Influence of Urban Pumping on Groundwater Quality

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Largest Delta in the world
Second highest water flux
Bangladesh Drinking Water History

Community Well Suction-style Hand Pump
Arsenic in Asian Deltas

Problem - Arsenic in shallow groundwater in the Ganges-Brahmaputra Delta is the largest case ever of drinking water poisoning

Causes – Arsenic naturally dissolves from minerals in the aquifer or soils. Associated with reducing, high DOC ground waters and monsoonal climates.

Impact – Vast increases in intestinal cancer, Kertosis (skin lesions)

Mitigation Options
1) Field testing
2) Lateral switching\(^1\)
3) Drilling deeper\(^2\)
4) Filtration

\(^1\) van Geen et al., *Bull. World Health Organ.*, 2002
\(^2\) DPHE/JICA, 2010
Above 30 m depth, spatial distribution is highly patchy
• Fastest Growing Mega City in the world
• 15 million people growing by 7% annually
• ¼ of people are homeless
Study Objectives and Hypotheses

Objective 1
Assess impact of Dhaka pumping on surrounding rural population’s access to low As aquifers

Objective 2
Assess impact of Dhaka pumping on sources and rates of recharge to deep aquifer

Hypothesis 1
Depressurization of the deep aquifer underlying Dhaka is limiting villager’s access to low-As aquifers

Hypothesis 2
Vertical recharge is accelerating within the expanding drawdown cone area. This increases the likelihood of downward migration of high As water
Community and Monitoring Wells with Continuous Water Level Measurements

Grey area represents modeled portion of deep aquifer
Fast Static dGPS Survey and Community Well Inventory (Feb-Apr, 2012)
Suggests Dhaka drawdown cone has reached eastern Arajhazar
Falling Water Levels in Rural Wells Limits Access to Low Arsenic Aquifers

Community Well Hydrograph

Water level declines are rendering hand pumps useless for longer periods in dry season limiting villager access to As-free drinking water.
Modeling Deep Aquifer Potentiometric Surface

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- 120m Wells
- Meghna River

Water Level (masl)

Distance from Meghna (m)

y = 1.3 + 0.00015x - 1.2e-08x^2
May 26, 2011 – Early Monsoon
Changing Recharge Amounts to Deep Aquifer

Late Dry Season/Early Wet Season
*minimum* vertical recharge but *maximum* Dhaka influence

Widespread Flooding

Late Wet Season/Early Dry Season
*maximum* vertical recharge due to rainfall and flooding
Quantifying Seasonal Vertical Fluxes

Average Vertical Darcy Flux 0.22 m/yr
60 equally probable realizations of the subsurface heterogeneity were modeled using MODFLOW.

Heterogeneous model ensemble predict minimum transport time to the deep aquifer of only 7 years, compared to 89 years for a homogeneous model.

Conclusions

1. Deep urban pumping combined with widespread, natural arsenic in shallow aquifers has created drinking water scarcity in one of the most fresh-water saturated place on earth.

2. Continued increases in Dhaka pumping could do irreparable damage to intermediate and deep aquifers with expected vertical movement of As ranging from ~5 cm/yr on the eastern edge of the drawdown cone (homogeneous model) to 10 m/yr closer to the city center (heterogeneous ensemble).
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Urban Footprints

Greater Dhaka
Population 16 million

Greater Houston
Population 6.6 million
Deep aquifer depressurization is drawing in more shallow aquifer water into low-As aquifers and possibly inducing Meghna River recharge.
Seasonal and Interannual Trends in Eastern Araihazar

- Average lateral gradient increasing
- Vertical recharge peaks in early dry season
Leaky Aquitard

RMSE = 0.8 m, AIC = 53.4

- $T = 14000 \, m^2/day$
- $S = 0.005$
- $b_{aqt} = 20 \, m$
- $K_{aqt} = 0.0014 \, m/day$
2. Methods – Measuring Water Levels

\[ \text{Wire Length} = P_{\text{water}} + \text{Water Level Depth} \]
Above 30 m depth, spatial distribution is highly patchy.
From 30-60 m depth, regional differences emerge
Below 60 m depth, groundwater is generally safe in Araihaazar
1. Background – Arsenic in Asian Deltas

DOC, Eh and soil type are good predictors of high arsenic concentrations in aquifers in Asian deltas

Berg et al., 2008
1. Background – Arsenic in Asian Deltas

Logistic Regression model trained with As concentrations from 1,756 wells in 6 southeast Asian deltas was able to correctly classify 70% of samples as <10 or >10 ppb As.

High As usually associated with Holocene aquifers.

Berg et al., 2008
Strong hydraulic gradient toward Dhaka in dry season.