially where this results from the cumulative impact of water sources installed by government, NGO and private activities.

Where mitigation is undertaken by household and small-scale community initiatives, it is essential to progressively revise the siting of public wells



Picture 10: The importance of the spatial distribution of safe tubewells

Source: (van Geen, 2015, Author manuscript)

Inequitable location of deep tubewells in an arsenic-affected rural area of Bangladesh demonstrating the benefit of GPS mapping arsenic tests. The coloured dots represent the arsenic concentration in all tubewells: As ≤ 10 $\mu\text{g/L}$ in blue; $>10 - 50$ $\mu\text{g/L}$ in green; >50 $\mu\text{g/L}$ in red). The black circles are drawn at a radius of 100 m around deep (>90 m) tubewells

to ensure that the most exposed populations are reached. Picture 10 shows an example of how the allocation of deep tubewells in an area was, on average, almost sufficient to give access to arsenic-safe water for the whole population but actually only provided access to less than half of the population. This failure of service provision is lost to central authorities when “average” reporting is used. The use of low-cost GPS and GIS technologies to record the position of all safe and contaminated wells in an area enables the public wells to be sited to give the optimum benefit to the maximum number of households. Failure to do this enables the location of public water infrastructure to be adversely influenced by local patronage politics negatively affecting access to safe water for the poor and disadvantaged groups. Compiling essential information on all public and private wells on an Open-Data Platform facilitates accurate up-to-date analysis of arsenic exposure routes and more effective allocation of public resources.

Confirming Successful Impact on Health

Determining whether the compliance with national drinking-water standards has been effective in improving health requires the

measurement of biomarkers of arsenic exposure. This is important because other sources of exposure may remain significant (Kippler, 2016). Continued high levels of arsenic exposure following apparently successful drinking water mitigation programmes are potentially attributable to either arsenic exposure in rice, inaccurate reporting of the use of safe water sources, exposure in the workplace or seasonal migration.

Additional Resources

Kippler, M., H. Skräder, S. M. Rahman, F. Tofail and M. Vahter (2016). Elevated childhood exposure to arsenic despite reduced drinking water concentrations - A longitudinal cohort study in rural Bangladesh. *Environment International* 86: 119-125. <https://www.sciencedirect.com/science/article/pii/S0160412015300830>

van Geen, A., K. M. Ahmed, E. B. Ahmed, I. Choudhury, M. R. Mozumder, B. C. Bostick and B. J. Mailloux (2016). Inequitable allocation of deep community wells for reducing arsenic exposure in Bangladesh. *Journal of Water Sanitation and Hygiene for Development* 6(1): 142-150. <https://www.ncbi.nlm.nih.gov/pubmed/27087915>

C10

Water Resources Management and Sustainability**Introduction**

Water supply interventions should be planned in consultation with, and preferably authorized by, water resources management authorities. The most likely problems to be guarded against are (i) over-abstraction of a surface water source or aquifer, and (ii) causing arsenic or other contaminants to be drawn from one aquifer into another. The latter is particularly important since switching to deeper aquifers has proven to be the most effective means of arsenic mitigation (see chapters B2 and C7). In all cases, there is likely to be considerable uncertainty about the size and time-scale of such impacts, and therefore the agencies leading mitigation activities should seek to strengthen both monitoring and the regulation of abstraction.

Sustainability of Water Sources in Arsenic-Contaminated Areas

Where groundwater is contaminated by arsenic, there are legitimate fears that arsenic will spread to contaminate neighbouring sources. Although the rates of change of arsenic contamination in existing wells are normally quite slow, understanding the arsenic pollution mechanism enables such changes to be predicted and managed. The three most likely factors to cause arsenic concentrations to increase in previously safe wells are:

- i. Changes in the geochemical conditions causing arsenic to be released from the rock or sediment into the water;
- ii. Contaminated water moving laterally within the aquifer; and
- iii. Contaminated water moving vertically from the under- or overlying aquifer or aquitard.

All of these factors are most likely to be associated with excessive groundwater abstraction.

Geochemical changes that initiate arsenic pollution are only likely to be important in areas where sulfide oxidation or alkali desorption

Chapter Summary:

- Water supply interventions should be planned with and preferably authorized by, water resource management authorities to protect against (i) over-abstraction of surface water or aquifer and (ii) causing arsenic or other contaminants to be drawn from one aquifer to another.
- Since rates of change of arsenic contamination in existing deep wells are normally slow, understanding arsenic pollution mechanisms enables such changes to be predicted and managed.
- In shallow wells monitoring, it has been confirmed that arsenic concentration levels can increase from safe to unsafe levels over a period of months, reinforcing the need for a periodic monitoring system rather than one-time testing.



operate and in particular where there has been either a rapid decline in the water table often associated with excessive groundwater abstraction. Other than that, the rapid deterioration of water quality will be resisted by three factors: time, geological barriers and geochemical barriers. Except in fractured rock aquifers, groundwater typically flows only a few metres to tens of metres a year. Higher horizontal flow rates occur close to pumping wells and wellfields potentially explaining the increased arsenic contamination in previously safe shallow wells and occasionally the reverse (McArthur, 2010).

In practice, there are almost always geological barriers that restrict arsenic migration. Aquifers almost invariably have vertical permeabilities typically ten to a thousand times lower than the horizontal permeability (vertical anisotropy). Where aquitard (e.g. clay) layers intervene, vertical flow rates are likely to be only fractions of a metre per year.

In addition to geological barriers, geochemical barriers are usually present between contaminated and uncontaminated zones. Wherever a well is not contaminated, the surrounding aquifer will have some potential to adsorb arsenic and slow down its migration. Studies in Bangladesh indicate that the rate of arsenic movement is slowed down (retarded) by a factor of 10 or more compared to the movement of water. The net result is that the rate of change in the extent of arsenic contamination will be slow even if the sustainability of aquifers is uncertain.

In Bangladesh and West Bengal (India), the depth below which arsenic concentrations are safe for drinking varies from tens of meters to as much as 150 m. Experience and modelling studies indicate that the deeper aquifers should remain safe for many decades. On the other hand, monitoring of shallow wells has confirmed that arsenic concentrations can increase from safe to unsafe levels over periods of a few months to a few years. This means that it is not sufficient to test wells once. All drinking-water wells should be part of a periodic monitoring programme (see Chapter C9).

When investigating cases of the unexpected contamination of wells, it is important to check for problems with the well design or construction. For instance, previous claims about arsenic migration from shallow to deep aquifers have been subsequently shown to be the result of badly constructed or damaged wells, or the misreporting of the well depth (Stahl, 2014). The failure to fully investigate such unlikely reports of contamination can result in falsely condemning a safe aquifer. Potential sources of contamination include misreporting on the actual depth of the well and the screen, leakage through pipe joints or splits in the casing or water that is flowing down along the outside of the casing to the screen.

Water Resource Monitoring

Monitoring the sustainability of safe water resources is the responsibility of water resources or environmental authorities but it is also the duty of care of water supply agencies and the other users of groundwater resources.

Groundwater safety monitoring networks should be carefully designed based on a sound conceptual model of flow and geochemical processes, and a qualitative or quantitative risk assessment. Although a fully dedicated network of groundwater monitoring of wells may be desirable, in practice valuable information can be derived from the compliance monitoring of existing water supplies along with some dedicated sentinel observation wells at critical locations to warn of any deterioration of water quality or dangerous decline in the water levels.

Institutional Aspects of Arsenic Mitigation

During the Assessment Phase, project-based structures may be set up in the short term to respond to the dedicated needs of generating information on arsenic in groundwater. In the longer run, arsenic mitigation activities should be situated within the broader framework for safe drinking water and water resources management. This does not preclude establishing a multi-sector monitoring and coordination unit to manage arsenic information issues with a mandate for public reporting and the independent surveillance of programmes.

Additional Resources

McArthur, J. M., D. M. Banerjee, S. Sengupta, P. Ravenscroft, S. Klump, A. Sarkar, B. Disch and R. Kipfer (2010). Migration of As, and $3\text{H}/3\text{He}$ ages, in groundwater from West Bengal: Implications for monitoring. *Water Research* 44(14): 4171-4185. https://www.ucl.ac.uk/lag/docstorage/McArthur_et_al_2010.pdf

Stahl, M. O., J. B. Ong, C. F. Harvey, C. D. Johnson, A. B. M. Badruzzaman, M. H. Tarek, A. van Geen, J. A. Anderson and J. W. Lane (2014). "Detecting Well Casing Leaks in Bangladesh Using a Salt Spiking Method." *Groundwater* 52(S1): 195-200. <http://doi.org/10.1111/gwat.12200>



D11

Health Sector - Palliative Treatment

Introduction

As described in Chapter B1, prolonged ingestion of arsenic leads to a wide range of diseases including skin conditions; cancers; gastrointestinal, cardiovascular and pulmonary conditions; and ultimately death. There is no cure for chronic arsenic poisoning other than to end exposure as soon as possible because the effects of poisoning are dose-dependent and cumulative. The most obvious actions for the health sector are the diagnosis and treatment of patients with skin lesions, however most people who develop arsenic-related cancers never displayed skin lesions while the mental health effects and inter-generational impacts on development of children have not been quantified. From a health treatment perspective, diagnosis is complicated by the latency of arsenic poisoning with potentially fatal diseases developing decades after exposure has ceased. From a health planning perspective, this future disease burden is not so much a risk as it is an expectation in arsenic-contaminated environments.

Medical Care: Survey and Diagnosis

Dermatologists have sometimes identified arsenic poisoning as the problem for patients presenting with skin lesions before arsenic contamination of drinking-water resources had been recognized. However, most health workers are not trained to identify and manage arsenicosis or identify the non-diagnostic effects of arsenic poisoning. Training of health workers is essential in responding to the discovery of arsenic in drinking water. For this purpose WHO has developed a field guide for health workers which includes a valuable algorithm for case classification of arsenicosis.

In the early stage of a response, health authorities will need to work closely with the agencies that are organizing water testing

Chapter Summary:

- Health care workers should be trained to identify and manage arsenicosis, and to recognize the symptoms of arsenic poisoning.
- Children are especially vulnerable to arsenic poisoning *in utero* and in the early years of development, therefore additional efforts to safeguard children from exposure to arsenic are required.
- The increased long-term risks of internal cancers, heart and lung disease will remain after the exposure to arsenic contamination has been removed.



surveys, which could include “arsenic camps” in highly contaminated areas to identify suspected arsenicosis cases, educate communities, and refer more seriously affected persons to hospital. At the second stage, health clinics should be organized to distribute symptomatic treatments. It is extremely important that Ministries of Health institute a system for the monitoring and evaluation of these programmes.

As the arsenic mitigation progresses from the Assessment to the Management Phase, health agencies should extend the scope of patient surveys to include identifying (i) the incidence of new cases; (ii) whether symptoms of registered patients are improving; (iii) the high prevalence of any non-specific symptoms; and (iv) the monitoring of biomarkers to determine whether actual exposure levels are reducing after mitigation of exposure through the drinking water.

Medical Care: Treatment

The primary “prescription” that can be given by doctors upon discovering a case of arsenic poisoning is to stop arsenic intake and find a safe source of drinking water. The effects of chronic arsenic poisoning are exacerbated by poverty and poor nutrition. In Asia, poverty is generally associated with a high consumption of rice and low intake of protein, minerals and vitamins and greater likelihood of using arsenic-contaminated well water. Dietary supplements and vitamins may reduce the symptoms, and so may be included in primary health programmes.

Symptomatic treatment of arsenicosis is possible. Keratosis can be lessened by application of ointments (particularly containing salicylic acid) and in more severe cases skin cancers can be removed through surgery. Exposure to acute arsenic poisoning has been treated using chelation therapy, however the effectiveness of this process in reducing accumulated chronic arsenic exposure from natural sources is unknown.

Care for Infants and Children

Even though symptoms may not be visible, children are particularly vulnerable to arsenic poisoning in utero and in the early years of their development. Not only does this lead to serious illness in later life but it also impairs intellectual development (Chapter B1). Special efforts to safeguard children from exposure to arsenic could include prioritizing (i) access to safe water for pregnant, lactating and bottle-feeding mothers; (ii) providing safe water in schools; (iii) arsenic-health education in schools; (iv) public education on the extra risks to children; and; and (v) additional teaching support. The risks of arsenic exposure through rice-based infant foods are described in Chapter D12.

Recovery of Patients

Once patients switch to a safe source of drinking water and the other routes of arsenic exposure are addressed, skin lesions should improve. In people with a folate deficient diet (as is common in South Asia), the elimination of residual arsenic can be accelerated through folic acid supplements. Anti-oxidant supplements (e.g. Vitamins A, C and E; selenium) are also believed to accelerate recovery but the effectiveness of such treatments is still unclear.

Removing exposure to arsenic contamination does not eliminate the heightened long-term risk of internal cancers, heart and lung disease even if the visible symptoms of arsenicosis fade away. This means that health authorities should plan and budget for increased future health-care costs with respect to cancer, heart and lung disease.

D12

Food, Agriculture and Nutrition

Introduction

Arsenic contamination of drinking water is the primary focus of this primer. As arsenic exposure through water and other routes is cumulative, the mitigation of exposure to arsenic in drinking water may not fully address the problem of arsenic exposure without the appropriate mitigation of exposure to arsenic in the food, agriculture and nutrition sectors.

Arsenic in Agriculture

When arsenic-contaminated groundwater is used for irrigation, especially if it is rich in iron, it tends to build up in the soil from where it will be transferred to crops in increasingly higher quantities. Potential arsenic-mitigation strategies in agriculture may include:

- (i) using irrigation water with low(er) arsenic concentrations;
- (ii) reducing the volume of irrigation water applied;
- (iii) changing the crop variety;
- (iv) changing the crop type;
- (v) changing in-field water management to establish an aerobic root zone where arsenic is less mobile;
- (vi) breeding of crops to reduce arsenic uptake; and
- (vii) remediation of soil by removal and safe disposal of topsoil (e.g. inclusion in bricks).

Caution needs to be exercised in the following situations:

- Arsenic accumulated in the soil will remain a health risk for many years after switching to a low-arsenic water source that limits the further accumulation of arsenic in the soil.
- The transfer of arsenic to the food chain can be greatly reduced (but not eliminated) by switching from rice to any other food grain.
- Creating aerobic soil conditions in traditional paddy fields through techniques like alternate wetting and drying or upland cultivation can reduce the transfer of arsenic to the food chain¹⁵.

Chapter Summary:

- When arsenic-contaminated groundwater is used for irrigation, there tends to be a build-up of arsenic in the soil where it will be transferred to crops; the accumulated arsenic will remain a health risk from many years, even after switching to a low arsenic water source.
 - Cooking can increase or decrease the intake of arsenic from food based on whether the food absorbs water during cooking or is cooked in an excess of water which is then discarded.
 - Rice and baby food pose the greatest risk of poisoning.
 - Some countries and agencies prescribe limits for arsenic in food. It is important that standards take into consideration local dietary practices.
 - Reducing the exposure to arsenic and its mitigation requires close cooperation between ministries and close involvement of local institutions.
-
- Arsenic mitigation in agriculture requires a broad water-resources management perspective requiring water supply and health practitioners to work closely with government and non-government counterparts in agriculture and water resources. Priority should be given to the long-term transfer from groundwater to the soil i.e. from water to the food chain.



Food Standards and Targets

Recognizing the risk of arsenic exposure through food, some countries and agencies (e.g. China, WHO and the European Union) have prescribed limits for arsenic in food (i.e. 0.2 mg/kg of inorganic arsenic) with the EU advising an even lower concentration (0.1 mg/kg of inorganic arsenic) for infant foods. However, global variations in consumption patterns are so great that it can be a serious mistake to focus on the standards independent of the local dietary practices. In South and Southeast Asia, the

¹⁵ There is a need to check that this does not substitute the accumulation of cadmium which is also highly toxic.

combined Average Daily Intake (ADI) of arsenic is more than double the previous FAO/WHO guideline of 130 µg/d without exceeding the maximum prescribed standards for arsenic in water or food.¹⁶

Given the risk of arsenic in food posed by rice, the ADI can be as much as seven times the guideline value in highly contaminated rice-growing areas of South Asia. Assessments should therefore concentrate on total arsenic ingestion considering that:
The targets should be defined and evaluated in terms of keeping total intake below 130 µg/d including exposure from both food and water; Inorganic and organic arsenic exposure should be counted separately;
Arsenic in food should be measured after cooking or any other processing; and
Exposure to vulnerable groups, notably infants and the poor, should be assessed separately.

Picture 11: Improved rice cooker

Source: Sengupta et al. 2005



Arsenic and cooking

Cooking can increase or decrease the intake of arsenic from food depending on whether the food absorbs water during cooking or is cooked in an excess of water which is then discarded after cooking. A study in northern Chile, where the diet is predominantly beans, maize and potato, showed that cooking with highly arsenic-contaminated water raised the average daily intake by a factor of 10 to over 1,000 µg/d.

If cooking water is contaminated with arsenic, there is a potential for this arsenic to be absorbed by the food during cooking. The absorption method of cooking rice practiced

in many areas of South Asia can substantially increase arsenic intake. On the other hand, arsenic-contaminated rice that is rinsed first and then cooked in an excess of arsenic-safe water that is then discarded will decrease the arsenic content in the rice. This recognition has led Jadavpur University in India to develop a rice cooker that is both energy efficient and maximises the removal of arsenic (Picture 11). However, caution should be exercised regarding the use of the excess water to ensure that this enriched arsenic water is not consumed by humans or fed to animals. There is also potential for further reducing arsenic intake from rice by optimizing milling and parboiling.

Arsenic in Infant Foods

There is a growing body of evidence of the elevated risks of exposure to arsenic *in utero* and in early childhood. Minimizing childhood exposure to inorganic arsenic requires the prioritizing of a nutritious diet that is low in arsenic for pregnant women and ensuring that infant milk formula is never made-up with arsenic-contaminated water.

Of concern is the exposure of young children to inorganic arsenic through rice and rice-based infant products such as rice cakes. This is because children under 5 years of age eat three times as much food on a body weight basis as compared to adults. Given that this effectively exposes these children to three times as much arsenic on a per body weight basis, efforts should be made to diversify the diets of young children and seek low arsenic sources of rice.

Additional Resources

Brammer, H. 2009. Mitigation of arsenic contamination in irrigated paddy soils in South and South-east Asia. *Environ. Int.*; 35: 856-863. <https://www.ncbi.nlm.nih.gov/pubmed/19394085>

Duxbury, J. and G. Panaullah. (2007). Remediation of arsenic for agriculture sustainability, food security and health in Bangladesh. FAO Working Paper. <https://www.ircwash.org/resources/remediation-arsenic-agriculture-sustainability-food-security-and-health-bangladesh>

¹⁶ A field worker consuming 4L of water containing 50 ppb As and 400 g of rice containing 0.2 µg/kg As will have a total intake 280 µg/d

Senanayake, N. and Mukherji A. (2014). Irrigating with arsenic contaminated groundwater in West Bengal and Bangladesh: A review of interventions for mitigating adverse health and crop outcomes. *Agricultural Water Management*, 135: 90-99. <https://doi.org/10.1016/j.agwat.2013.12.015>

Sengupta M, Hossain M, Mukherjee A, Ahamed S, Das B, Nayak B (2005) Arsenic burden of cooked rice: Traditional and modern methods. *Food Chem. Toxicol.*; 44, 1823-1829. <http://citeseerx.ist.psu.edu/viewdoc/download?doi=10.1.1.578.757&rep=rep1&type=pdf>

Signes-Pastor, A.J., Carey M, Meharg A.A., (2016) Inorganic arsenic in rice-based products for infants and young children. *Food Chemistry*, 191: 128-134. <https://www.sciencedirect.com/science/article/pii/S030881461401807X> download?doi=10.1.1.578.757&rep=rep1&type=pdf

Signes-Pastor, A.J., Carey M, Meharg A.A., (2016) Inorganic arsenic in rice-based products for infants and young children. *Food Chemistry*, 191: 128-134. <https://www.sciencedirect.com/science/article/pii/S030881461401807X>

Photo Credits

Cover: © UNICEF/Nargis Akter

Page 4: © UNICEF/UNI101207/Omi

Page 6: © UNICEF/UNI142276/Haque

Page 7: © UNICEF/UNI158242/Albouy

Page 12 Top: © UNICEF/UNI4692/Noorani

Page 12 Bottom: © UNICEF/UNI101602/Sujan

Page 26 Top: © UNICEF/UNI138391/Haque

Page 26 Bottom: © UNICEF/UNI142311/Haque

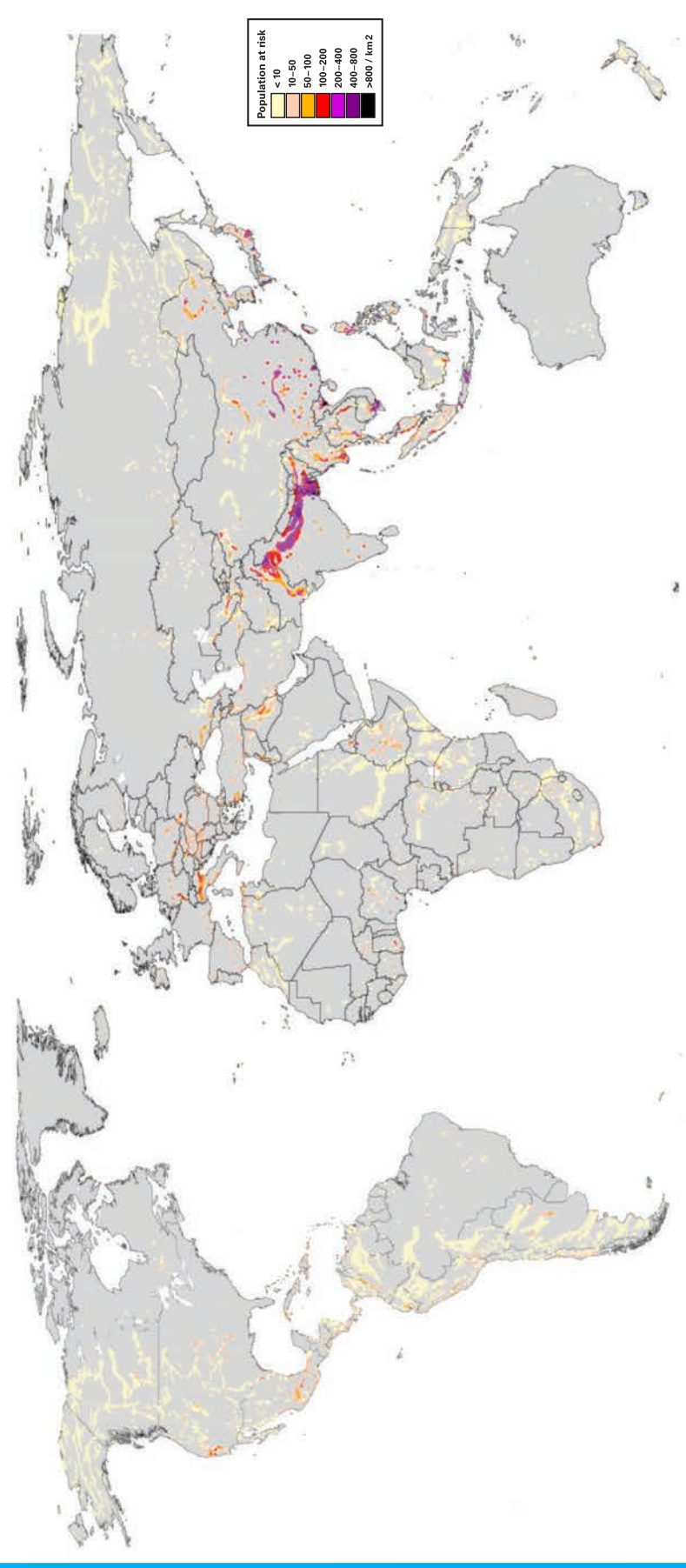
Page 34: © UNICEF/UNI79826/Purushotham

Page 40: © UNICEF/142272

Page 43: © UNICEF/2005/Nickson

Page 62 Top: © UNICEF/UNI79827/Purushotham

Page 62 Bottom: © UNICEF/UNI15218/Holmes



Prediction of the population at risk from arsenic contamination (based on a global 2007 study commissioned by UNICEF, see www.gapmaps.org).