

Medical Hydrogeology Lessons on groundwater and health from SE Asia

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Medical Hydrogeology

Lessons on groundwater and health from SE Asia

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Overview

- Motivation working with epidemiologists
- Salinity
- Arsenic
- Medical hydrogeology
- Conclusions

Groundwater and epidemiology

September 1854

"In consequence of what I said, the handle of the pump was removed on the following day."

John Snow, letter to the editor of the Medical Times and Gazette





Broad Street Pump replica



Motivation: working with epidemiologists



Association of salinity and maternal health



Salt and health

□The World Health Organisation (WHO) recommends a maximum daily intake of 5 g of salt (2 g sodium)

□ In the UK most of our intake comes from food

In parts of coastal Bangladesh, the concentration of salt (sodium) in water sources is such that drinking 2 litres a day can result in this limit being exceeded!

This is before intake from food is taken into account

This has important health implications, as excessive sodium intake increases the risk of hypertension & cardiovascular events, e.g. stroke & heart disease

Key questions

- 1. What are the controls on high salinity levels in drinking water sources in coastal Bangladesh?
- 2. What are the health impacts of this high salinity water?
- 3. What interventions could reduce these impacts?

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Coastal south and south east Asia



Drinking water vulnerability: coastal South East Asia

Key factors:

- Storm surge from tropical cyclones
- Elevation
- Geomorphology
- Population density
- Rainfall (amount)
- Groundwater availability

Coastal drinking water vulnerability (CVI)



Hoque et al., Drinking water vulnerability to climate change and alternatives for adaptation in coastal South and South East Asia, Climate Change, DOI 10.1007/s10584-016-1617-1.

Storm surge impacts – Tropical Cyclone Sidr (Nov 2007)



Source: GCC News Brief https://hendrawanm.wordpress.com/2011/03/09/carbon-based-climate-change-debate-must-include-womens-voices/

Image courtesy of MODIS Rapid Response Project at NASA/GSFC

Bangladesh

Extensive flooding

- > 3,300 deaths
- ~ 1.5 million homes destroyed [Source: British Red Cross]



Bangladesh – mega delta



Satellite image of Bangladesh. Much of the country is a vast river delta for the Ganges, Brahmaputra and Meghna Rivers.

Coastal Bangladesh: Land Reclamation / Polders



Hydraulics of polders



- Elevation difference between inside and outside the polders
- Purpose built ponds used for drinking water
- Tidal rivers
- Communities are inside the polder where they rely on agriculture and also, though rarely, in temporary refuge

Drinking water sources

• Rainwater

Pond water

• River water



• Groundwater water (tubewells)

Saline (shallow) Variable (deep)



Drinking water in coastal Bangladesh



GROUNDWATER provides potable water to >94% of Bangladesh but in coastal areas this resource is pervasively saline, and hence people avoid it.

Investigation into health impacts of high salinity water

Investigating controls on sources of high salinity water and impacts on health in S. Bangladesh. Funded by Leverhulme.



Site locations

- Two sites in Dacope Upazila, Southern Bangladesh
- Communal drinking
 water ponds
- Linked with aquifer storage & recovery schemes operated by U Dhaka





Study sites



Two representative drinking water ponds (DAS – Srinagar, and DAB-Baroikhali) in Dacope Upazila of Khulna District in southwest Bangladesh were monitored over two years to better understand the controls on drinking water salinity.



Field sites





Pond monitoring





Rainfall, evaporation, pond and groundwater level, abstraction, and solute concentration were monitored. Piezometers were also set-up around the ponds.



Pond monitoring



Water level data (DAB site)



Seasonable pond and groundwater response (DAB site)



Sediment properties





For Sand 5%, Silt 70%, Clay 25% BD 2.353 g/cm3 K=3.5x10⁻⁸ m/sec = 3.3 mm/day

Pond salinity (DAB site)



Pond salinity (DAB site)



Conceptual model (water & salt balance)



Pond models for water & salt balance



Mathewson, 2015

Importance of inundation events





Cyclones & storm surges

Northwest part of Polder 32 After Cyclone Aila, 27 May 2009 Image by Google Earth Dated 11/04/2010

London

Imperial College

Pond remediation 2 years after inundation



Pond remediation 2 weeks after inundation



Ponds' salinity in different polders





Ponds in the least affected (by Cyclone Aila) polders have lower salinity compared to polders which were inundated by saline water during Aila, apart from those that have been remediated.
Salinity modelling



Salinisation of Groundwater in Coastal Bangladesh



Effects of cyclones occur every a) every 10 year, b) every 5 year, c) every year After Islam et al., in prep

Land use & groundwater salinity



Effects of land-use types in groundwater for a) current land use, b) modified land use without shrimp farm, c) all shrimp farms. After Islam, 2016

Activities contributing to the problem



Water salinity in coastal Bangladesh

Therefore we identify the following to be associated with salinisation -

- Cyclone induced storm surges
- Land use, particularly shrimp farm
- Embanked landscape
- Reduced upstream flow

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Epidemiology field programme

- Cohort study
- 3 rounds of data collection (Dacope)
- Questionnaires, BP measurements, water analyses
- or icddr,b with iccdr,b



Water sodium in Dacope



Khan, et al, 2014

Participants



Imperial College London Epidemiological study: Sodium concentrations of drinking water sources



Scheelbeek, PhD thesis, 2015

Imperial College London Epidemiological studies: Sodium concentration & blood pressure



Scheelbeek, PhD thesis, 2015

Epidemiological results

- Longitudinal study (581 coastal participants)
- Most participants were exposed to high sodium concentrations, which were associated with relatively high blood pressure
- Decreasing sodium concentrations in drinking water were significantly associated with decreases in blood pressure
 - For each 100mg/l decrease in sodium, blood pressure dropped on average with 0.95/0.57 mmHg;
- Odds of hypertension decreased under the same reduction with 20% and 14% for systolic and diastolic hypertension respectively.

Implications: If sodium content in drinking water could be lowered this would lead to a reduction in blood pressure and hence a reduced risk of hypertension

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Mitigation

- Increasing the height of the embankments will reduced the risk of overtopping and the related salinisation of drinking water.
- Rainwater harvesting
- Identifying freshwater zones could be an alternative source of supply in some water stressed areas. Tubewells in coastal areas should always be fitted with raised concrete platforms.
- The use of aquifer storage and recovery (ASR) to source freshwater by creating a freshwater bubble in saline aquifers to be used in dry season.
- Desalinisation could also be an option to produce fresh water from saline or brackish water.





Rainwater harvesting

Currently, government and NGO's are supporting rainwater harvesting as a source of fresh drinking water

- However, often very little facilities for storage
- Larger units expensive





Rainwater Harvesting in Sutarkhali, Khulna. 2009

Aquifer storage and recovery

- Harvest rain water from roofs and use relatively low salinity from ponds
- Inject into underlying sand with brackish water to create a freshwater "bubble"
- Extract water during dry season

Funding by UNICEF, developed & implemented by Dept Geology, U Dhaka





Modelling aquifer storage and recovery (DAB)



Imperial College London Epidemiological study: Sodium concentrations of drinking water sources



Scheelbeek, PhD thesis, 2015

Small scale solar distillation



Photograph: M. A. Hoque

Allows dilution of high salinity water

New area of work Funded by Welcome Trust



Photograph: M. A. Hoque

Imperial College London Modelling methodology – cost / benefit analysis of water resource options



Summary

- Mega-deltas of SE Asia are vulnerable to saline water
- Serious health impacts for those using saline water resources
- This is likely to increase under climate change
 - Sea level rise
 - Monsoon / tropical cyclones
 - Population increase
- Bangladesh is at the forefront of this concern
- Working with Univ. Dhaka to understand controls on salinity in drinking ponds in southern Bangladesh and impacts on health
- Exploring innovative solutions to help mitigate these impacts
 - Rainwater harvesting
 - Aquifer Storage and Recovery
 - Solar distillation / desalination
- Optimal solutions will be explored using cost-benefit modelling

Arsenic



Realgar (AsS)

Framboidal pyrite



- Arsenic is a naturally occurring element (~1.8 ppm), found in many minerals, usually in conjunction with sulphur and metals; and as adsorbed state on the ferric or manganese oxides.
- The main uses of metallic arsenic are for strengthening alloys of copper.
- Arsenic and its compounds are also used in the production of pesticides, treated wood products, herbicides, and insecticides.

Iron coated grains

Arsenic in Bangladesh is an Ongoing Crisis



arsenic in Bangladesh.

Nearly 20 million Bangladeshis are still drinking water poisoned with high levels of arsenic despite millions of wells being tested and hundreds of thousands of safe ones having been bored to avert a major health crisis, a new report has suggested.

Why is it dangerous?



http://ventography.wordpress.com/

- AsO₄-³ replaces PO₄-³ causing cell death
- AsO₄-³ inhibits oxidative phosphorylation in the ATP energy cycle
- AsO₃-³ replaces S in thiol groups (organosulfur compound) and inhibits protein functions

Colourless, Odourless...



Invisible





Toxicity



- Absorbed by inhalation or digestion and transferred via the bloodstream to all organs producing systemic damage.
- Long term low level exposure causes hyper pigmentation (black spots on skin), followed by skin malignancy, peripheral arteriosclerosis (black foot disease)
- Lung, liver and kidney cancer develop over time.
- Acute arsenic exposure results in vomiting, abdominal pain and bloody diarrhea and death.

Global problem

Documented cases of arsenic problems in groundwater to natural contamination. Cases include some of the major mining and geothermal occurrences reported in literature. Arsenic poisoning affects some 70 countries.



Arsenic in groundwater

A small amount of arsenic in aquifer sediments can create a large problem in groundwater



Bangladesh Standard is 50 µg/L, & WHO Guideline value 10 µg/L

Physically weathered but not-chemically weathered Fe-Mg minerals in rapidly accumulating sediment (Holocene delta/fluvial plain, glacial till)

Why is it a problem for the poor?



It is all about the cost of treatment.



What gives rise to As in groundwater in Bangladesh?



Groundwater in Bangladesh: Pathogen to Poison



- In 1970s people moved from pond water to groundwater (tube well) to avoid pathogen
- >10 millions of wells have been installed
- As of 2009, some 22 million people drink groundwater containing more than 50 µg/L of As, and applying the WHO Guideline Value 10 µg/L raises the exposed population to 52 million in Bangladesh
- Arsenic water is linked to 1 in 5 deaths in Bangladesh 5000





Spatial distribution of As : DPHE/BGS Laboratory Testing Data



Spatial heterogeneities of As both laterally and vertically



Site A & Adjoining Area





Brown Sand Aquifer (intermediate depth)

Hoque et al, 2014

Summarising As distribution



Schematic illustration of the low-As groundwater environments (numerical system consistent with left Fig.). 1, 2 and 4H are within Holocene sediments; 3 represents the Plio-Pleistocene inliers; 4D represents deeply buried Pleistocene sediments (both oxidised and reduced sediment types). 'Flushing of As' and 'Sediments Redox' condition are the two major processes in controlling the distribution pattern in deltas.
Arsenic and Patient Distribution Map (BAMWSP Data)

Patients Well As **Arsenicosis Patients In Bangladesh Arsenic Contamination In Bangladesh** (Per 100,000 Population) #of Patients/100,000 Population Percentage of Contaminated Wells (Union level) 0-51 0 - 20 20 - 4052 - 180 40 - 60 181 - 445 60 - 80 446 - 952 80 - 100 953 - 1894 b) a)

BAMWSP screening reported 38,118 suspected patients. Patients are found almost all over the country except in the extreme NW and SE and mostly in the areas with high arsenic in groundwater

Hoque & Butler, 2106

Some health impact statistics

- Around 52 million people in Bangladesh are currently exposed to >10 µg/l concentrations of arsenic in their drinking water.
- Available epidemiologic studies performed in Bangladesh, Chile, Argentina, Taiwan, and the United States, estimated about 4.51 additional lung cancer cases per 100,000 people for a maximum contamination level of 10 µg/L of arsenic in drinking water.



DALYs per 1,000 population caused by skin lesions due to elevated drinking water arsenic concentrations. After, Fewtrell et al., 2005

The **disability-adjusted life year** (**DALY**) is a measure of overall disease burden, expressed as the number of years lost due to ill-health, disability or early death.

Medical Hydrogeology: Drinking water composition in Bangladesh



GROUNDWATER provides potable water to >94% of Bangladeshi (Hoque & Butler, 2016)

Ca, Mg, Fe & Na Intake



- Dietary intake, estimated from dietary surveys, contribute around 200 to 400 mg/d of Ca, which is generally less than 50% of the RDI (Hels et al. 2003)
- Bangladesh has an iron deficiency prevalence of about 60 percent depending on the indicators used (Ahmed 2000).



From Drinking Water

Groundwater Calcium (% RDI)

- Significant amounts, up to 50% of RDI for Ca, can be derived from groundwater in parts of Bangladesh.
- If food habits are similar throughout the country then in some areas people should not suffer from Ca deficiency.



Groundwater Magnesium (%RDI)

- Significant amounts, up to 25-50% of RDI for Mg, can be derived from groundwater in parts of Bangladesh.
- In Bangladesh spatial differences in tube well Mg concentrations are also significant.



Groundwater Iron (%RDI)

- Most tubewells contain significant amounts, up to over 50% of RDI for Fe in parts of Bangladesh.
- Previous studies have found the link between tubewell Fe and plasma ferritin and total body iron in an area where tubewell iron is higher.



Groundwater Iron (%RDI) and anemia



Other Asian Deltas

We see, using augmented datasets from three Asian deltas (Bengal, Mekong, and Red River), that the chemical content of groundwater is similar in other Asian deltas too and individuals obtain up to 50% or more of the recommended daily intake (RDI) of some nutrients (e.g., calcium, magnesium, iron) from just two litres of drinking water.



Arsenic & Nutrients – toxicity decrease?



The adverse effects of As in Bangladesh Groundwater are well known, but the same water contains beneficial mineral nutrients (e.g. Ca, Mg, Fe) too. The linkage of arsenic toxicity with other water constituents is unknown.



Mitigation of Arsenic Pollution > mineral balance

- Knowing and avoiding the polluted well and switching to arsenic-safe well
- Installing tubewell in brown-sands
- Installing deep-well As-safe well



Mitigation of Arsenic Pollution > mineral balance



Adopted from Hoque et al., 2014

Summary

- Groundwater in Bangladesh contains significant amount of mineral nutrients that may be beneficial to human health.
- The issue of estimating usual intake distributions of nutrients considering only food sources may be counterfactual, particularly in areas with high levels of dissolved solids in groundwater sources, as the contribution of drinking water to nutrient and mineral supply can be substantial.
- Often the health impacts of groundwater toxicants are studied in isolation, for instance As, F, and Na, but other ions present in the same water, which can potentially reduce the toxicity, indicate the need for a holistic approach.



Conclusions

- Bangladesh, along with other developing countries, faces many challenges in terms of human health
- Hydrogeologists, working with epidemiologists, can play an important role in understanding the controls on disease and ways to mitigate their impacts
- Whilst focusing on specific issues (Na, As) is important, our work shows that taking an holist view reveals important potential benefits in terms of the mineral doses that groundwater provides (e.g. Ca, Fe)
- Hence, our designation of a new area of research: Medical Hydrogeology



John Thow

Thank you. Any questions?

Aquifer Recharge site, Dacope, Bangladesh



Imperial College team with Prof Matin Ahmed, Dept. Geol, Univ. Dhaka