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Education

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May 2019 Residential School

Yangon University

20 – 24 May 2019

Introduction to Water Quality and Water Remediation

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WATER AND POLLUTION:
INTRODUCTION TO WATER QUALITY AND WATER REMEDIATION

Dr. Laura Richards
School of Earth and Environmental Sciences
The University of Manchester
as part of the TIDE May 2019 Residential School

This content has been adapted from previous short courses/seminars, in particular: (i) Training for Environmental Research (Richards, Sovann, Downie, Uhlemann, Naden, Polya), Royal University of Phnom Penh, Cambodia, 2015 ; and (ii) Myanmar Partner University Water Research Seminar Series (Richards and Pincetti Zúñiga, with input from Tun and Polya), locations across Myanmar, 2017, with support from NERC (NE/J023833/1, Polya et al.); The Leverhulme Trust (ECF2015-657, Richards); EPSRC GCRF (IS 2016, Richards et al.) and EPSRC Improving Diversity (2017, Richards et al.). We are grateful for translations of content; in case of material differences, the English interpretation should be used. For further information: Laura.Richards@manchester.ac.uk.

Tutor Introduction

Dr. Laura Richards

BSc: Chemical Engineering

MSc: Environmental Engineering

PhD: Membrane Technology

PDRA & Research Fellowship: Environmental Geochemistry

Research Expertise: Water Quality & Water Remediation, with a focus on trace contaminants (e.g. arsenic) in groundwater, including in S/SE Asia

Today's Sessions

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- **Session 1:** Introduction to Water Sampling and Field Measurements
- **Session 2:** Introduction to Water Remediation I
- **Session 3:** Introduction to Water Remediation II

- **Learning Outcomes:**
  - Knowledge of selected key theoretical and practical considerations for water sampling and field measurements
  - Knowledge of basic principles and considerations for selected drinking water remediation strategies illustrated by theory and practice

SESSION 1: WATER SAMPLING & FIELD MEASUREMENTS

What We'll Cover

- Part A: Introduction & Theory (~ 30 minutes)
  - Why collect water samples?
  - Water quality guidelines
  - Sampling design considerations
  - Field and laboratory measurements
  - Quality assurance and quality control
  - Case studies: Cambodia & Myanmar
- Part B: Practical & Discussion (~ 60 minutes)
  - Filtering water samples
  - Basic field measurements (pH, EC, temperature, GPS, nitrate/nitrite)
  - Recording data
  - Presenting data
- Questions

SESSION 1: WATER SAMPLING & FIELD MEASUREMENTS

PART A: Introduction & Theory

Why do we collect water samples?

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- To better understand water and pollution
- To test a theory
  - Research!
- To comply with regulations
- As a job requirement
  - Environmental scientists
  - Engineers
  - Field assistants
  - Many more….!

Why do we collect water samples?

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- To collect data for water quality monitoring
  - To identify safety of drinking water sources
  - To identify specific pollutants or sources of pollution
  - To determine trends
  - To determine if a water is appropriate for a certain use
- Important for environmental studies, water resource management, estimating exposure to pollutants & public health

Collecting and analysing water samples is a key component of environmental research

World Health Organization Guidelines (Partial list)

- Aesthetic
- Micro-organisms
- Chemical
  - Inorganic chemicals
  - Organic chemicals
  - Disinfection byproducts
  - Radionuclides
  - Emerging pollutants

*Provisional guideline on the basis of treatment performance and analytical achievability.

Chemical	Adverse Effect	Guideline mg/L
Antimony	Blood disorders	0.02
Arsenic	Skin damage, toxic, cancer	0.01*
Barium	Hypertension	1.3
Boron	Short term irritant and organ effects	2.4
Cadmium	Kidney damage	0.003
Chromium	Dermatitis, possible carcinogen	0.05*
Copper	Gastrointestinal, liver or kidney damage	2
Fluoride	Dental and skeletal fluorosis	1.5
Nitrite	Toxic, leads to baby-blue syndrome	50
Selenium	Long-term toxic effects	0.04*
Uranium	Possible carcinogen	0.03*

Adapted from World Heatlh Guidelines (http://www.who.int/water_sanitation_health/dwq/gdwq3rev/en/, accessed May 2012) and Dr. Peter Shanahan, MIT Opencourseware, Water & Wastewater Treatment Engineering Lecture 2

Some Typical Measurements

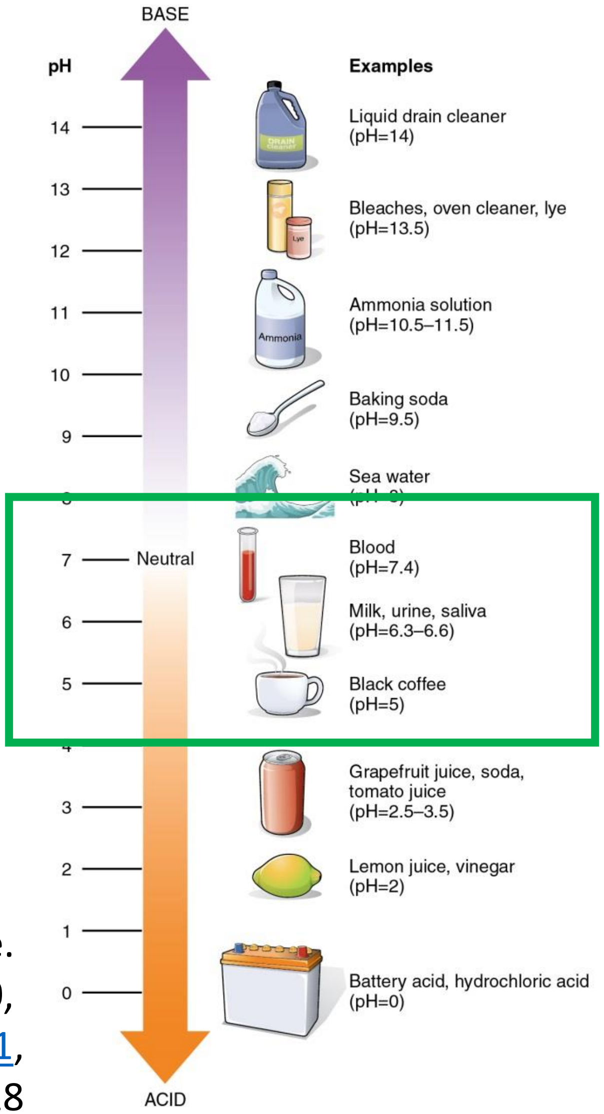
- Today we will focus on some basic field measurements that can be made and are common for many studies on water and pollution
  - pH
  - Electrical conductivity
  - Temperature
  - GPS
  - Nitrate
- Specialized analytical equipment is required to measure some other important water quality parameters (e.g. trace metals, etc.)
  - Samples may need to be collected and stored for analysis in a laboratory
- See Richards et al., 2017 (STOTEN) and Polya & Watts 2017 (IWA Chapter 5) for details on typical sample preservation & analysis & QA/QC

pH

- Measure of the acidity/basicity of an aqueous solution
- Relates to concentration of H^+ and OH^- ions
- Can be measured using:
  - pH strips
  - pH-meter / Pocket pH Tester
  - Multi-parameter meter
- Precision & accuracy varies with method
- Calibration is important

Photo from Gianfranco Pincetti Zúñiga, 2018

Natural waters



Electrical Conductivity

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- Measures the ability of water to pass an electrical current
- Can be measured using portable meters
- Can be used to estimate total dissolved solid (TDS)

↑ Dissolved inorganic solids (e.g. Cl^-, Na^+, Ca^{2+}, Mg^{2+}, HCO_3^-, etc.)

↑ Temperature 2-3% per °C

↑ Conductivity

Water Type	Typical Ranges (*can vary greatly with composition)
Distilled Water	~ 1 µS/cm
Rain water	~ 2 – 100 µS/cm
Surface / Groundwater	~ 50 – 50,000 µS/cm (usually surface water < groundwater)
Seawater	~ 50,000 µS/cm

Global Positioning System (GPS)

- A global satellite navigation system that provides geo-location and time data
- Important for marking locations
- Can use GPS device or most smart phones

Photo from Gianfranco Pincetti Zúñiga, 2018

Nitrate (NO_3^-)

- A naturally occurring ion that is part of the nitrogen cycle
- A major component of inorganic fertilizers
- Nitrate in surface or groundwater can be a marker of water pollution, and in particular, agricultural activity
- Test strips can be used to estimate concentrations; more advanced analytical methods in field or laboratory settings offer improved detection/accuracy

Photo from Gianfranco Pincetti Zúñiga, 2018

For more information: World Health Organization "Nitrate and nitrite in drinking water", WHO/SDE/WSH/07.01/16/Rev/1, http://www.who.int/water_sanitation_health/dwq/chemicals/nitratenitrite2ndadd.pdf, accessed 17 April 2018

Sampling Design Considerations

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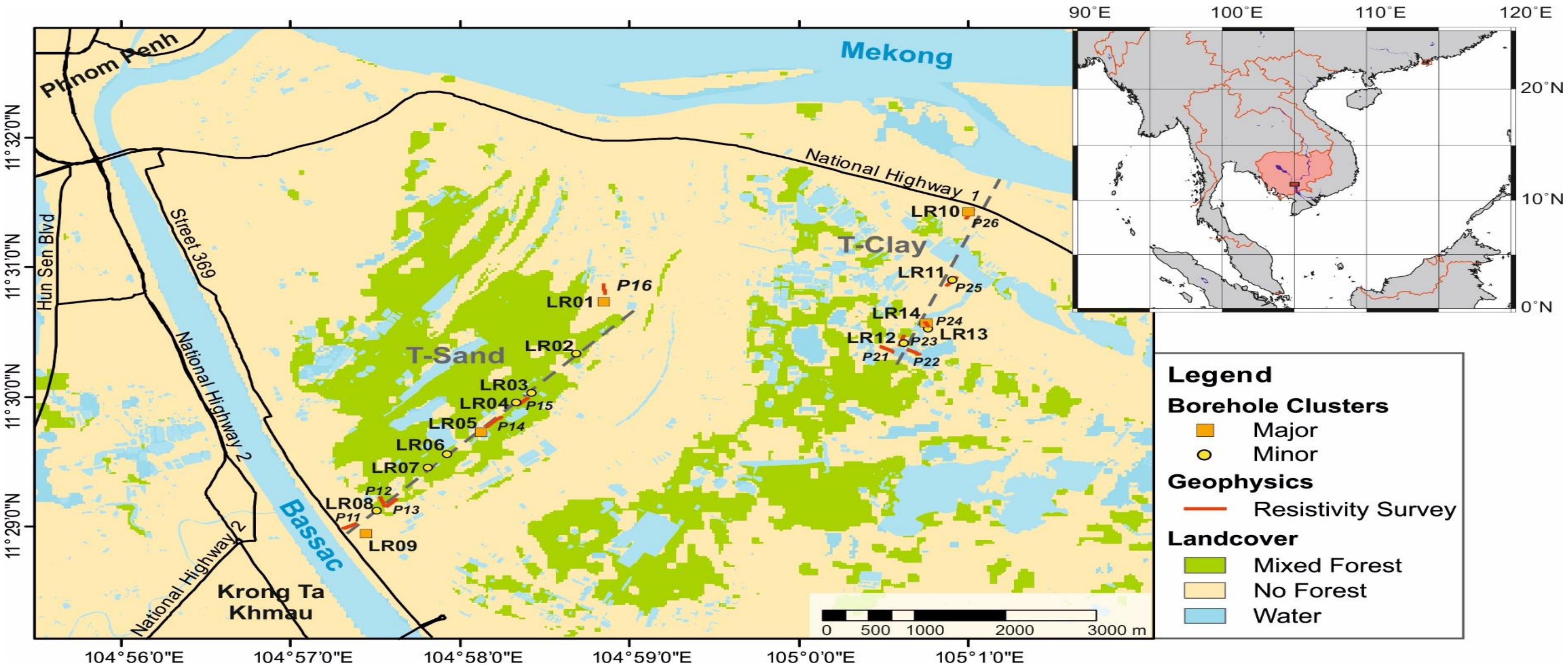
- The type of sample we need
- How we can collect the sample
- The type of measurements we need (field vs laboratory)
- Materials (e.g. bottles, filters, other equipment, data recording, etc.)
- Permissions & site access
- Health and safety
- What other information do we need? (site characterization, weather information, *etc.*)
- **Sampling design depends on project objectives**

Site Selection

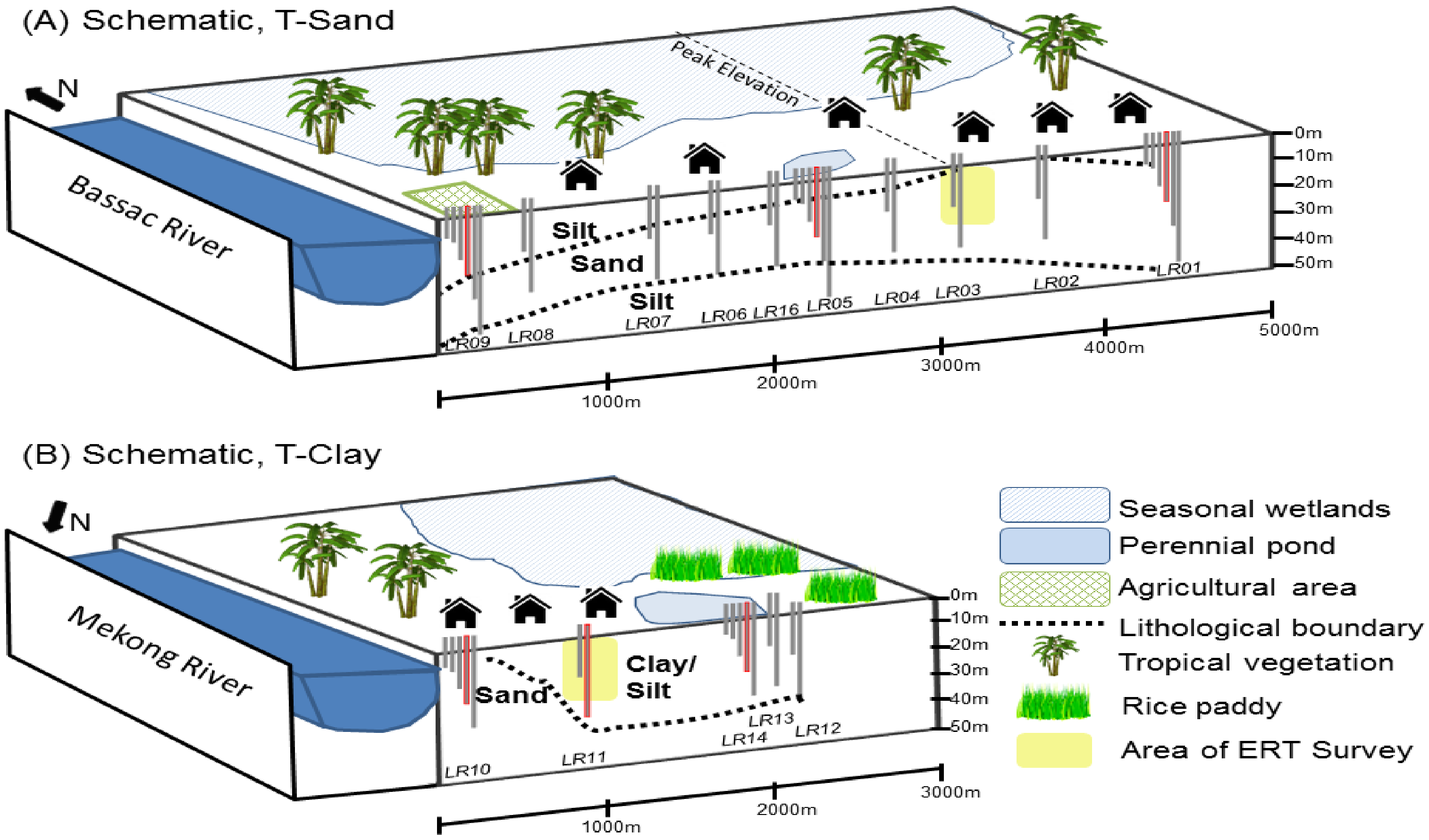
- Consider possible pollution sources
  - Point source versus non-point source
  - Natural (e.g. “geogenic” versus anthropogenic)
- Baseline values
- Depends on project objectives
- Site “X”

Case Study: Arsenic in Cambodia



Richards et al., 2017, Sci. Tot. Environ. (http://dx.doi.org/10.1016/j.scitotenv.2017.02.217, *open access CC-BY 4.0)*

Case Study: Arsenic in Cambodia



Richards et al., 2017, Sci. Tot. Environ. (http://dx.doi.org/10.1016/j.scitotenv.2017.02.217, open access CC-BY 4.0)

Case Study: Myanmar Survey

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- Cross-country exploratory groundwater quality survey (December 2017)

Photo from Laura Richards, 2017

Map from Google Earth

Sampling Preparations

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- Prepare sampling bottles – fill out labels, double check, clear tape to "waterproof"
- Prepare data sheets
- Daily calibrations

Photos from Laura Richards, 2014

Groundwater Sampling Setup

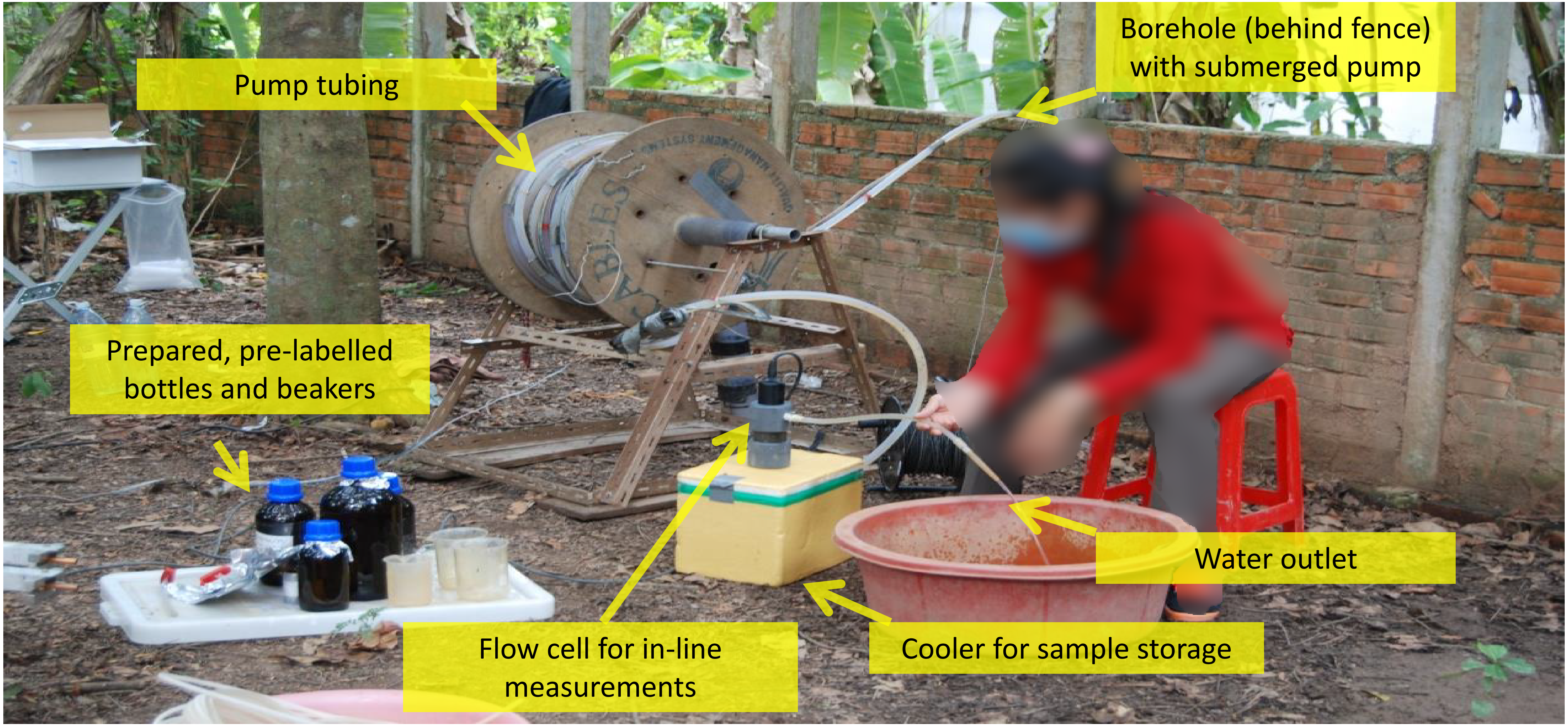

Photo from Laura Richards, 2014

Data Quality Assurance & Control

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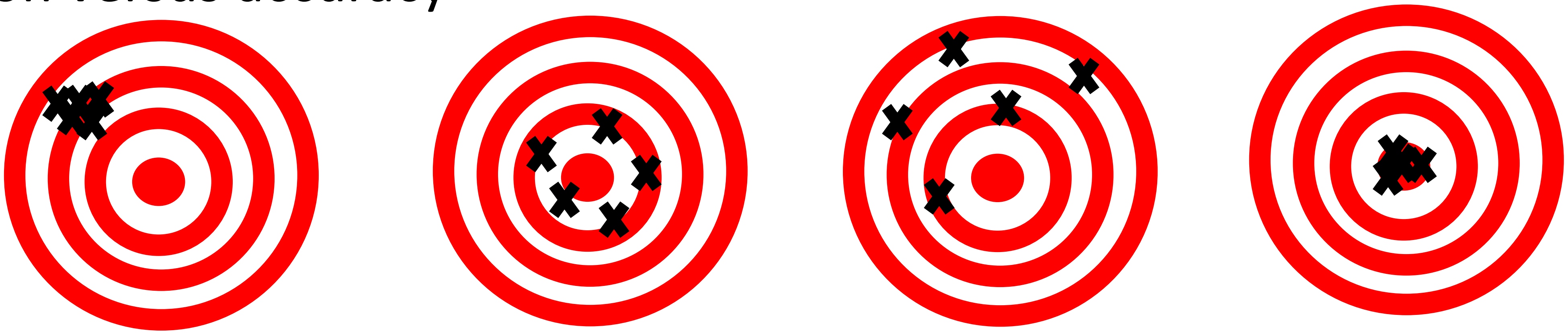
- Quality control (multiple samples, multiple measurements, blanks, etc)
  - Take duplicate or triplicate samples (~ 5 – 10 %)
  - Blanks and procedural blanks
  - Estimate and understand uncertainties and errors
  - How do we ensure the sample is representative?
- Minimize contamination
  - Clean thoroughly
  - Start with least contaminated samples
- Use good data management practices (notebooks, etc)
- Consider other sampling and analytical QA/QC procedures (see Polya et al., 2017 and Polya & Watts 2017 IWA chapters for more details)

Data Quality Assurance & Control

- Understanding measurements
    - Regular calibrations (often daily)
    - Detection limits
    - Appropriate operational range
    - Read equipment manuals and operate properly; ensure proper training
    - Verify requirements for preservation and degradation time of parameters
- Precision versus accuracy



Precision ✓ Accuracy ✗	Precision ✗ Accuracy ✓	Precision ✗ Accuracy ✗	Precision ✓ Accuracy ✓

Data Quality Assurance & Control

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- Based in electro-neutrality property of water
- Charge balance:

$$CB\ error\ (\%) = 100 * \frac{(\sum cations\ - \sum anions)}{(\sum cations\ + \sum anions)}$$

- Units must be converted from mg to meq
- Usually 5% threshold (depends on project requirements)

Data Sheets & Recording

- Prepare labels and datasheets before you go
- Information to include (depends on objectives)
  - Name, date, location
  - Samples collected
  - In-field measurements
  - Always include an “Other” category
- Take lots of notes (even if you’re not sure if it is important) – be complete
- Take photos of completed datasheets as backup
- Store datasheets somewhere safe and dry (ideally in waterproof sleeves; write in waterproof pen)

Water Sampling Challenges

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All sorts of unplanned challenges can come up; creativity and positivity go a long way in sorting out a desired outcome

Photos from Laura Richards, 2014

Water Sampling Top Tips

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- Plan ahead
- Design sampling according to project objectives
- Make sure your labels are correct
- Pay attention to things that might affect your results
- Write everything down in a notebook (even if it doesn't seem important at the time)
- Follow a set procedure for each sampling event (ideally, although sometimes things change)
- Be flexible and creative, and have fun!

WATER SAMPLING & FIELD MEASUREMENTS:

PART B:
Practical & Discussion: Filtering, pH, EC, data interpretation, data presentation

Activity 1 (~30 minutes)

- Collect your water sample and supplies
- The course leaders will first demonstrate techniques
- We will practice
  - Filtering samples with a syringe filter
  - pH measurements (meter)
  - Electrical Conductivity Measurements (meter)
  - Nitrate (test strips)
- When your group is finished, come write your results on the big paper in the front of the room
- Group discussion

Discussion Topics

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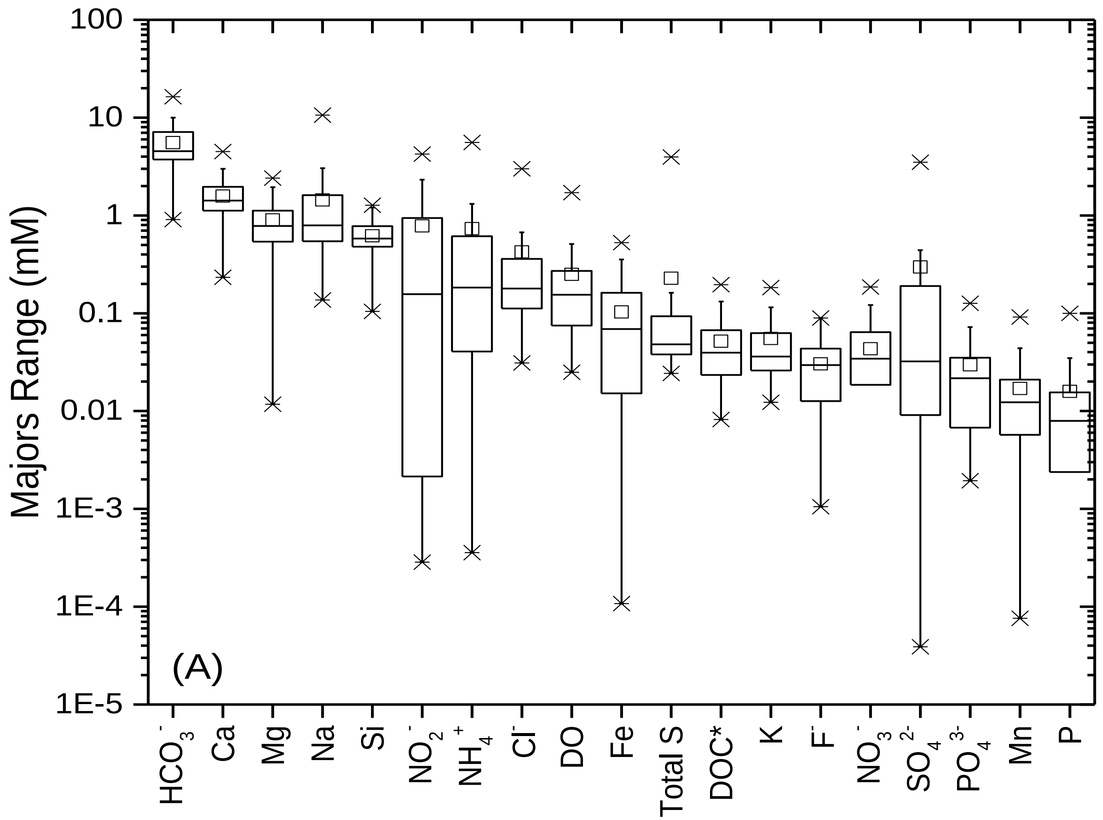
- What can we deduce about the water samples?
- How do your measurements compare to other groups'?
- How could we present this data?
- How could we interpret this data?
- What additional measurements would we like to do?

Presenting Data

- There are many ways to present data
- A few examples are shown here:
  - Box and whisker plots
  - Bubble plots
  - Map views
  - Piper diagrams
- The best way to present data depends on project objectives and what you would like to show

Box and Whisker Plots

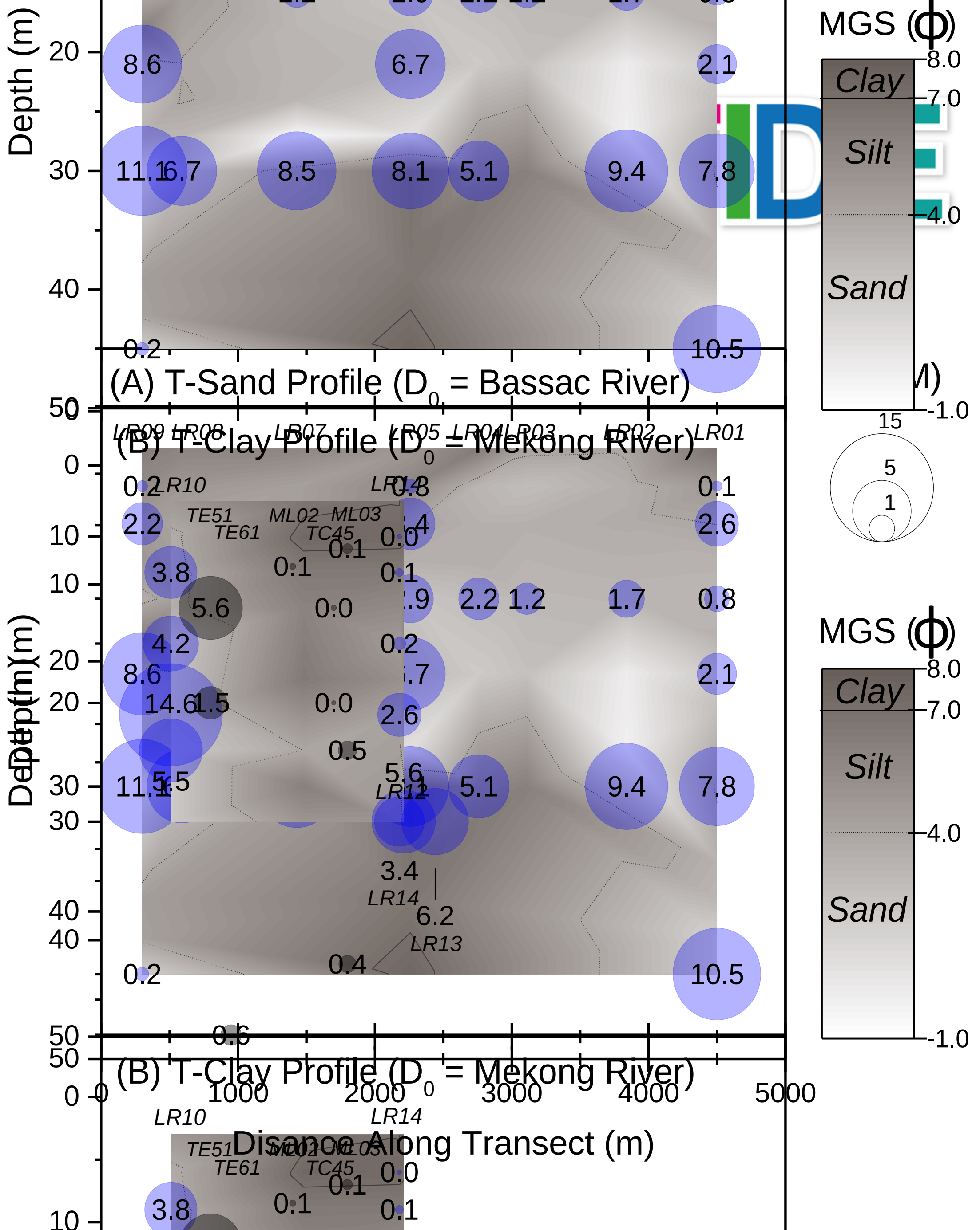
- Good for showing summary statistics of various parameters
- Good for showing statistical distribution



Richards et al., 2017, Sci. Tot. Environ. (http://dx.doi.org/10.1016/j.scitotenv.2017.02.217, open access)

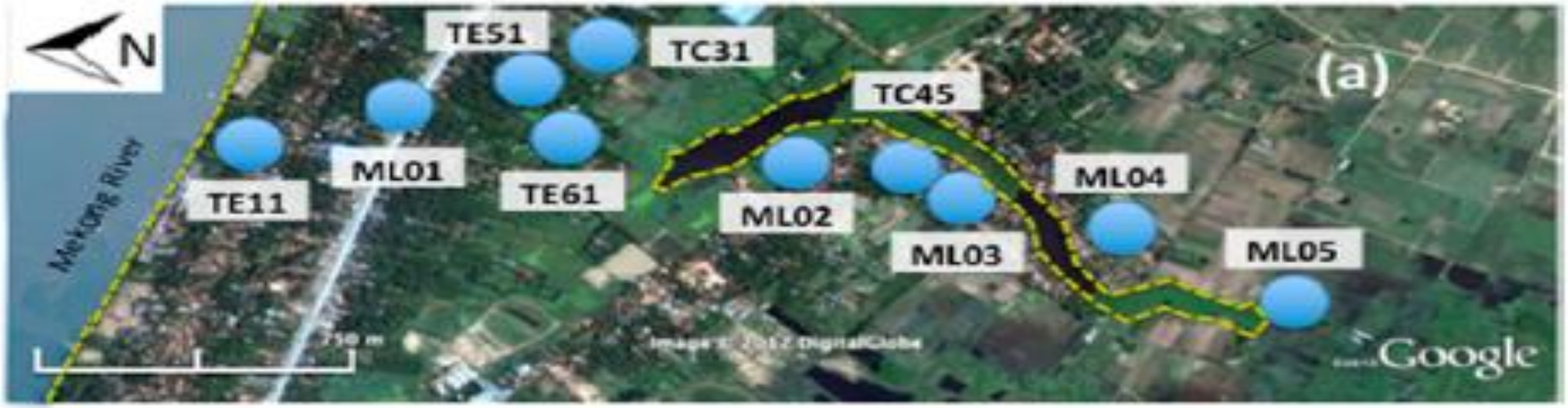
Bubble Plots

- Good for showing multiple dimensions of information (e.g. arsenic, depth, distance, grain size)



Richards et al., 2017, Sci. Tot. Environ. (http://dx.doi.org/10.1016/j.scitotenv.2017.02.217, open access CC-BY 4.0)

Map Views

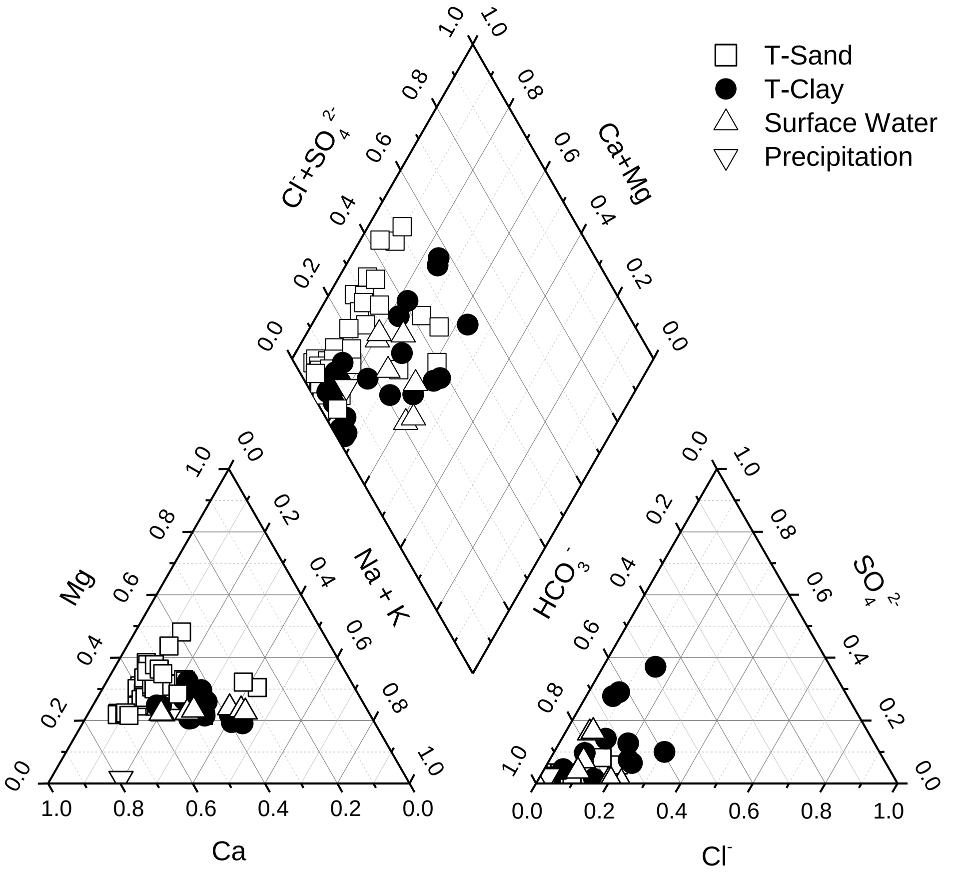


- Good for showing along with geographical features, or to show a field area
- Can combine with bubble and Stiff plots

Figure 2A from Lawson et al., 2013, Environmental Science and Technology, (open access CC-BY)

Piper Diagrams

- Good for characterizing water and showing trends (e.g. water-rock interactions)
- From chemical analysis, obtain concentrations of cations and anions
- Calculate the proportions (in meq or molar concentration) of major:
  - Cations: $Na^+ + K^+$, Mg^{2+}, Ca^{2+}, Mn^{2+}
  - Anions: $Cl^- + NO^-_3$, HCO^-_3, SO^{-2}_4
- Plot cations on one triangular diagram and anions on the other



For example: Richards et al., 2017, Sci. Tot. Environ. (http://dx.doi.org/10.1016/j.scitotenv.2017.02.217, open access CC-BY 4.0)

Activity 2: Calibration (~ 30 minutes)

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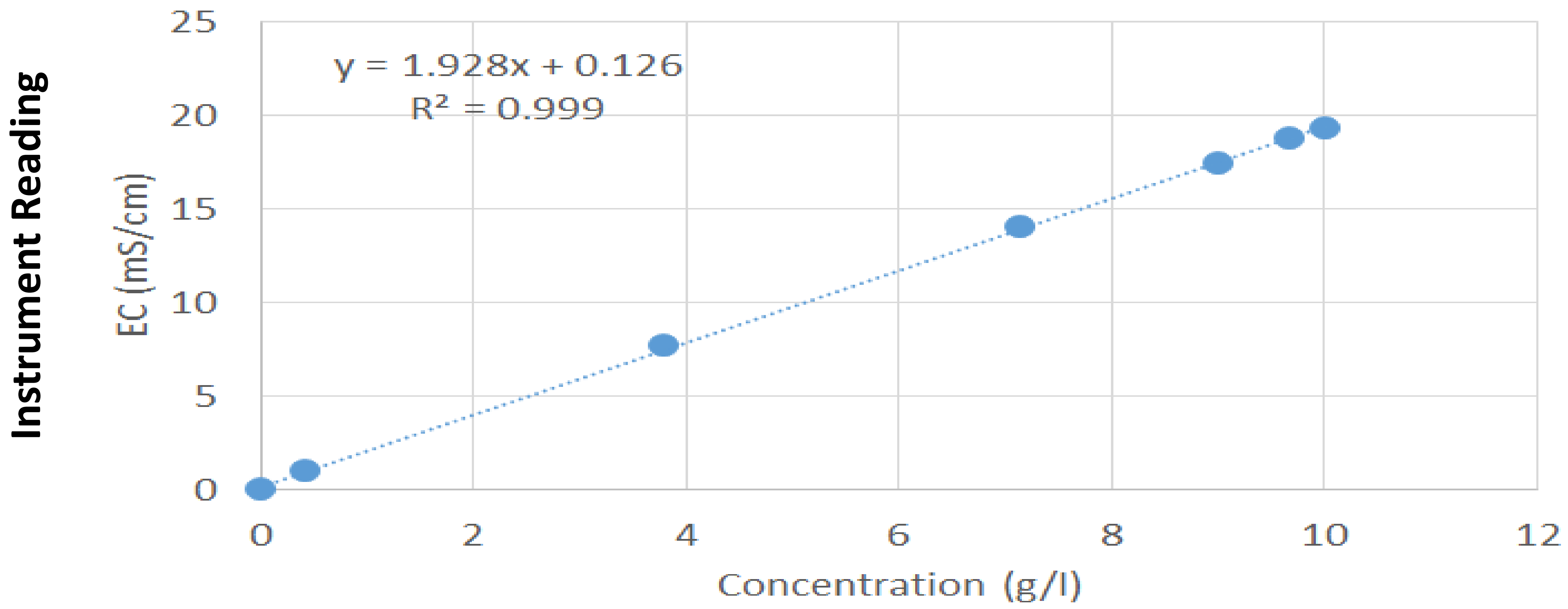
- The process of evaluating and adjusting measurement equipment
- Proper calibration:
  - Improves the precision and accuracy of measurement equipment
  - Allows a safe working environment
  - Assists in data interpretation
  - Essential for producing valid data

Calibration



How much salt you add

Activity 2

- Electrical Conductivity Experiment
- Get out the water sample you brought and the table salt (NaCl)
- Now add some of the table salt to your water sample
  - What do you think will happen to the electrical conductivity?
  - Next we will measure the electrical conductivity to test your hypothesis
  - Continue adding increasing concentrations of salt and measure electrical conductivity
  - Plot your results on the graph paper provided
- When your group is finished, bring your calibration plot to the flip chart in the front of the room

Discussion Topics

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- How does your group's calibration "curve" compare to the others?
- What happens to the measurement if we don't add enough salt? Too much salt?
- How does this compare to sea water?
- Understanding calibrations & troubleshooting common problems

References

- Lawson *et al.*, (2013), Pond-Derived Organic Carbon Driving Changes in Arsenic Hazard Found in Asian Groundwaters, ES&T 47 (13), 7085 – 7094, http://pubs.acs.org/doi/abs/10.1021/es400114q (open access)
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- U.S. Environmental Protection Agency, Chapter 5 Water Quality Conditions, http://water.epa.gov/type/rsl/monitoring/vms50.cfm, accessed 18 Nov 2015, free
- World Health Organization, Guidelines for Drinking Water Quality, 4th Ed, 2011, http://www.who.int/water_sanitation_health/publications/2011/dwq_guidelines/en/, accessed 18 Nov 2015, free

WATER SAMPLING & FIELD MEASUREMENTS: SESSION 1 REVIEW

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- Today, we covered a basic introduction to
  - Basic water sampling and field measurements
  - Recording data
  - Presenting data
  - Calibration
- Feedback form
- Questions?

Thank you!

Dr. Laura Richards, University of Manchester
May 2019 TIDE Residential School

SESSION 2: INTRODUCTION TO WATER REMEDIATION I

What We'll Cover

- Part A: Introduction & Theory (~ 45 minutes)
  - Water quality and health
  - Typical types of pollution
  - Overview of various drinking water treatment technologies
  - Case studies
- Part B: Practical & Discussion: Sand Filters (~ 45 minutes)
  - Construction of sand filters
  - How effective?
- Questions

INTRODUCTION TO DRINKING WATER REMEDIATION

PART A: Introduction & Theory

Why is Water Quality Important?

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- Improved water quality may:
  - Protect public health
  - Increase economic productivity and/or educational attendance
  - Increase overall well-being
  - Be associated with improved food quality (*e.g.* rice)
  - Meet regulatory and/or health-based guidelines
- Protecting public health is now the primary reason for drinking water standards

Water quality is linked with many of the Sustainable Development Goals

http://www.un.org/sustainabledevelopment/sustainable-development-goals/, accessed 22 Nov 2016

World Health Organization Guidelines (Partial list)

- Aesthetic (taste, odor, *etc.*)
- Micro-organisms
- Chemical
  - Inorganic chemicals including heavy metals
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  - Disinfection byproducts
  - Radionuclides
  - Emerging pollutants

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Adapted from World Heatlh Guidelines (http://www.who.int/water_sanitation_health/dwq/gdwq3rev/en/, accessed May 2012) and Dr. Peter Shanahan, MIT Opencourseware, Water & Wastewater Treatment Engineering Lecture 2

Diarrhoea and Mortality

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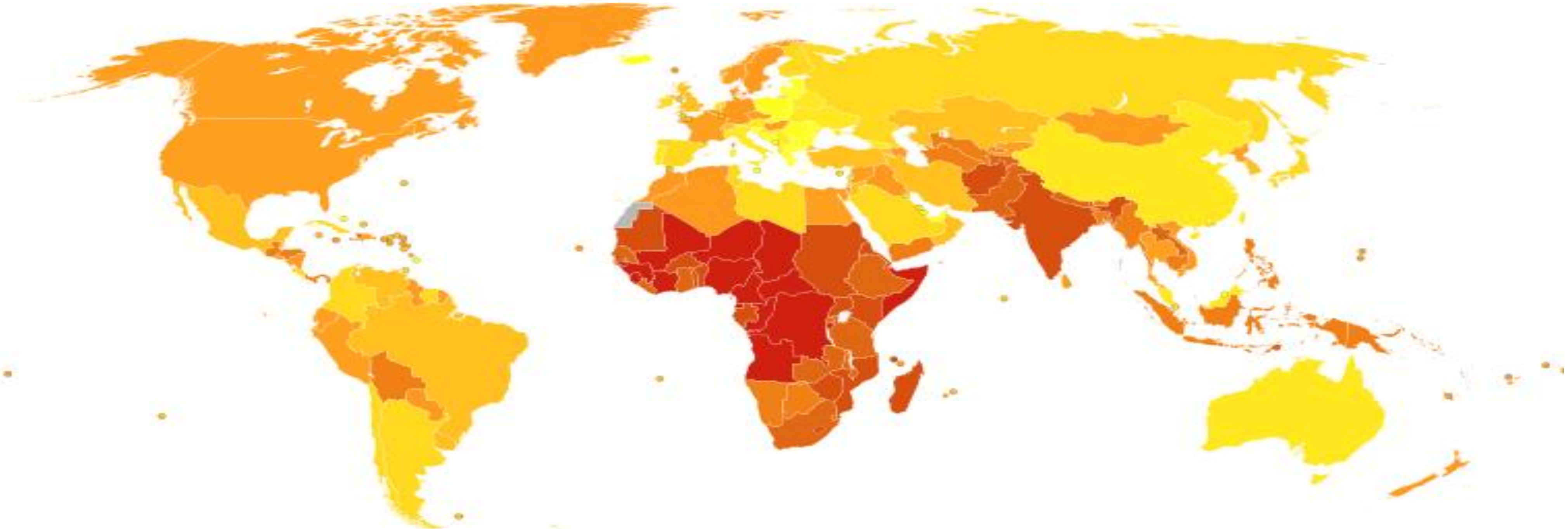

In South Asia, ~ 10 % of deaths of children < 5 years in age are attributable to diarrhoea (2015)

https://en.wikipedia.org/wiki/Diarrhea, Figure CC-BY-SA 4.0, accessed 15 Oct 2017

WHO & Maternal & Child Epidemiology Estimation Group (MCEE) prov. est. 2015. https://data.unicef.org/

Arsenic: A Public Health Emergency

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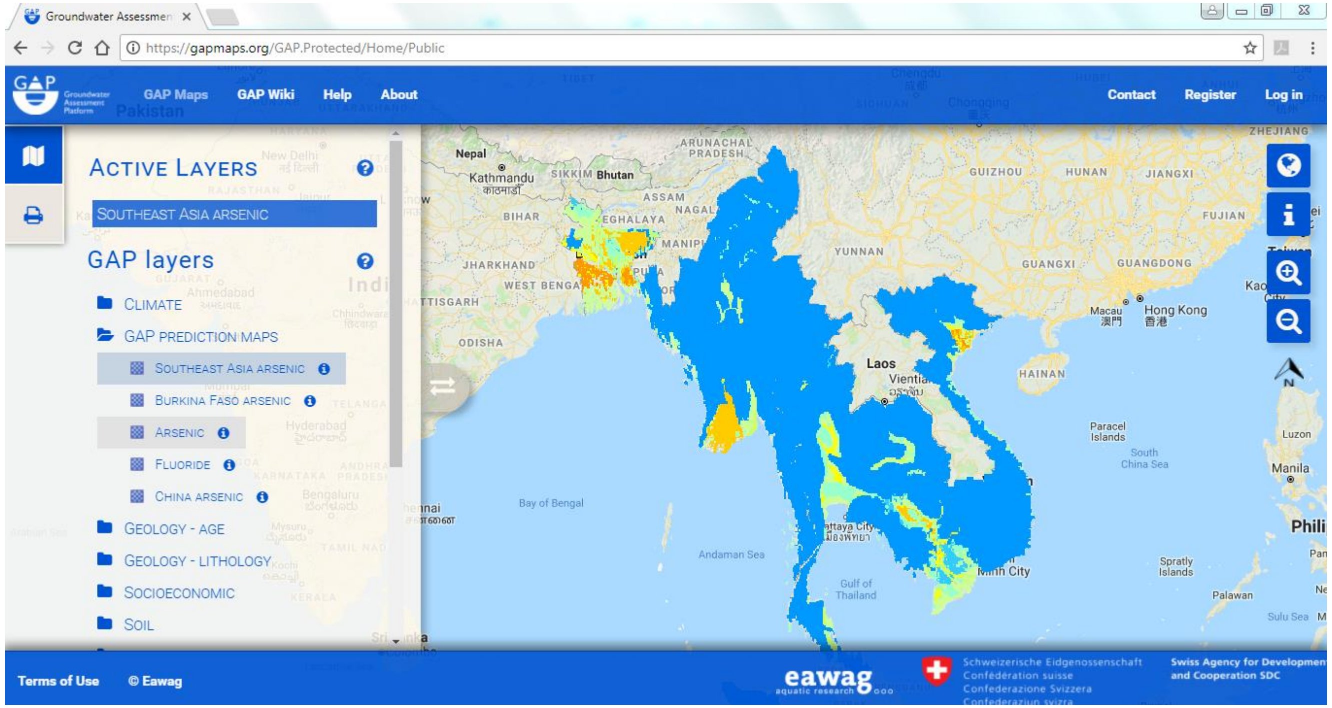
Millions of people in S/SE Asia are exposed to arsenic in groundwater in concentrations exceeding health guidelines; it is "the largest poisoning of a population in history" (Smith et al., 2000)

- In Myanmar, some high risk areas have been identified, particularly in Irrawaddy delta
- Known problem in particular areas in Cambodia, India, Bangladesh, Nepal, China, etc
- Arsenic occurrence is particularly associated with organic-rich, recent alluvial and deltaic deposits
- Some areas remain poorly characterized
- For more information:
  - GAP Maps platform
  - Winkel *et. al.* (2008) "Predicting groundwater arsenic contamination in Southeast Asia from surface parameters", Nature Geoscience, 1 (536), http://dx.doi.org/10.1038/ngeo254
  - van Geen *et al.* (2014) "Confirmation of elevated arsenic levels in groundwater of Myanmar", Science of the Total Environment, 478 (21 – 24), http://dx.doi.org/10.1016/j.scitotenv.2014.01.073

Ravenscroft, UNICEF 2007; Smith et al., Bulletin of the World Health Organization, 2000, 78 (9): 1093

GAP Maps Platform

- https://gapmaps.org/gap.protected/
- Free, open source mapping and information platform for geogenic groundwater contamination
- Developed by EAWAG with support of Swiss Agency for Development and Cooperation
- Help function and wiki give instructions for use; workshops also available



Screenshot shown for demonstration ONLY, Southeast Asia Arsenic Map, www.gapmaps.org (accessed 29 July 2018)

Health Effects (Arsenic)

Cambodia, suspected arsenicosis, December 2016 (Photo from Laura Richards)

Skin lesions due to arsenic poisoning
(typical latency ~10 years; picture from Smith et al., 2000)

World Health Organization guideline value is 10 µg/L. Concentrations of ~ 1 – 2 µg/L in groundwater are widespread. Natural concentrations have been reported up to 12,000 µg/L.

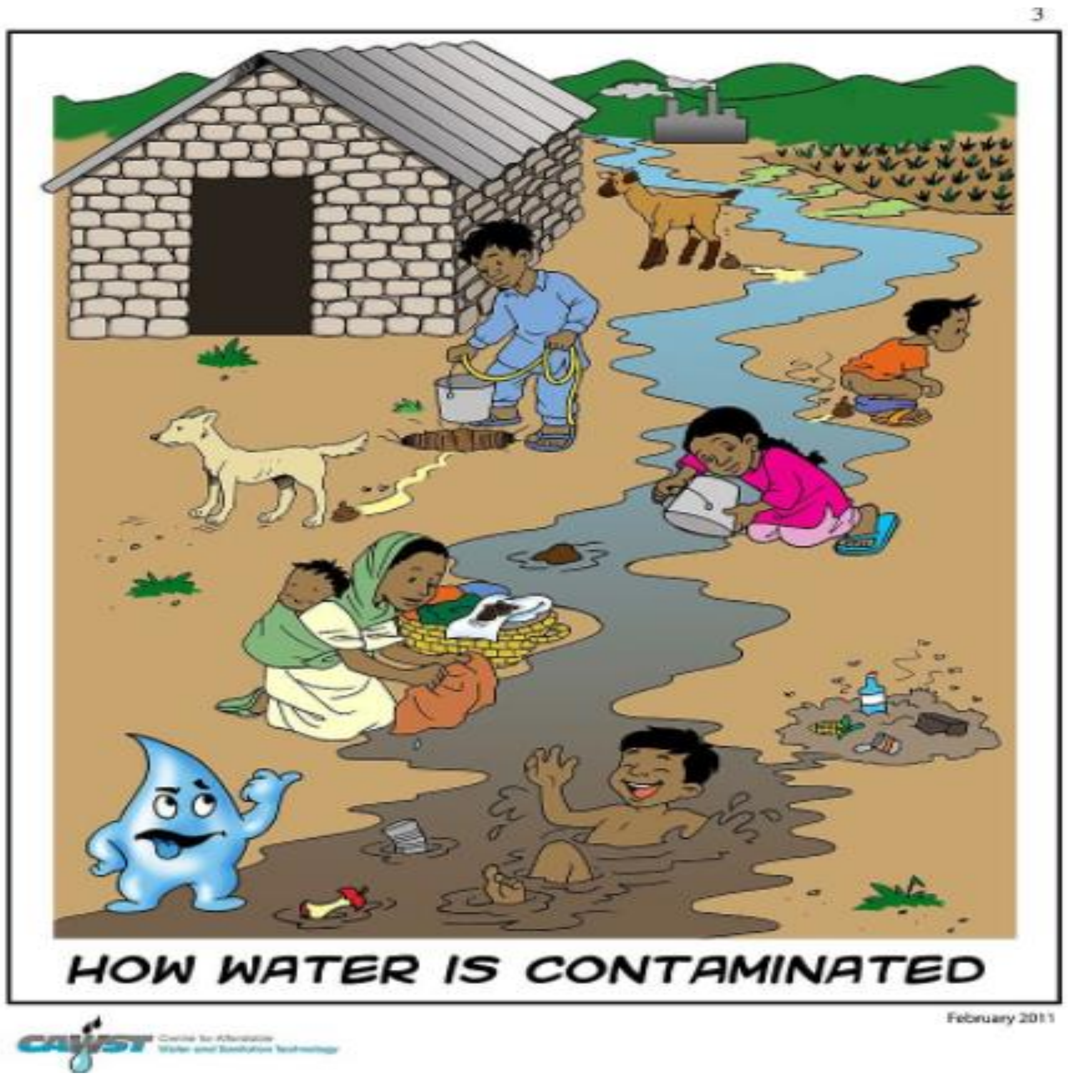
Long-term effects: skin lesions, skin cancers, internal cancers (bladder, kidney, lung), neurological effects, hypertension and cardiovascular disease, pulmonary disease, peripheral vascular disease diabetes mellitus

Exposure Concentration	**Amount Consumed**	**Cancer Risk (including liver, lung, kidney or bladder)**
50 µg/L	1 L / day over lifetime	Up to 13 in 1000 people
500 µg/L	1 L / day over lifetime	Up to 13 in 100 people

Smith et al., Bullet. World Health Org., 2000, 78 (9): 1093 and ref within, Licence: Creative Commons BY 3.0 IGO; *World Health Organization 2011*

Water Pollution

- Sources
  - **Anthropogenic**: industry, waste, etc.
  - **Natural**: geology (“geogenic”), etc.
  - Point vs non-point source
- Surface waters usually more vulnerable
- Importance of residence time
- The acceptability of water quality may vary depending on uses (e.g. drinking, irrigation, industry, etc.)



https://en.wikipedia.org/wiki/Water_pollution, Figure CC-BY 2.0, accessed 15 Oct 2017

Typical Sources of Drinking Water

- Surface Water (lakes, waters, streams, all "freshwater")
  - ☺ Relatively accessible (in some areas)
  - ☹ Generally higher micro-organism contamination, availability can vary greatly depending on location and/or time of year (e.g. monsoon versus dry season)
- Groundwater (underground aquifers) (* ~ 71 % of Myanmar's population use groundwater for drinking, NIVA 2017)
  - ☺ Available in arid areas and/or when quantity/quality/reliability of surface water is insufficient
  - ☹ Requires pumping, can be brackish or contain natural or anthropogenic chemical contamination which threaten human health, increase treatment requirements
- Rainwater
  - ☺ Generally higher chemical and/or microbiological quality (storage conditions can impact)
  - ☹ Availability is seasonal and location-dependant; storage conditions important

Types of Drinking Water: Myanmar

- Rain Water

- Storage conditions important for water safety
- Typically lower microbial and chemical contamination
- Only available seasonally

Photos from Laura Richards, 2017

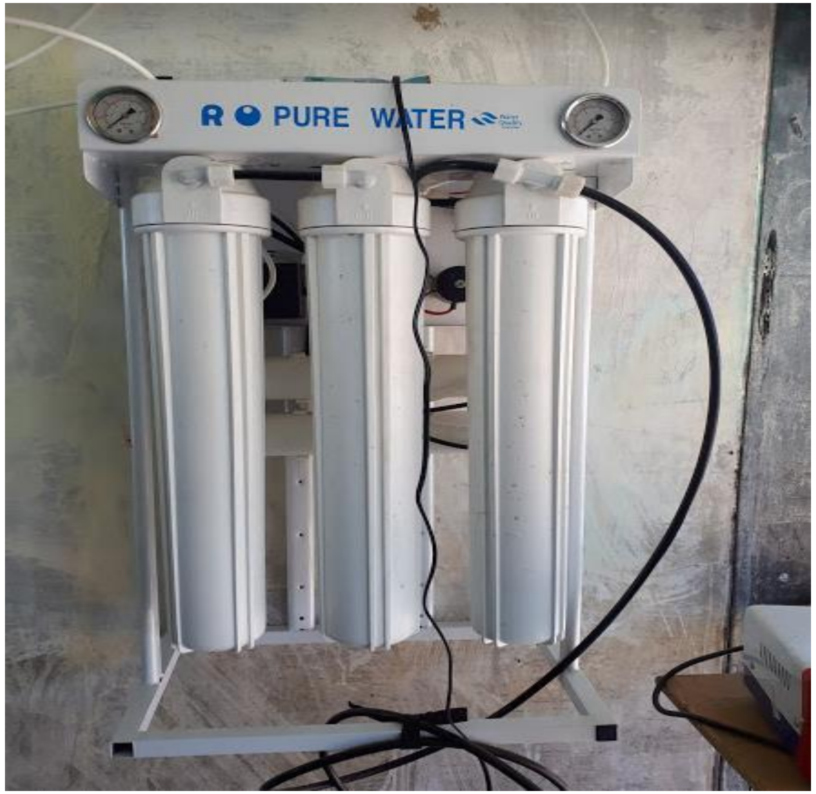
Types of Drinking Water: Myanmar

- Groundwater
  - Dug Wells
  - Tube Wells

- Typically lower microbial contamination but chemical contaminants can be very dangerous (and do not taste or smell)
- Sanitary care is important
- Sometimes available when rain/surface water is not

Photos from Laura Richards, 2017

Types of Drinking Water: Myanmar



- “Purification” Systems
  - Variable performance
  - Require proper technology selection and maintenance

Photos from Laura Richards, 2017

Types of Drinking Water

- United Nations Economic and Social Commission for Asia and the Pacific
- New article (Polya & Richards 2017)
- http://www.techmonitor.net/tm/images/7/73/17jul_sep_sf2.pdf

ARSENIC AND THE PROVISION OF SAFE AND SUSTAINABLE DRINKING WATER

ASPECTS OF INNOVATION AND KNOWLEDGE TRANSFER

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Discuss: Which one would you prefer?

- Multiple parameters to consider
- ‘Invisible hazards’
- Assessment and monitoring are critical

Photo from Laura Richards, 2016

Drinking Water Remediation

- Include a number of processes which can be used to improve the quality of water for drinking
- The aims are usually a combination of:
  - Improving the chemical quality of water (e.g. contaminants like arsenic, lead, other heavy metals, salts, etc)
  - Improving the microbial quality of water (e.g. bacteria or viruses)
  - Improving the taste, smell or color of water to make it more aesthetically appealing

There are Many Ways to Treat Water

- Today we will focus on arsenic remediation technologies, which are often also used for the removal of other contaminants too
- Some common technologies/methods
  - Source switching (e.g. lower arsenic groundwater, treated surface water, rain water)
  - Precipitation (e.g. Fe/Mn removal, coagulation-filtration, softening)
  - Adsorption/Ion Exchange (e.g. activated alumina, Fe/nanomaterial based sorbents, geological materials)
  - Membrane Filtration (e.g. nanofiltration/reverse osmosis, ultrafiltration/microfiltration, hybrid processes)
  - Oxidation (e.g. Air/chemical oxidation, photochemical oxidation, *in-situ* oxidation)
  - Bioremediation (e.g. Biosorbents, biological oxidation)

Ahmed, Richards, Bhattacharya, Chpt 7, Best Practice Guide on the Control of Arsenic in Drinking Water, International Water Association, 2016

Source Substitution

- The simplest thing to do is to find another source of better quality water to drink
- In practice this is challenging because of potential trade-offs in quality, reliability or cost between different types of water
- Deeper groundwater has been claimed to be safer than shallower groundwater, although research shows that this is not always the case and it is not safe to assume this is true
- Some studies have painted wells red to indicate that tests say there are high levels of arsenic (and green if arsenic was low)

Ahmed, Richards, Bhattacharya, Chpt 7, Best Practice Guide on the Control of Arsenic in Drinking Water, International Water Association, 2016 and references within

Precipitation

- Coagulation (using alum or iron-based coagulant), iron/manganese removal by aeration-filtration and lime softening are traditional technologies
- Rely on co-precipitation of arsenic with metal (hydr)oxides

Bulk Alum, photo CC BY-SA 3.0, https://commons.wikimedia.org/w/index.php?curid=920362, accessed Dec 2016

Iron oxide mineral solutions ,Helen Downie, University of Manchester, 2016

Advantages	Disadvantages
Relatively low capital cost	Difficult to optimize
Simple in operation	Poor removal of some contaminants (e.g. As^{3+})
Chemicals usually available in cities	Sludge produced
Generally effective over wide water quality range	Other steps required (e.g. sedimentation, filtration)
Well-established design and operation	pH (re)adjustment sometimes needed
	Chemicals required

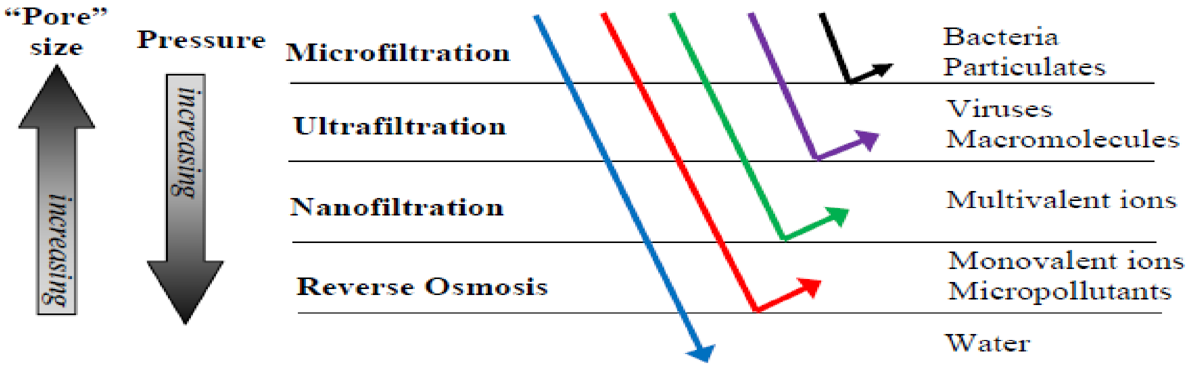
Adsorption

- One of the most common technologies used for arsenic removal
- Simple process where water passes through a bed of solid media which adsorbs contaminants

Advantages	Disadvantages
Natural and commercial products available	Variable effectiveness
Low cost options possible	Complex interactions with other dissolved solutes in the water
Relatively easy operation	Hard to predict overall performance
Commonly used	Needs frequent maintenance
Well-studied	Often does not remove other contaminants of concern (like microbes)

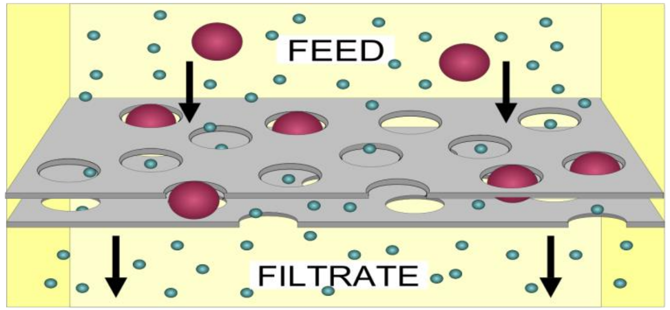
Filtration

- Filters types range from clay pots to advanced membrane technologies
- Selective barriers which separate suspended and dissolved components, to varying degrees, from water



From L. A. Richards PhD Thesis, 2012

Advantages	Disadvantages
For NF/RO generally very good performance	Can be more expensive (sometimes)
Can be linked to renewable energy	NF/RO needs high pressure/energy
Easily scalable and modular	Concentrated waste stream
Remove lots of different contaminants	Membrane fouling
Possible single stage process	Pre-treatment usually required



By Wikiwayman at English Wikipedia, CC BY-SA 3.0, https://commons.wikimedia.org/w/index.php?curid=12841159, accessed Dec 2016

Examples of Arsenic Interventions

Type of intervention	Example	Ref
Adsorption based As removal	11 different ARPs tested – fixed to tube wells	Hossain et al 2005
	Hydrocalcite-like compound for Ba and As removal	Kato et al 2013
	Zeolites	Figueiredo 2014
Bioremediation	As tolerant PNSB (bacteria) for As transformations, methylation, volatilisation	Nookongbut et al 2016
Biosand	Household sand filters in Vietnam	Berg et al 2006
ZVI & biosand	Kanchan filter – rusted nails	Chiew et al 2009, Uy et al 2009, Ngai et al 2007, Singh et al 2014
	SONO filter – iron filings	Neuman et al 2013
Coagulation / flocculation	Electro-coagulation As removal (ECAR) plant	Amrose et al 2014
Diet supplement	Taking folic acid helped to reduce blood As	Peters et al 2015
HAIX	LayneRT® resin embedded HFO	Sarkar et al 2007, German et al 2014
Deep wells	Well depth of 150 – 180 m recommended in district of Mushiganj, Bangladesh	Hug et al 2011
Subsurface arsenic remediation	Pump oxygenated water down tube well, Injection/abstraction design	Frietas 2014

Scale Matters

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- Household systems
- Community systems
- City systems

Can you think of how systems designed for different scales might be different? (Hint, think of the resources available, for one!)
(Discuss for 2 – 3 minutes)

INTRODUCTION TO DRINKING WATER REMEDIATION:

PART B: Sand Filtration (~ 45 minutes)

Introduction

TIDE

- This practical experiment will help to demonstrate the principles and practical aspects of water filtration for reducing turbidity and/or selected contaminants
- The aim is to make a model to test a 2 part filtration system: flocculation and sand filtration
- <u>Note: this is for demonstration only and should not be used for preparing drinking water. Do not drink the filtered water, even if it looks clean.</u>

Structure of the practical

- Listen to description of materials and experiment
- Arrange into groups of 3 people
- Collect the materials needed
- Conduct part 1: flocculation experiment
- Conduct part 2: assemble sand filters and add treated water
- Wait for water to go through filter
- Discuss chemical processes in more detail
- Visually assess the quality of the water
- What improvements could be made?

Context

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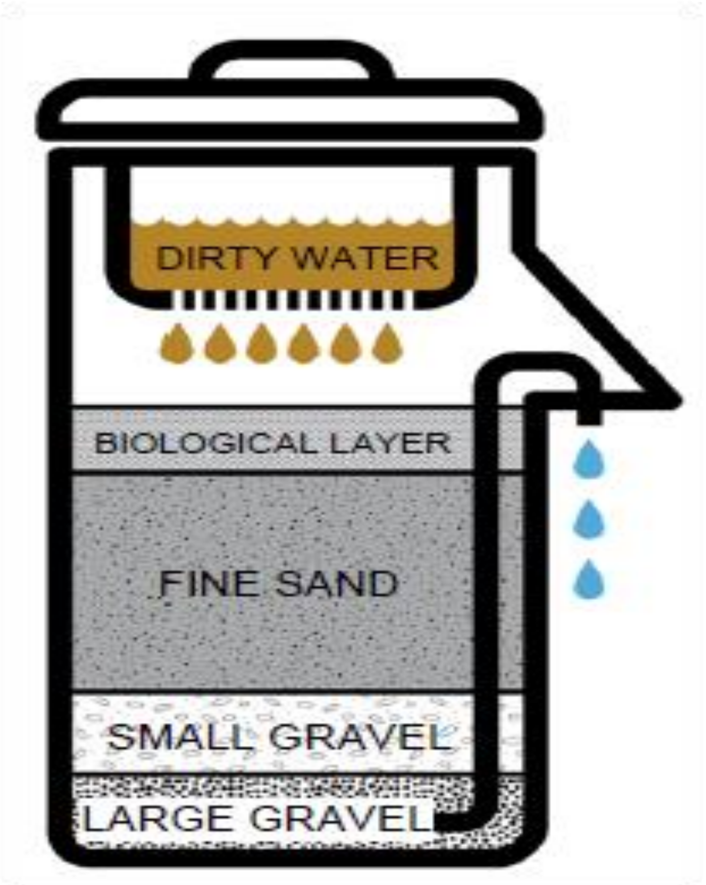
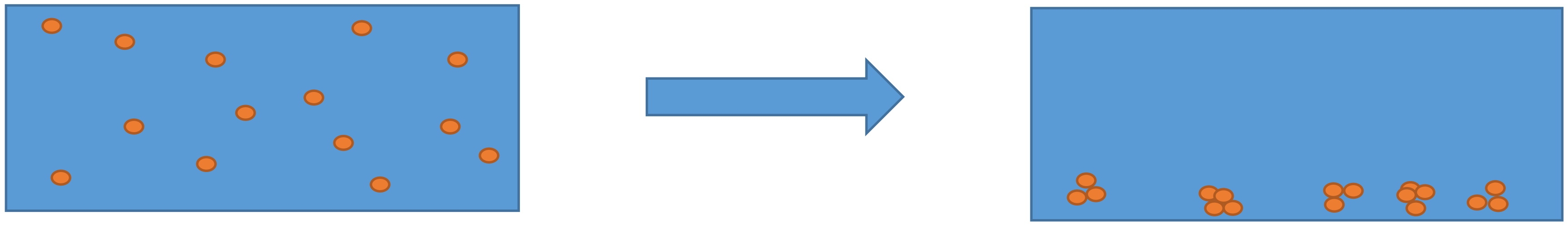
- Flocculation and sand filtration are 2 important water treatment methods which could be used in rural Myanmar. Have you seen or used these kinds of water treatment systems?
- Potential for removing large particles and some inorganics, organic matter and bacteria, with varying degrees of effectiveness
- Iron often added to enhance removal of arsenic
- Initial water composition affects performance
- Usually sand filters are much bigger than the ones we will construct. These are demonstration models.



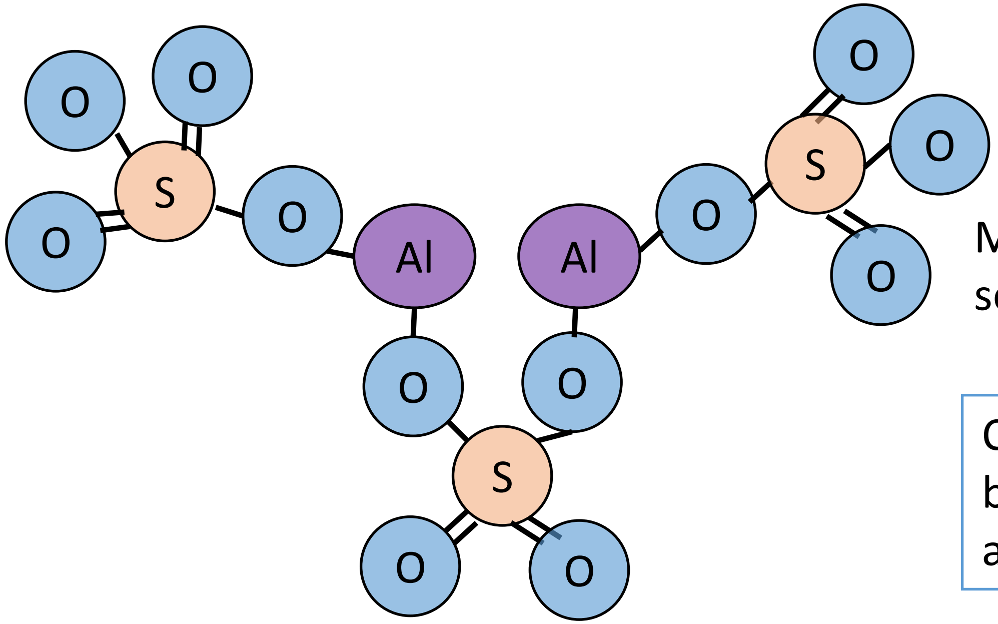
Biosand filter schematic, image from https://en.wikipedia.org/wiki/Biosand_filter (accessed 18 April 2018), CC BY 3.0

Flocculation: Theory

Brings colloids out of suspension by clumping together into flocs



We used "alum" or aluminium sulphate $Al_2(SO_4)_3$



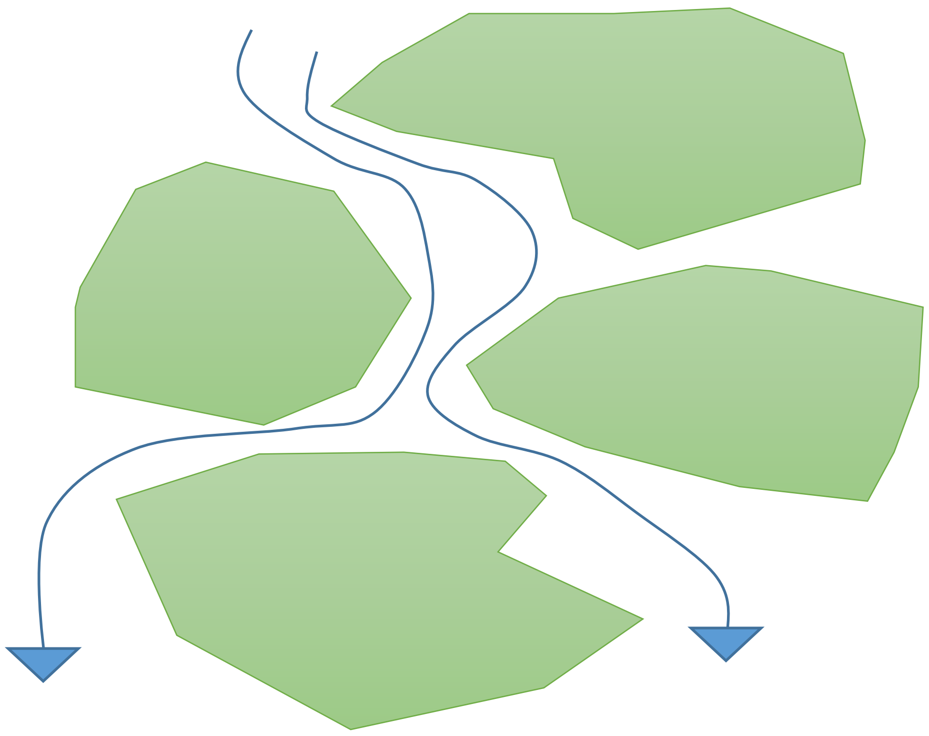
Metal cation and sulphate anion separate (dissociate) in water

Colloids with surface charge bind together with these ions and then settle

Sand filtration Theory

Removing small particles with big particles

- Not effective for very dirty water because of clogging

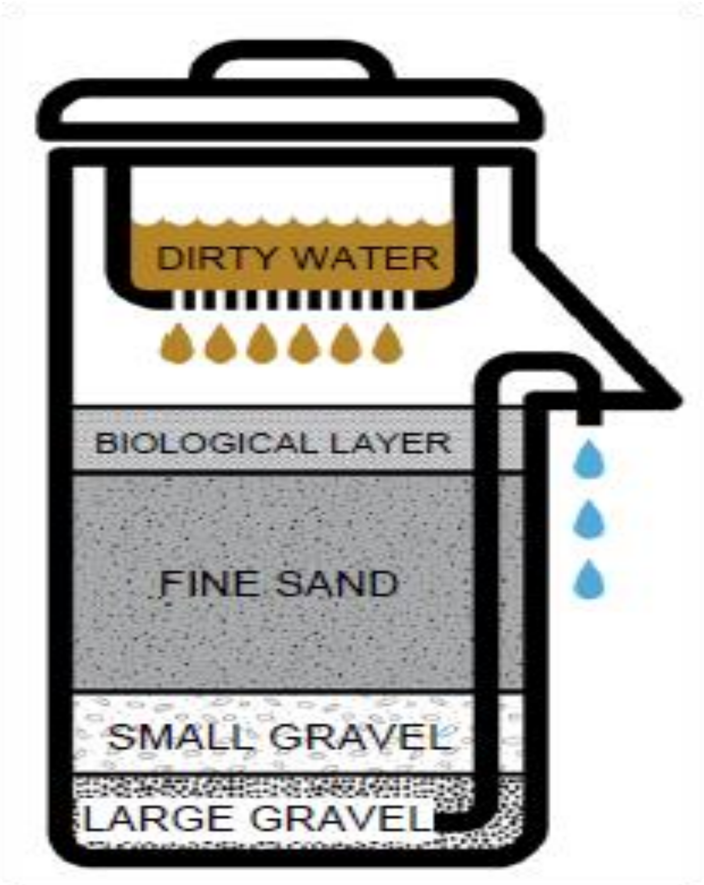


Mechanisms:

- Transport of particles to a surface
  - Molecular diffusion
  - Inertia
  - Gravity
  - Interception
- Attachment to the surface
  - Straining
  - Van der Waals forces

Biological filtration: Theory

TIDE



Biosand filter schematic, image from https://en.wikipedia.org/wiki/Biosand_filter (accessed 18 April 2018), CC BY 3.0

Mechanisms of reducing pathogens

- Predation
  - Micro-organisms in the biolayer "eat" some pathogens
- Trapping
  - Some pathogens are trapped in between sand grains
- Adsorption
  - Some pathogens are "stuck" or sorbed to sand grains
- Natural death
  - Some pathogens die due to lack of food/air/etc
- All of these mechanisms work to reduce pathogens if a biosand filter is working properly

For more info and schematics: http://aztechlabs.org/filters/ (accessed 21 April 2018)

Materials

- 1 Bottle of dirty water
- 1 cut bottle
- 1 rubber band
- 2 large cups
- 1 spoon of Alum (flocculent)
- 1 coffee filter
- 1 spoon
- 1 cup of pebbles
- 1 cup of coarse sand
- 1 cup fine sand

Methods

1. Aerate the dirty water by shaking the bottle
2. Pour into large cup and pour between 2 cups 3 or 4 times.
3. Add spoon of alum and stir for 5 minutes
4. Allow to stand still for 20 minutes
5. Now construct the filter by fixing the coffee filter to the end of the cut bottle with a rubber band
6. Add the pebbles to the bottle and flatten
7. Add the coarse sand on top of the pebbles and flatten
8. Add the fine sand on top of the coarse sand and flatten
9. Rinse the filter by pouring a cup of clean tap water through
10. Once the dirty water has been still for 20 minutes, carefully add half or 2/3 of the water to the filter.
11. Observe the filtered water
12. Do not drink!

SESSION 3: INTRODUCTION TO WATER REMEDIATION II

What We'll Cover

- Part A: Discussion: Sand Filters (~ 60 minutes)
  - Review of Filters – variation of performance, addition of a coagulant?
  - How effective are they?
  - What improvements could be made?
  - Criteria for Evaluation
- Part B: Practical & Discussion: Remediation Selection (~ 30 minutes)
  - Selection of remediation strategies (technical, socio-economic, regulatory, etc considerations)
  - Socio-economic and regulatory considerations
  - Potential barriers to successful interventions
  - Case studies / scenarios for discussion
- Questions

INTRODUCTION TO DRINKING WATER REMEDIATION II

PART A: Discussion of Sand Filters

Experiment Results: Discuss

TIDE

- How does the appearance and smell of the filtered water compare with the dirty water?
- How could you **quantify** your results?
  - How effective was the flocculation?
  - How effective was the sand filter?
- What other measurements would we like to take?
- Are there any ways in which the water filter system could be improved?
- What are the **variables** which you could change and test?
- What are the **implications** of your results?

Examples of Variables

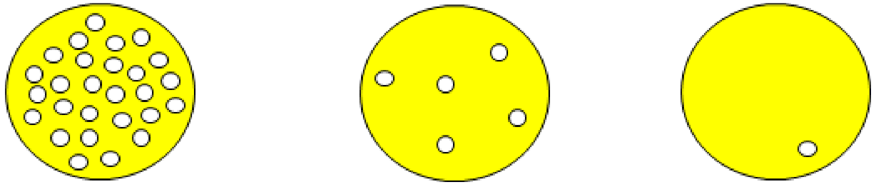
- Composition of the start water (pH, elemental constituents, turbidity, dissolved gasses)
- Flocculation (flocculent, amount of alum, stirring and /or settling time)
- Sand filter construction (amount of sand…)
- Process (rinsing volume, time…)
- Can you think of others?

How could we evaluate our results?

- Chemical tests: See Session 1

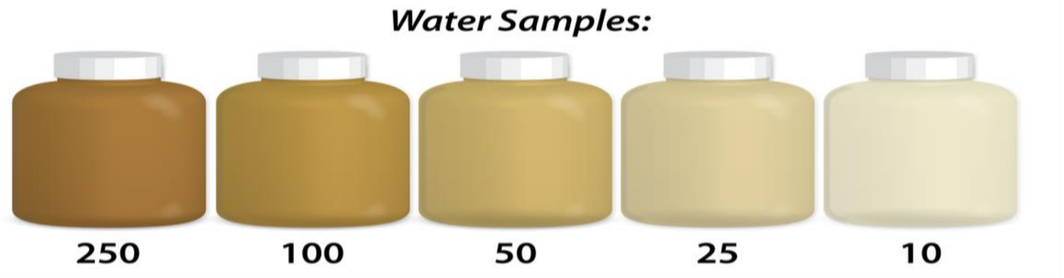
- What could we measure?
- How could we measure it?

- Biological tests: estimate the degree of contamination from pathogens



- Methods include incubation & bacteria number counting, E Coli bags, TTC methods
- See World Health Organization Guidelines

- Turbidity: measure of the "cloudiness" of water



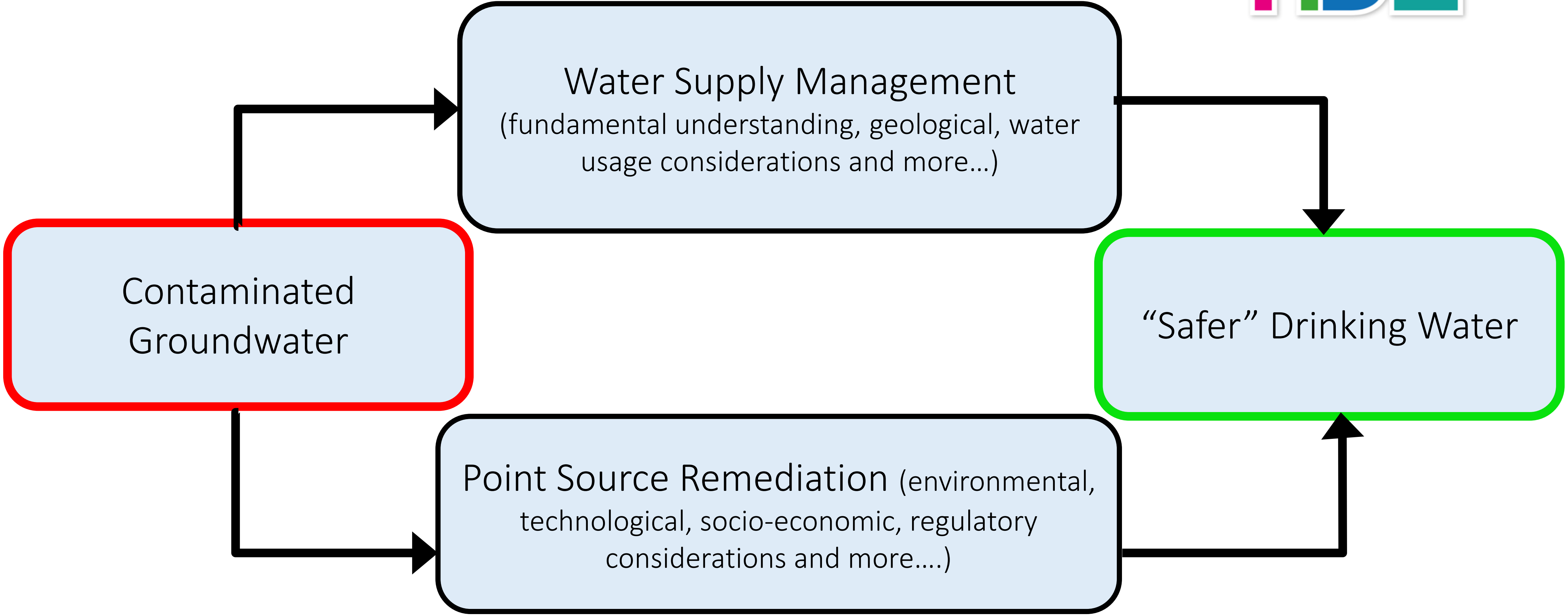
- Indicates the amount of solids in the water
- Measured by passing light through water
- Color scale allows visual estimation

Image from LearnNC.org, http://www.learnnc.org/lp/media/uploads/2010/05/turbidity_chart_2.png, Creative Commons, accessed Dec 2016

INTRODUCTION TO DRINKING WATER REMEDIATION II

PART B: Selection of Remediation Strategies

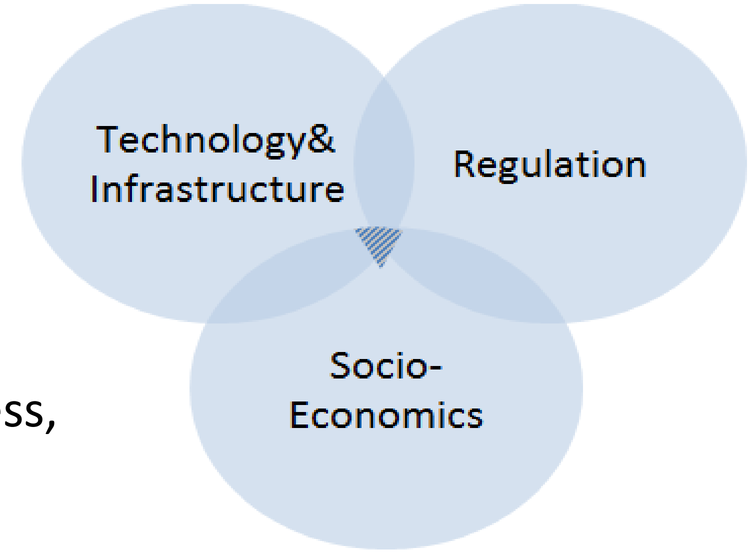
Remediation Strategies



Consideration of alternate water supplies can also be a remediation strategy

Developing Management Frameworks

- Technical Aspects
  - Effectiveness, complexity, suitability for particular environmental/ geochemical conditions and/or user populations, maintenance requirements, etc
- Environmental Aspects
  - Geological/geochemical conditions
- Socio-Economic Aspects
  - Infrastructure, socio-economic conditions, education/awareness, cultural factors, etc
- Regulatory structures
  - Water quality regulations, monitoring, support structures, etc



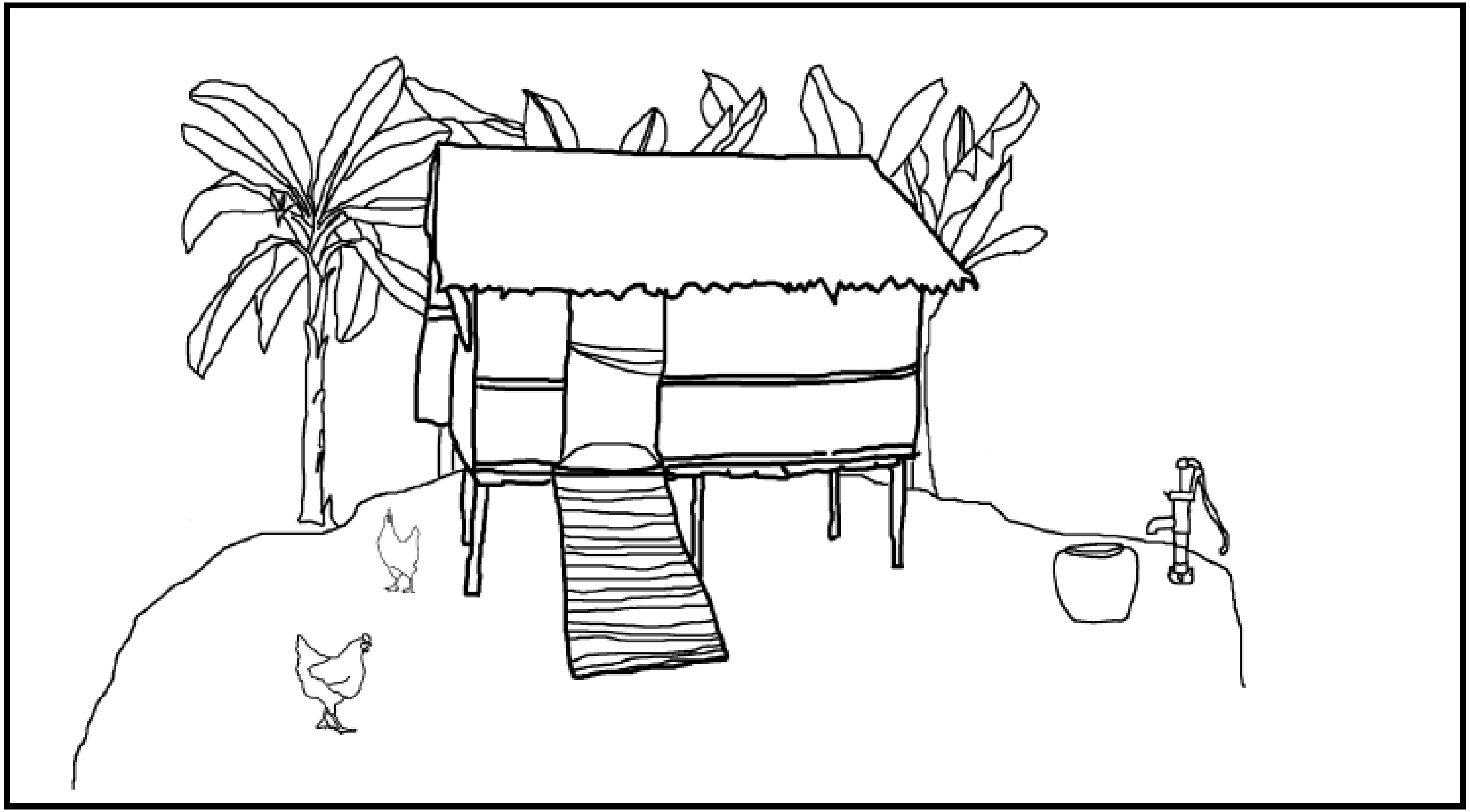
All of these factors need to be considered to develop a sustainable strategy. There is no "One Size Fits All" solution.

See Richards (2017). Chapter 6: Selection of Arsenic Remediation Strategies in the Context of Water Safety Plans, 2017, in P. Bhattacharya, D. Jovanovic, & D. Polya (Eds.), International Water Association Best Practice Guide for the Control of Arsenic in Drinking Water (ISBN13: 9781843393856)

Complex Challenges

- Despite the availability of many technologies, many remediation projects are abandoned. Why?
- Some potential reasons may include:
  - Poor economic conditions
  - Lack of infrastructure, facilities and/or supplies
  - Convenience and maintenance requirements
  - Lack of satisfaction with treated water
  - Poor technical effectiveness
  - Poor awareness /education and/or access to information
  - Lack of monitoring by regulatory bodies
  - Lack of regulatory incentive
  - Lack of motivation by various stakeholders
  - And more…..
- What works well in Myanmar?

Considering Trade-offs



Discuss:

- What information would we need to consider when thinking about what remediation options might be best in a scenario like this?

Drawing by Helen Downie, 2016

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- Plus other references as listed throughout – please contact if further reference details are needed

INTRODUCTION TO DRINKING WATER REMEDIATION: SESSION 2 & 3 REVIEW

TIDE

- Today, we covered a basic introduction to
  - Why it is important to consider drinking water remediation
  - An overview of selected remediation options
  - Construction and testing of basic sand filters
  - Considerations for selecting effective remediation strategies
- Feedback form
- Questions?

Thank you!

Dr. Laura Richards, University of Manchester
May 2018 TIDE Residential School

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