Water and Global Health

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ENV H 111

11/22/11

Global Water Overview

- Water Scarcity
  - Consumption
  - Advanced treatment
- Diarrheal disease prevention
  - Point-of-use water treatment techniques
- Groundwater contaminants
  - Arsenic
  - Fluoride
  - Nitrate

Historical Water Use

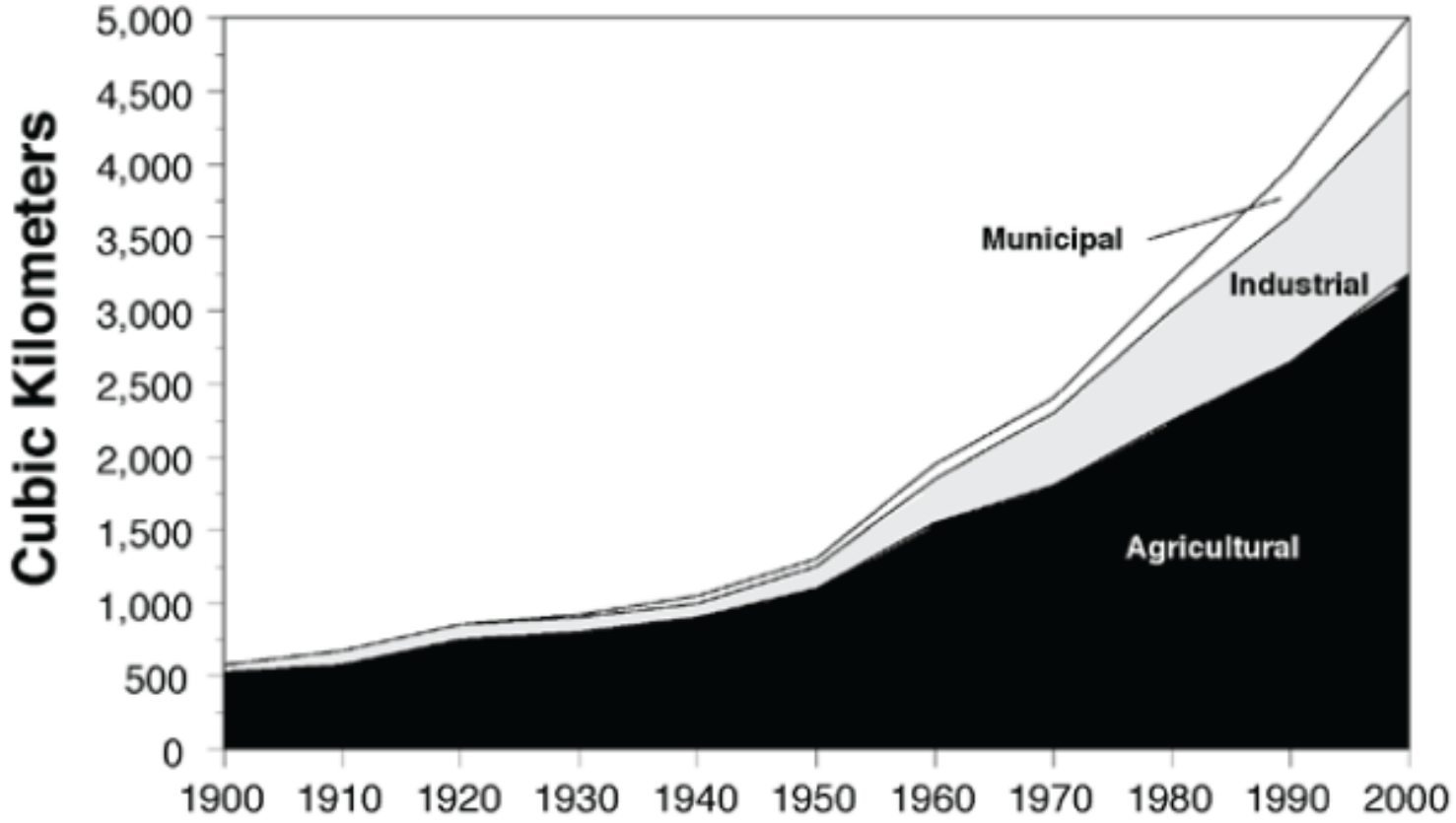


FIGURE 5-3 Global annual water withdrawal by sector, 1900–2000. Global water use has been rapidly increasing during the past century for all purposes—agricultural, industrial, and municipal. Agriculture use has had the largest increase.
SOURCE: Worldwatch Institute, *Imperiled Waters, Impoverished Future: The Decline of Freshwater Ecosystems*. www.worldwatch.org. Reprinted with permission.

Water Use and Trade

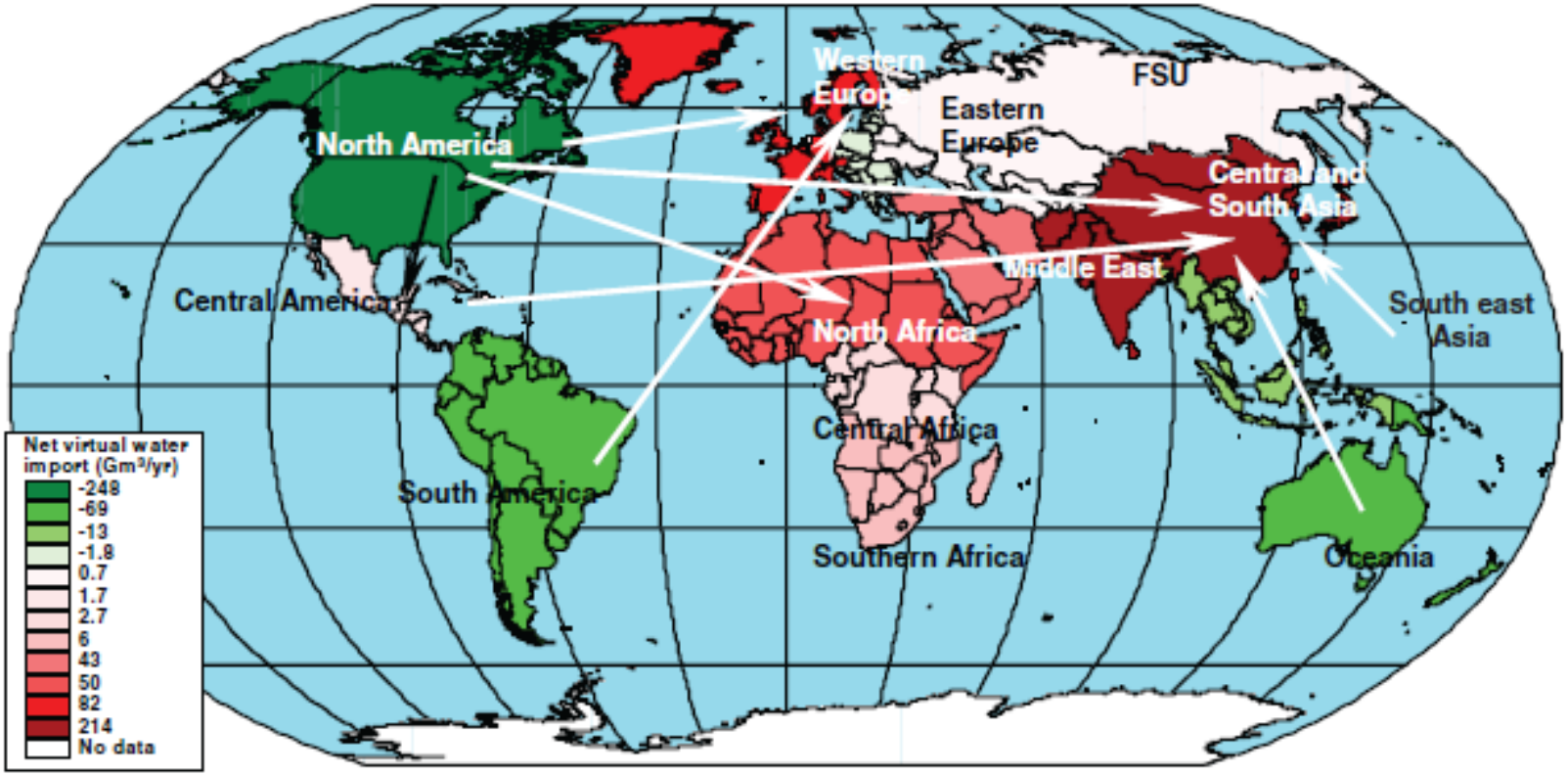
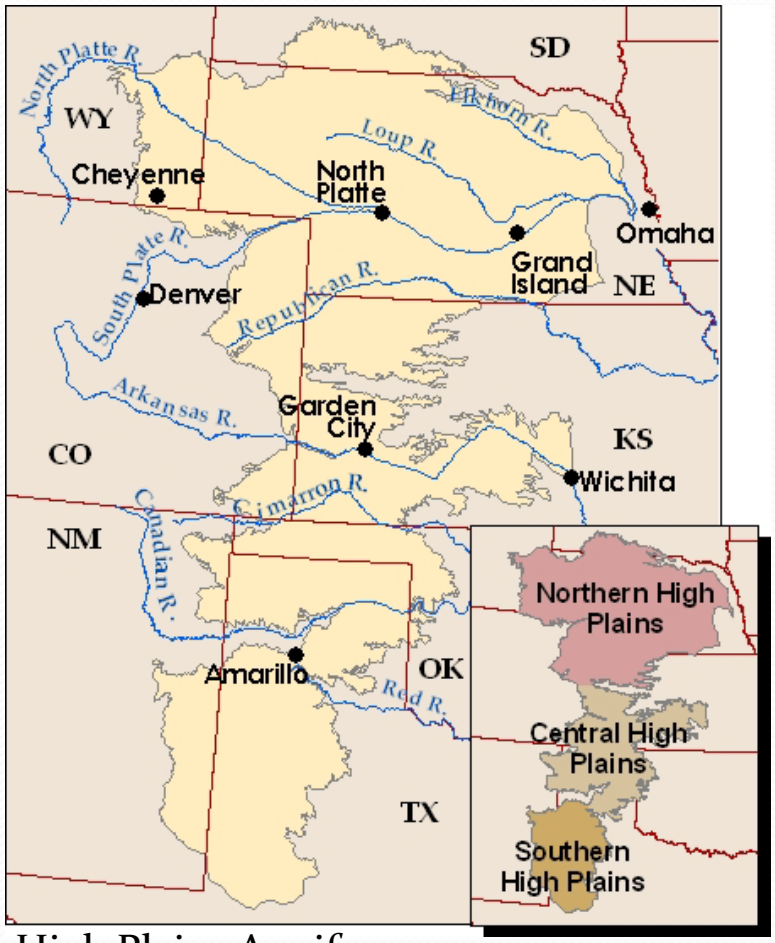


FIGURE 5-4 Virtual water balances of the 13 world regions, 1995–1999. The biggest net flows (> 20 Gm3/yr) as a result of the trade of water-intensive products are indicated with arrows.

SOURCE: Hoekstra, A.Y., and P.Q. Hung. 2002. Virtual water trade. A quantification of virtual water flows between nations in relation to international crop trade. The Netherlands:

Water Resources and Water Scarcity



High Plains Aquifer
co.water.usgs.gov/nawqa/hpgw

- High Plains Aquifer
  - 30% irrigation in US
  - Source: fossil water
  - Withdrawal rate > return
  - Will empty in 20-30 yrs
  - Agriculture has influenced water quality

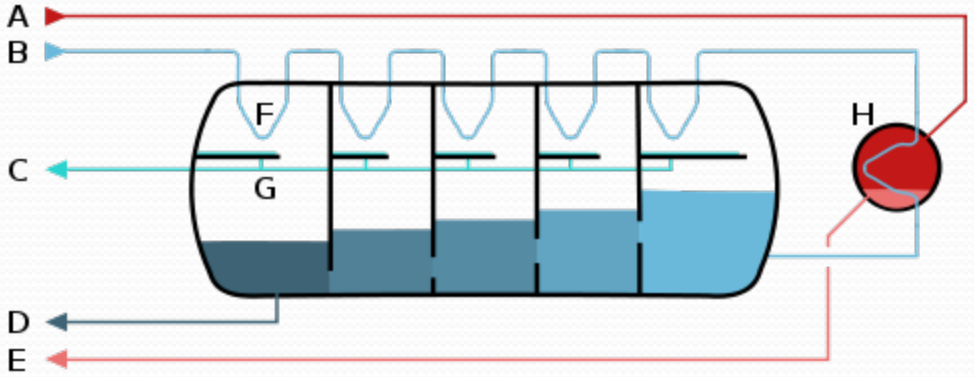
Water Supply

1 m^3 = 1000 liters

- Water Stress: Water supply ≤ 1700 m^3/person/year
- Water Scarcity: Water supply ≤ 1000 m^3/person/year
- Water conservation
  - Behavior & lifestyle changes
    - Less meat consumption & water waste
  - Distribution system improvement
    - Repair leaky pipes
  - Efficient irrigation & land use
- Climate Change
  - Aquifer storage & recovery
  - Building additional reservoirs
  - Using seawater as water resource

Desalination

- Removal of salt and other minerals from water
  - Water for human consumption
  - Irrigation water
  - Table salt
- Requires energy and specialized equipment
- Not dependent on rainfall
- Common Methods
  - Distillation
  - Ion exchange
  - Membrane Filtration
    - Reverse Osmosis



Schematic of a multiflash evaporator
A - Steam in, B - Seawater in, C - Potable water out,
D - Waste out, E - Steam out, F - Heat exchange,
G - Condensation collection, H - Brine heater

Castelnuovo (2010)

Fundamentals

- Filtration Media
  - Sorption
    - Hydrophobic compounds stick to surface of particles
    - ex: Sand or granular activated carbon (GAC)
  - Ion Exchange (cation or anion)
    - Contains ionic pairs on particle surface that exchange ions for ionic chemical contaminants
  - Reverse Osmosis
    - Pressure applied to one side of membrane causes contaminants to be retained and water to pass through
- Units of chemical contaminants in water
  - PPB = µg/L
  - PPM = mg/L

Water Reuse – Reclaimed Water

- Process of separating solids from liquids in wastewater and reusing liquid (after treatment)
  - Industrial cooling
  - Irrigation of non-edible plants (high N and P)
  - Toilet flushing
  - Recharge groundwater aquifers

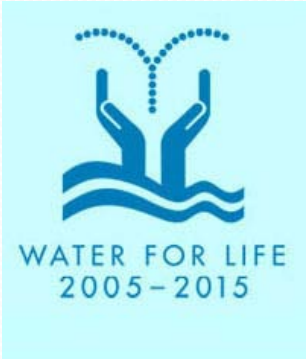
- Wastewater separation
  - Black water: toilet wastes & garbage disposal
  - Gray Water: bath & shower water

Diarrheal Disease

Prevention through Household Water Treatment

Water For Life (2005-2015)

- Millenium Development Goal set by WHO/UNICEF
  - 50% reduction in population lacking access to improved water & sanitation by 2015
- International Decade for Action:
  - Water & Sanitation improvement projects
    - Public-private partnerships
    - Investments by large corporations
    - Focus on microfinancing & local initiatives with community-based and nongovernmental organizations (NGOs)
  - Ecological sanitation that's culturally acceptable
  - Develop water safety plan accounting for scarcity
  - Greater use of household water treatment



Improved water access

- Household connections
- Public standpipes
- Rainwater collection
- Boreholes
- Protected wells

- NOT
  - Water vendors
  - Unprotected wells, springs, rivers, ponds
  - Tanker truck water

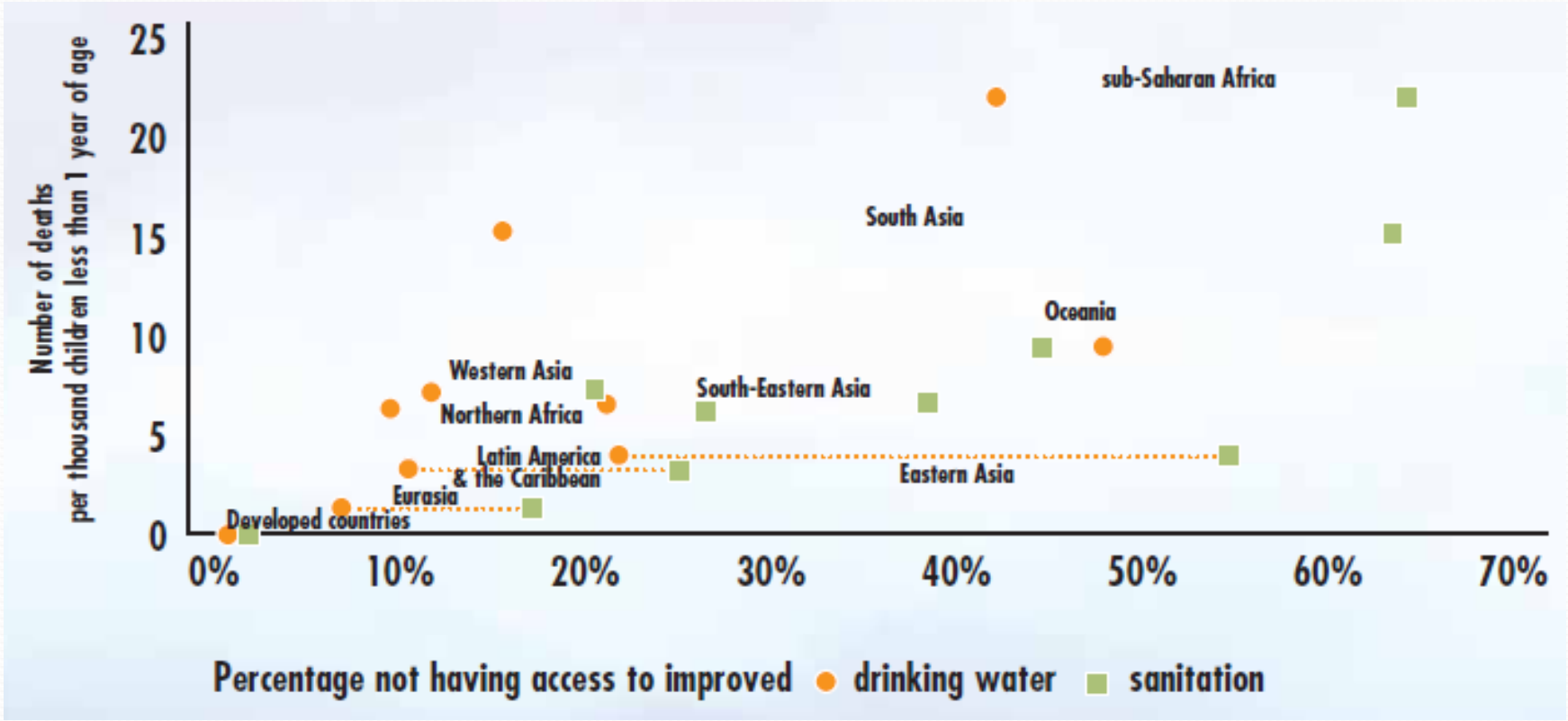
Improved sanitation

- Connection to
  - Public sewers
  - Septic systems
  - Pour-flush and improved pit latrines

- NOT
  - Shared, traditional or open pit latrines

Diarrheal Disease

- 2.2 million deaths per year from unsafe water



WHO/UNICEF (2005)

Potential Contamination

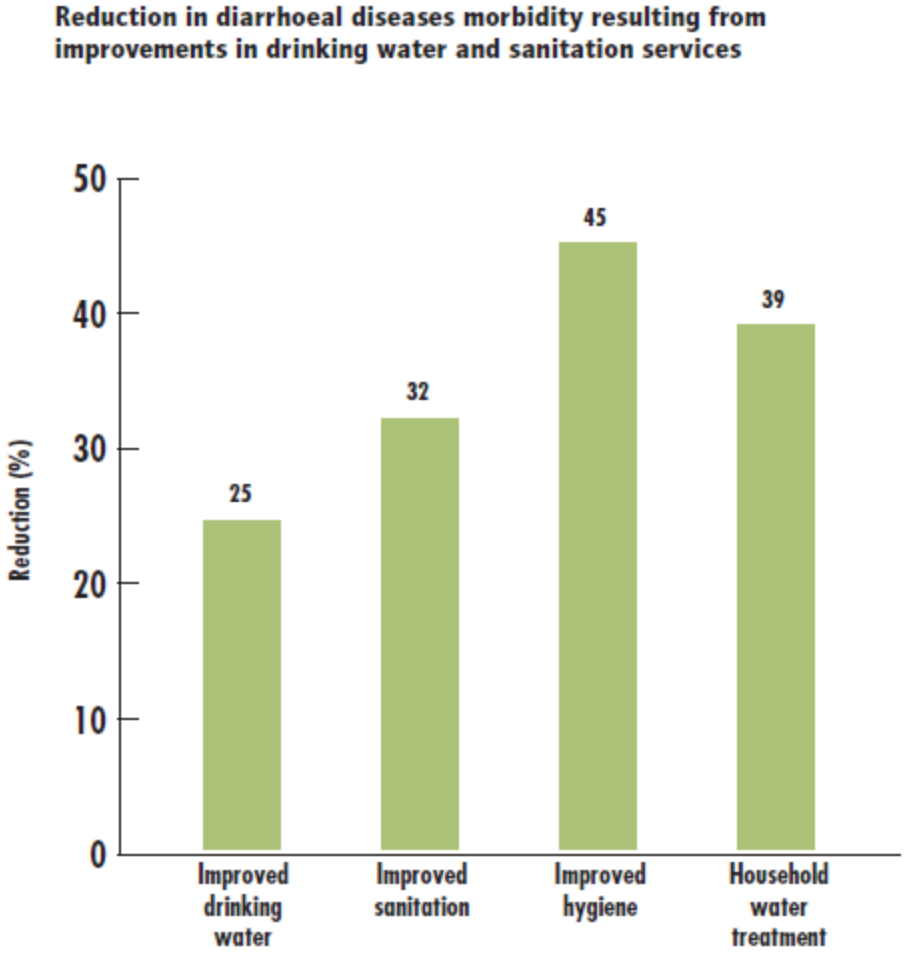
Collection **Transport** **Storage** **Consumption**

Every step in the chain presents an opportunity for water to be contaminated.

Red Cross (2008)

Point-of-use Water Treatment: Prevention of Diarrheal Disease

- CDC recommends
  - Chlorination
  - Ceramic Filtration
  - SODIS (solar disinfection)
  - PUR packets
- Red Cross recommends
  - Disinfection
  - Sedimentation
  - Filtration



WHO/UNICEF (2005)

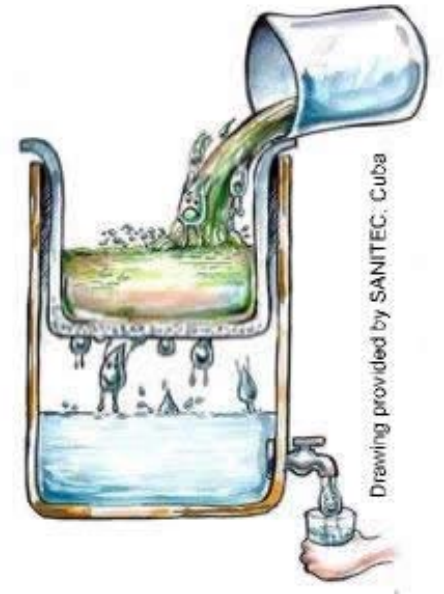
Household Chlorination

- Procedure
  - Capful added to water storage container
- Benefits
  - 22-84% reduction in diarrhea
  - Cost **0.05 cents/liter**
  - Residual disinfectant
  - Easy to use
  - Scalable
- Drawbacks
  - Taste and odor
  - Less protection against organisms in turbid water

The PSI Chlorination Product in Nigeria

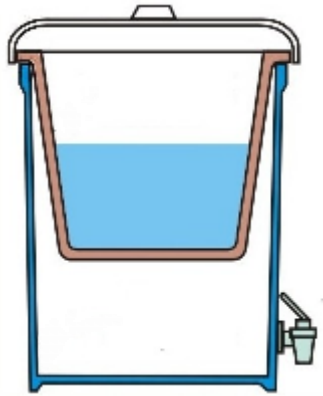
Ceramic Filtration – Potters for Peace

- Trains local potters to make filters and creates local industry
- Production
  - Local clay placed in metal mold
  - Press by truck jack
  - Fire in kiln
  - Check flow is 1-2.5 L/hr
  - Optional: dip in colloidal silver
- Procedure
  - Pour water in bucket containing filter
- Disease Prevention
  - Filter removes pathogens > 0.2 µm size
  - Silver inactivates bacteria, viruses, fungi, parasites



Ceramic Filtration – Potters for Peace

- Benefits
  - 60-70% reduction in diarrhea (safe storage)
  - Cost 0.14 cents/liter
  - Easy to use
  - Long filter life
  - Local production
- Drawbacks
  - Unknown virus protection
  - Lack of residual disinfectant (potential recontamination)
  - Necessary user education for clean filter and receptacle
  - Slow flow rates

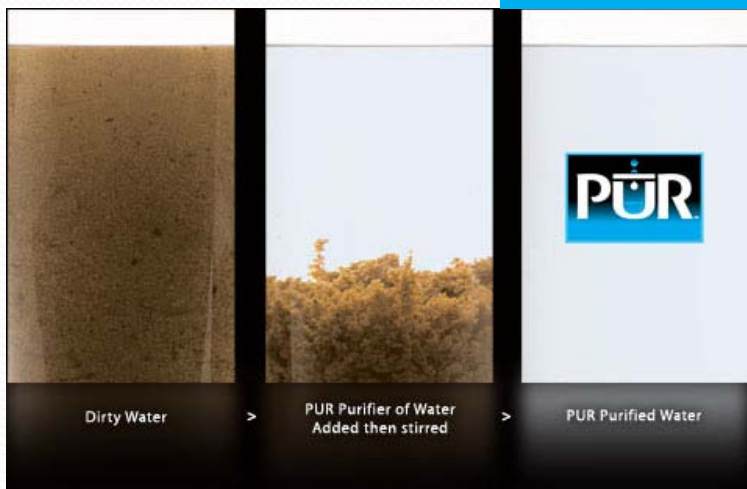


Solar Disinfection

- Procedure
  - Pour water into plastic bottles
  - Place in direct sunlight for 6 hours
- Benefits
  - UV irradiation kills pathogens (E.coli)
  - Infrared irradiation raises temp to 50 °C, killing pathogens
  - Prevents 9-86% diarrhea
  - **ZERO** Cost
  - Easy to use
- Drawbacks
  - Turbid water requires pretreatment
  - Limited water volume
  - Time required
  - Plastic bottles required

PUR: Flocculant / Disinfectant Powder

- Ingredients: iron sulfate and sodium hypochlorite (NaOCl)
- Procedure
  - Sachet added to 10 Liters water, stirred, settled, filtered through cotton cloth, wait 20 minutes
- Benefits
  - 16->90% reduction in diarrhea
  - Cost **1 cent/liter**
  - Removes turbidity & some chemical contaminants
  - Kills viruses & bacteria
  - Disinfecting residual protection
- Drawbacks
  - Multiple steps
  - Materials needed



www.purpurifierofwater.com

Arsenic and Fluoride

Naturally-occurring Groundwater Contaminants

Bangladesh

- Many polluted rivers
- 1970's – 250,000 children died per year from waterborne disease
- 1970-80's - 12 million shallow (<50 m) tube wells installed by UNICEF and World Bank
- 1990's – Observed health effects from chronic Arsenic ingestion
  - 30% tube wells contain high Arsenic levels

sciguru.com

Arsenic Ingestion Health Effects

- Long-term exposure
  - Cancer (skin, bladder, kidney, liver, lung)
  - Skin lesions
    - Hyper-pigmentation
    - Keratosis
  - Peripheral vascular disease
  - Liver necrosis (as low as 10 µg/L)
  - GI disturbances
  - Fatigue

Keratosis
Hussam (2009) Global Environmental Health

Arsenic

- Sources
  - Anthropogenic – pesticides
  - Volcanic – hot springs
  - Natural weathering of arsenic bearing minerals – arsenopyrite
    - Strongly reducing conditions
    - Arid environments with high pH
    - Mining activities (low pH)
- Natural abundance
  - South Asia - Bangladesh
  - South America
- 10 µg/L MCL in drinking water
  - US EPA and WHO guidelines

Leupin (2004) ETH Thesis

World Arsenic Map

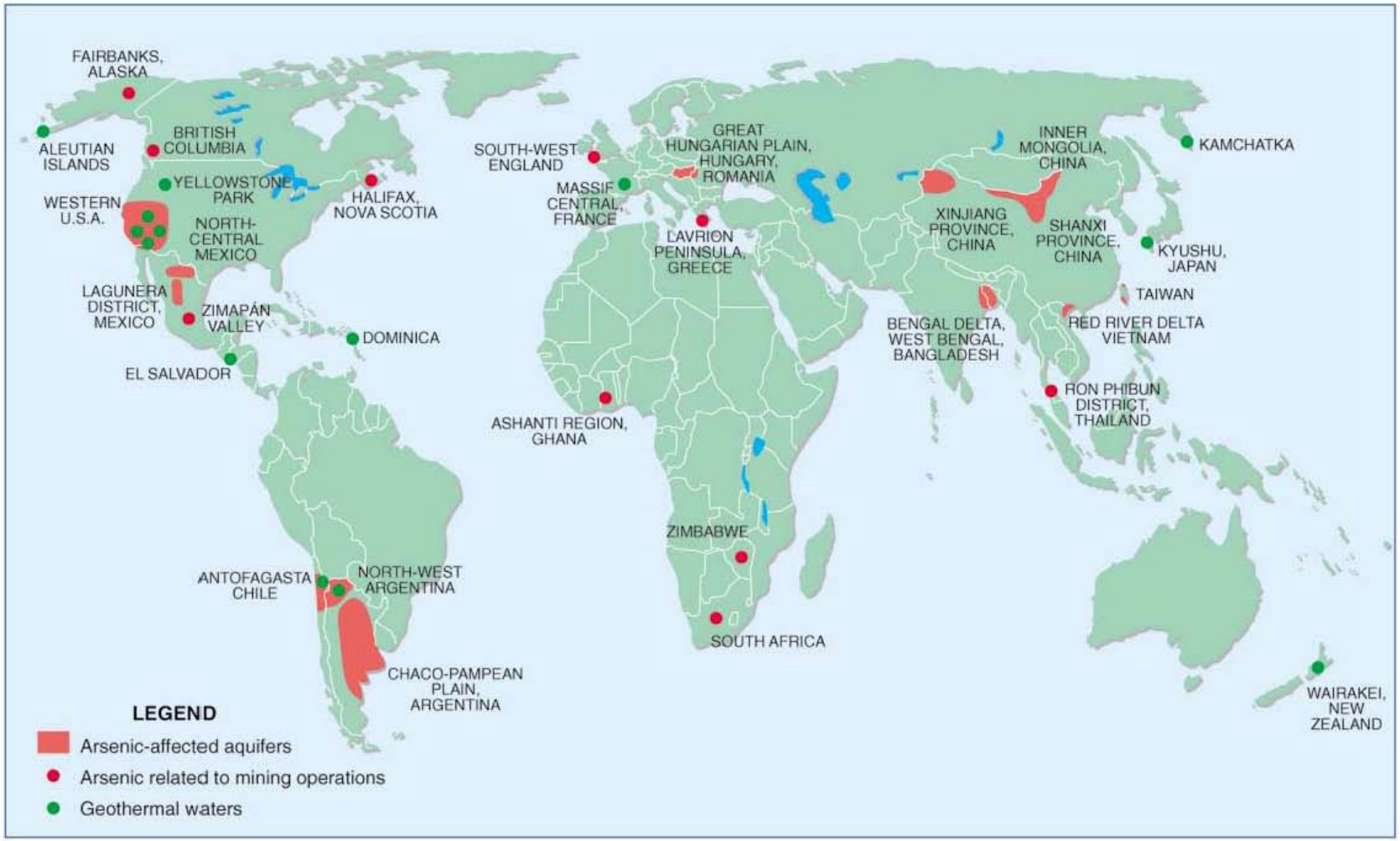
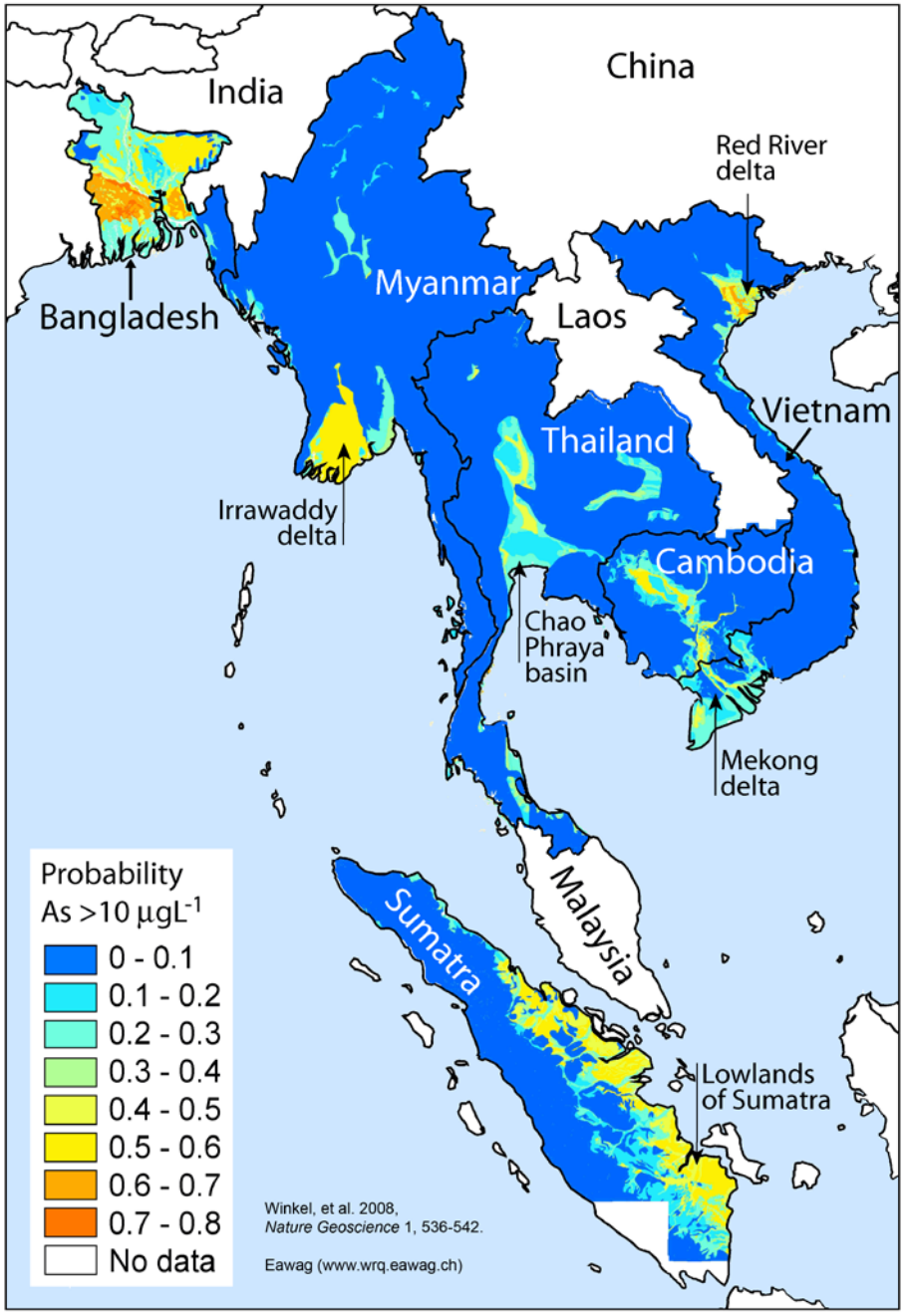
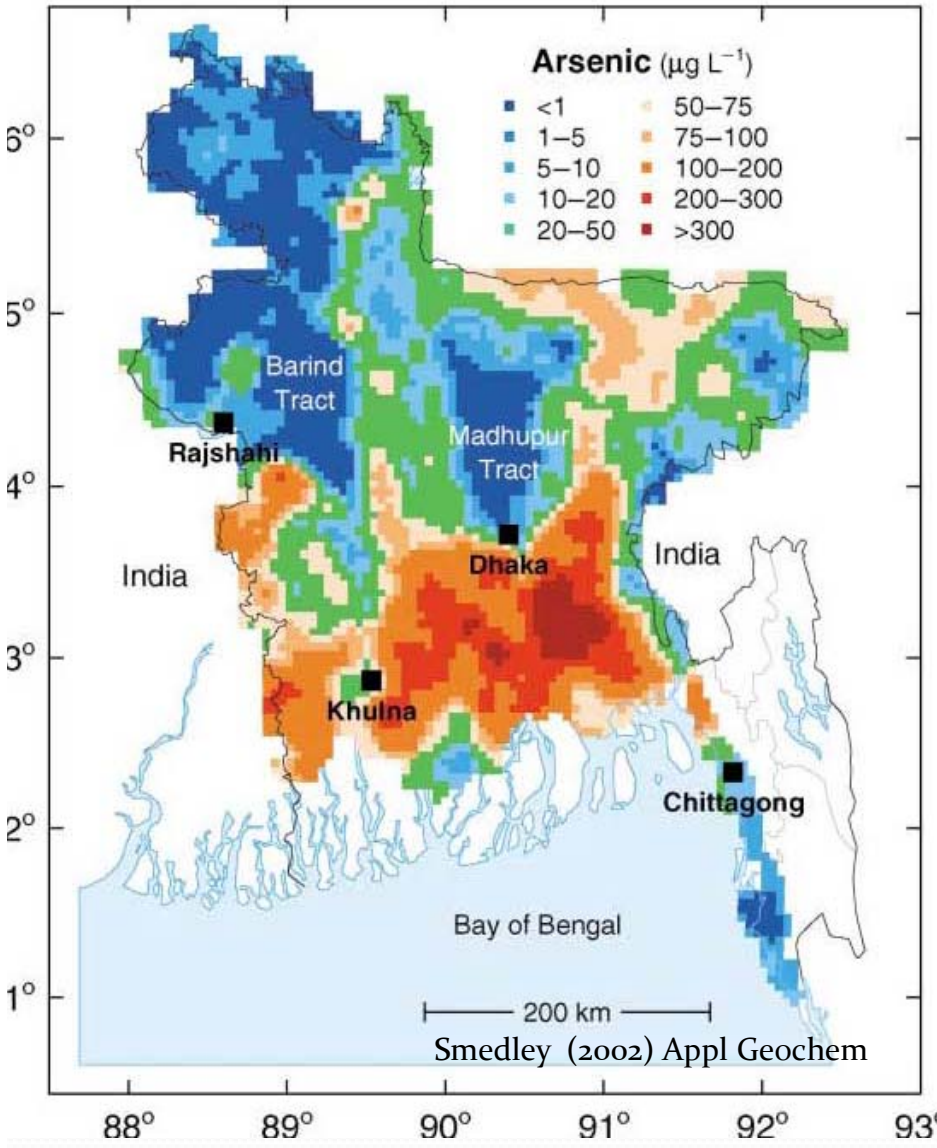


Fig. 3. Distribution of documented world problems with As in groundwater in major aquifers as well as water and environmental problems related to mining and geothermal sources. Areas in blue are lakes.

Smedley (2002) Appl Geochem

Bangladesh Arsenic Map





Smedley (2002) Appl Geochem

Arsenic Chemistry

- Oxidation State
  - **As(III)**: Arsenite AsO_3^{-3}
    - Occurs in highly reduced sediments
    - More mobile in groundwater
    - Removal difficult at pH < 9
    - Most toxic form (1000 x)
  - **As(V)**: Arsenate AsO_4^{-3}
    - Strong adsorbs to mineral surfaces
- Removal by Filtration
  - Reverse Osmosis
  - Ion exchange
  - Iron oxidation and absorption
    - Cast iron turnings

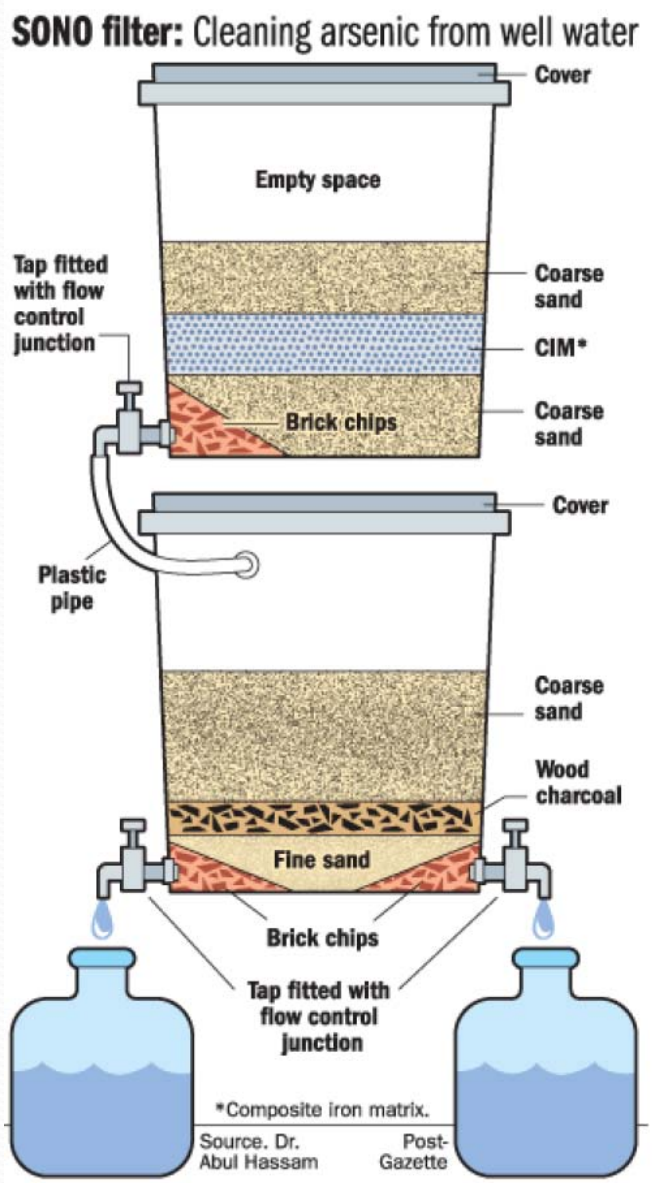
Oxygen (O_2) ↓

Oxidation & Attenuation ←

FIGURE 3-5 Water that appears to be of high quality (right) upon initial draw from the tube well can contain high concentrations of iron and arsenic—the water starts to become turbid (left) through a process of oxidization and self-attenuation.

Hussam (2009) Global Environ Health

Arsenic Treatment



CIM: Composite Iron Matrix

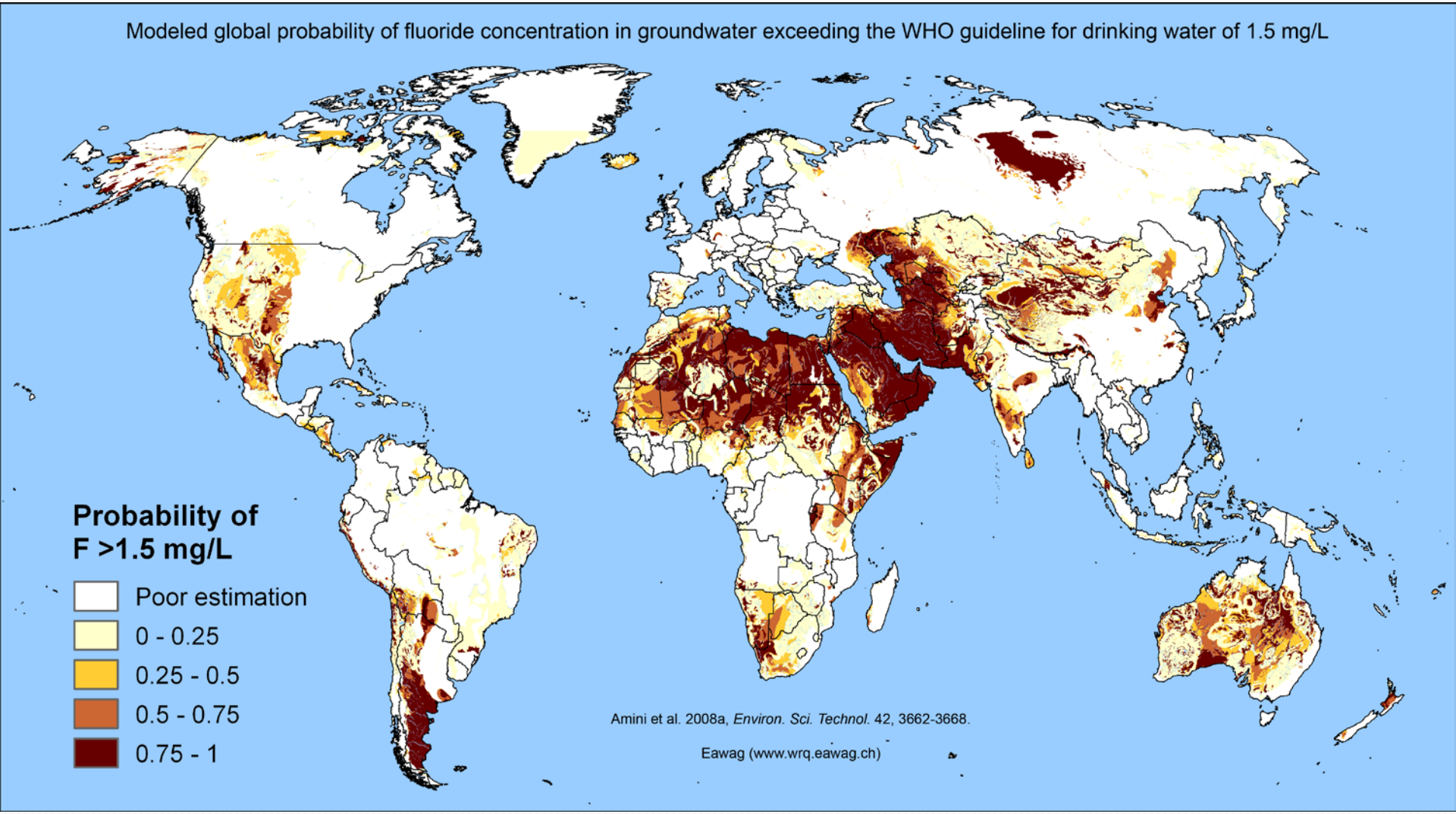
Hussam (2007) J Environ Sci Health

Hussam (2009) Global Environmental Health

Arsenic Removal

- Benefits
  - 20-60 liters/hour (5 years)
  - Effluent <10 µg/L total As, <2 µg/L arsenite
  - Removal of manganese, iron, barium, etc.
  - CIM can be recycled for new filter or metallic iron
- Drawbacks
  - Cost $40
  - When iron hydroxide precipitates in sand, have to clean or replace it
- Removal of arsenic from drinking water can significantly reduce body burden of As within 2 years.

Fluoride Map



Fluoride Removal

- WHO guideline 1.5 mg/L
- Up to 10 mg/L detected in groundwater
- Filtration through Bone Charcoal
  - ion-exchange/adsorption process
- Benefits
  - Prevention of dental/skeletal fluorosis
- Drawbacks
  - Taste and odor
  - Social resistance to handling fresh bone
  - Materials & time (kiln @400 °C, 5 days)

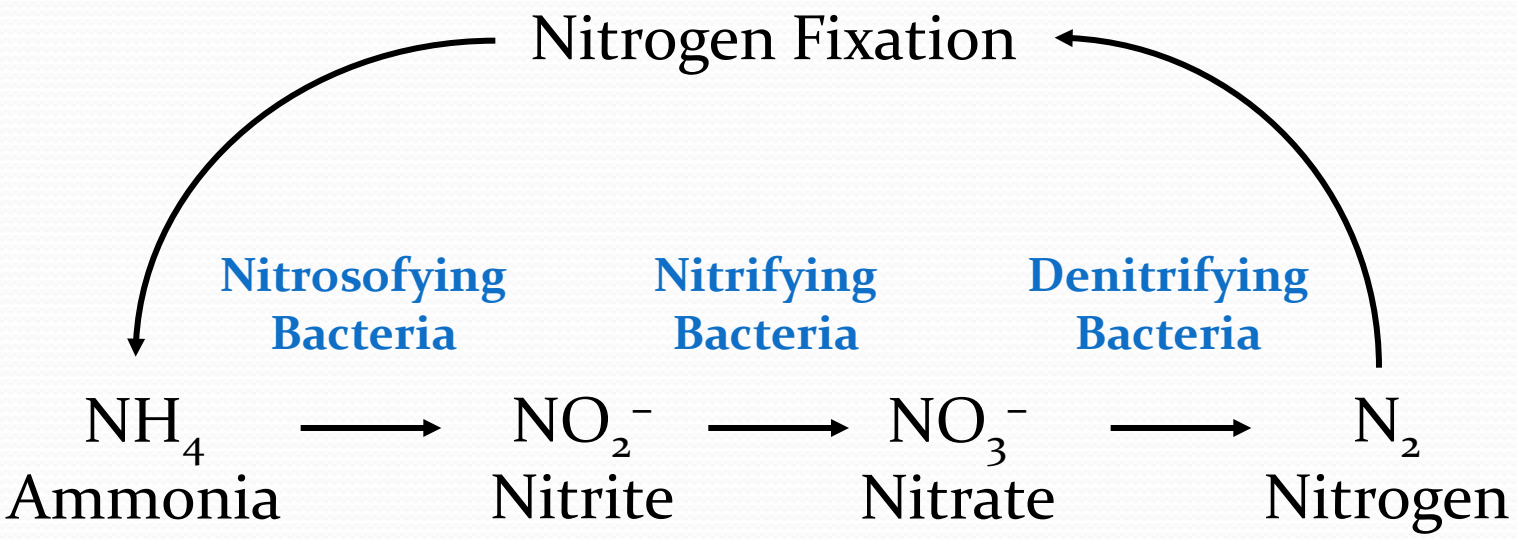
Skeletal Fluorosis
www.unicef.org

Bone char filter
www.eawag.ch

Nitrates

NO_3^-

Simplified Nitrogen Cycle



Nitrification	Denitrification
Aerobic	Anaerobic

Sources of Nitrates in Water

- Septic systems
  - on-site waste water disposal systems
- Runoff and leaching from
  - agricultural land, residential lawns and gardens (nitrogenous fertilizers)
- Animal wastes
  - confined animal feeding operations
  - horses in the pasture

Health Effects of Nitrates:

Blue Baby Syndrome

- Methemoglobinemia
  - In humans, nitrate (NO_3^-) is reduced to nitrite (NO_2^-)
  - Nitrite binds with hemoglobin to form methemoglobin (metHb), a substance that cannot bind and transport oxygen
  - Methemoglobinemia affects bottle-fed infants and pregnant women when >10% metHb
- Maximum nitrite and nitrate concentrations allowed in drinking water are 1 mg/L NO_2-N and 10 mg/L NO_3-N

Health Effects of Nitrates: Cancer Risk

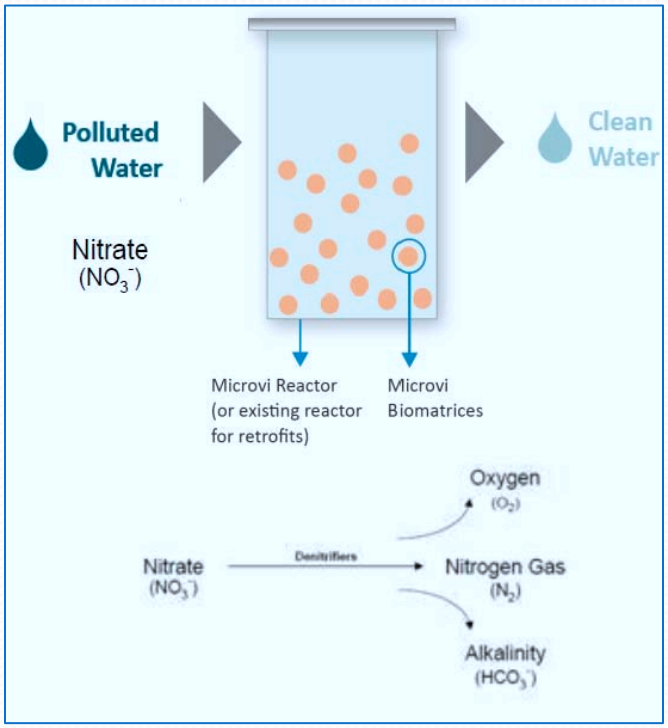
- Nitrate is reduced to nitrite (by denitrifying bacteria in the body)
- Nitrite generates a variety of $H_xN_yO_z$ species that can nitrosate amino acids
- Formation of genotoxic N-nitroso-compounds (NOC): nitrosamines & nitrosamides
- Nitrate exposure has been associated with cancers of the esophagus, stomach, colon, bladder, lymphatic system, and hematopoietic system

Ward MH, deKok TM, Levallois P, Brender J, Gulis G, Nolan BT, et al. **Workgroup report: Drinking-water nitrate and health-recent findings and research needs.** Environ Health Perspect. 2005;113(11):1607-14.

Nitrate Removal

- Methods
  - Reverse Osmosis
  - Ion exchange
  - Biological denitrification
- Considerations
  - Cost (~$300/unit)
  - Maintenance
  - Availability

- NOT:
  - Boiling
  - GAC filtration (Brita)



Shirazi (2011) Microvi Biotechnologies

Case Study: Yakima Valley, WA

- Nitrate is the most common contaminant drinking water wells in Washington State → Dept of Health Study
- The specific objectives of this study were to:

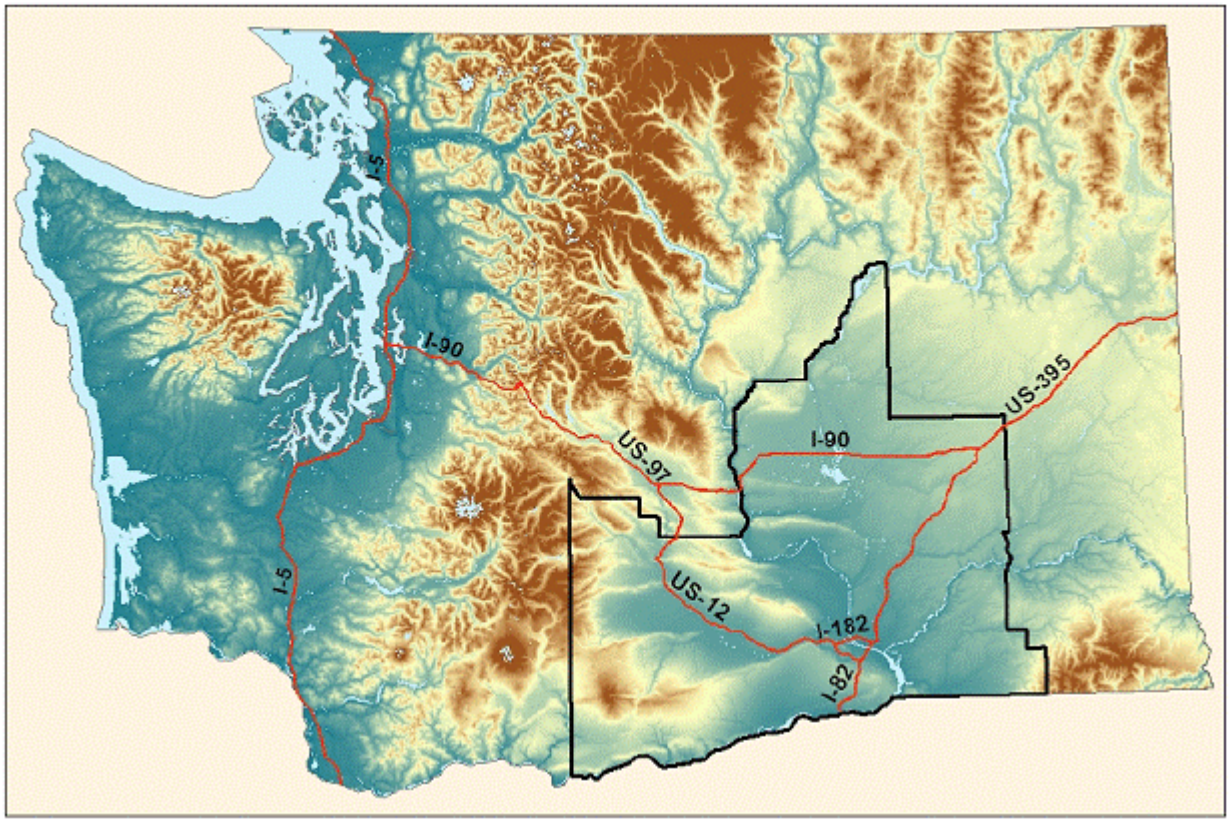
1. Estimate the intake of methemoglobin inducers (i.e., nitrate, copper, chlorination products, medications) by infants and their effects on methemoglobin levels.
2. Estimate the effect of potential endogenous production of nitrite (i.e. symptoms of infection and GI distress) on the level of methemoglobin in infants.
3. Examine mothers' knowledge and attitudes regarding the risks associated with the use of private well water for infants.

http://cfpub.epa.gov/ncer_abstracts/index.cfm/fuseaction/display.abstractDetail/abstract/5379

VanDerslice J. Dose-Response of Nitrate and Other Methemoglobin Inducers on Methemoglobin Levels of Infants: US EPA National Center For Environmental Research, WSD Health 2007. EPA Grant Number: R829781

Case Study: Yakima Valley, WA

Figure 1. Study area, Washington State



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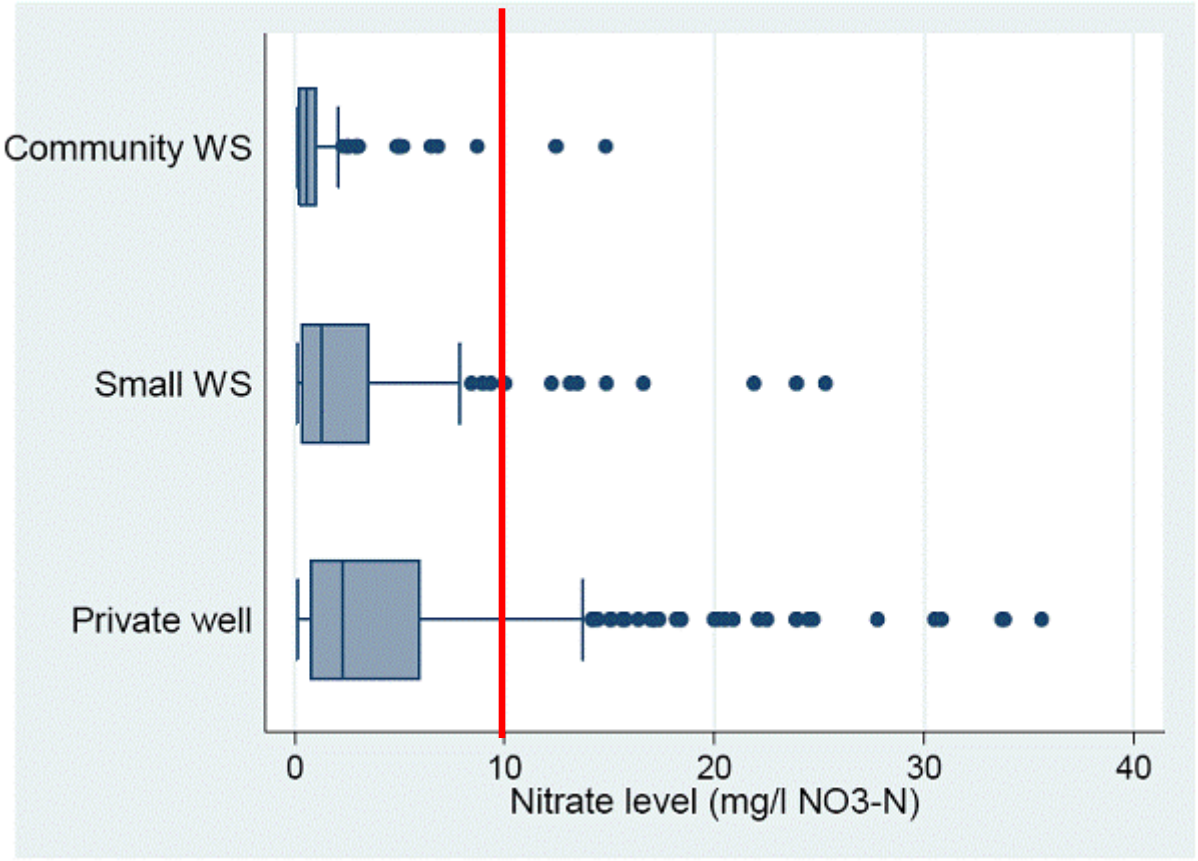

Figure 3. Distribution of tap water nitrate levels by source of tap water

VanDerslice J. Dose-Response of Nitrate and Other Methemoglobin Inducers on Methemoglobin Levels of Infants: US EPA National Center For Environmental Research, WSD Health 2007. EPA Grant Number: R829781

Case Study: Yakima Valley, WA

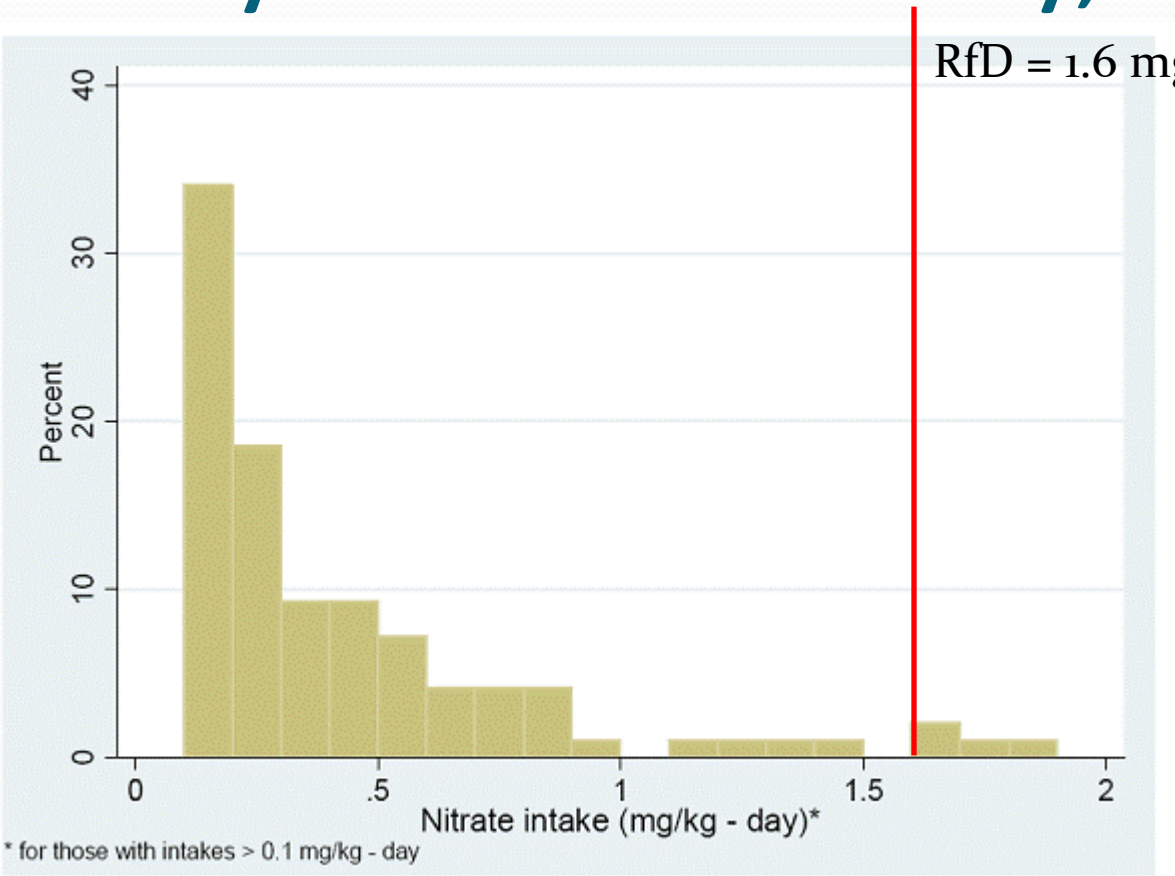

Figure 7. Distribution of nitrate intake (mg NO3-N/ kg body weight – day)

* reference dose (RfD) is the US EPA's maximum acceptable oral dose of a toxic substance.

VanDerslice J. Dose-Response of Nitrate and Other Methemoglobin Inducers on Methemoglobin Levels of Infants: US EPA National Center For Environmental Research, WSD Health 2007. EPA Grant Number: R829781

Case Study: Yakima Valley, WA

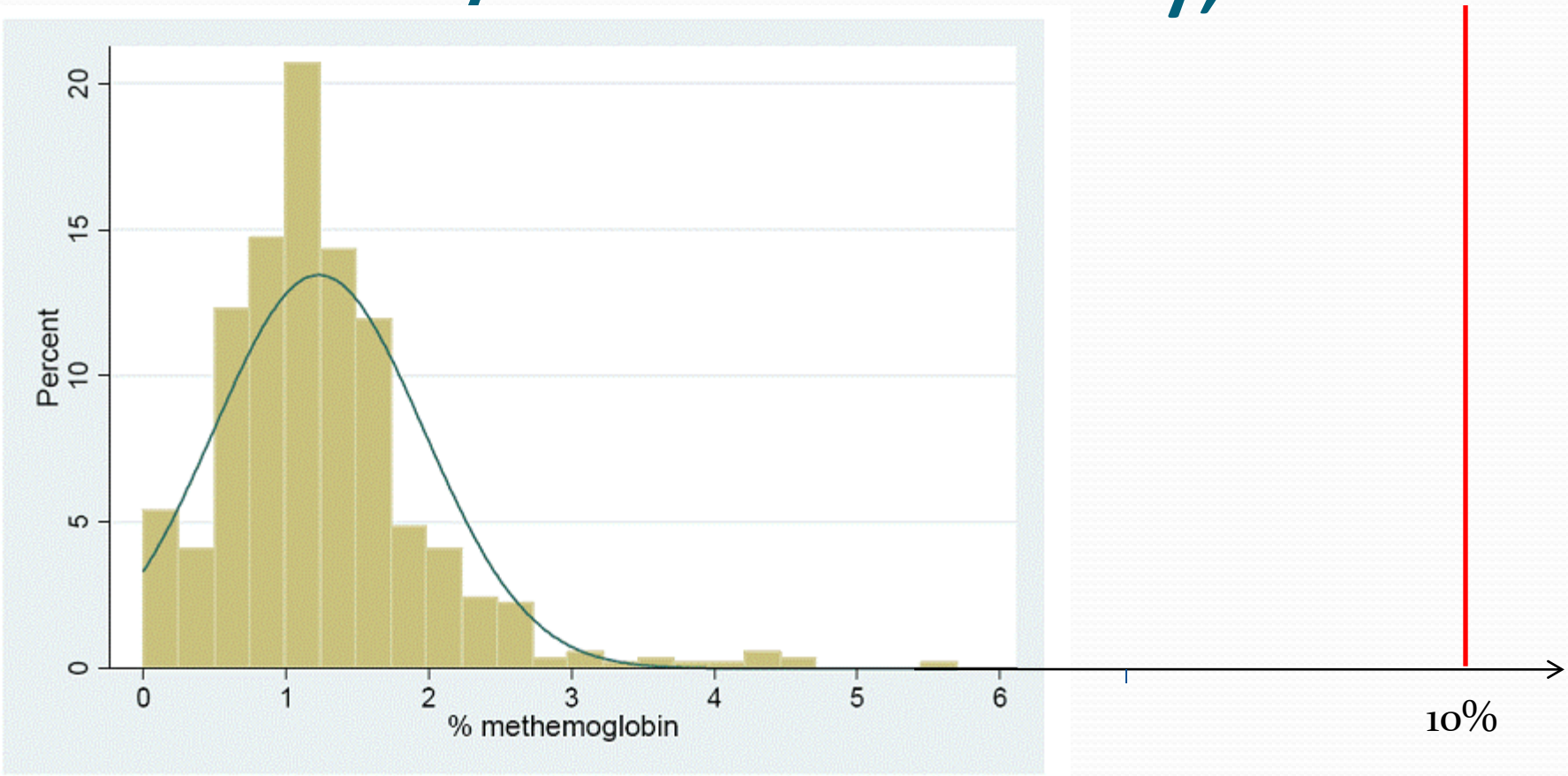

Figure 8. Distribution of methemoglobin levels

VanDerslice J. Dose-Response of Nitrate and Other Methemoglobin Inducers on Methemoglobin Levels of Infants: US EPA National Center For Environmental Research, WSD Health 2007. EPA Grant Number: R829781

Case Study: Yakima Valley, WA

- No clinical cases of methemoglobinemia (>10% metHb)
- Exposure to nitrate from drinking water increases the risk of an infant having elevated levels of methemoglobin
- Risk for exposures >0.5 mg NO_3-N/kg day, 1/3 of RfD*
- 4 % of infants (1-5 months) with this exposure
- Infants who were given water containing >5 mg/L NO_3-N had exposures >0.5 mg/kg day.
- Exposure to Total Coliforms or E.Coli positive drinking water was associated with having > 2 % metHb.

* reference dose (RfD) is the US EPA's maximum acceptable oral dose of a toxic substance.

VanDerslice J. Dose-Response of Nitrate and Other Methemoglobin Inducers on Methemoglobin Levels of Infants: US EPA National Center For Environmental Research, WSD Health 2007. EPA Grant Number: R829781

Current US EPA Studies in Yakima Valley

Nitrate Treatment Pilot Program Final Report - June 30, 2011
www.yakimacounty.us/nitrateprogram/english/default.htm

Lower Yakima Valley Groundwater. 2010
http://yosemite.epa.gov/R10/WATER.NSF/GWPU/lyakimagw

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