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Using Logistic Regression to Model Arsenic Risk in Dhaka City, Bangladesh

Four geostatistical risk models were developed to assess the current risk of arsenic contamination in shallow groundwater of Dhaka city. Jannatul Ferdous[1], Kazi Matin Ahmed[1], Sarmin Sultana[1], Manouchehr Amini[2], Michael Berg[2], Richard Johnston[2]

Introduction

In Dhaka, the capital of Bangladesh, some 15 million people rely on groundwater for most of their water supply. Due to high demand and insufficient recharge, groundwater levels have been declining 2–3 meters per year over the last few years. Groundwater elevation contour maps show a number of cones of depressions at heavy abstraction areas where regional groundwater flows are converging from all sides. Though the Pleistocene aquifers underlying Dhaka are historically free from As, shallow groundwater in young Holocene aquifers in the surrounding areas contain high concentrations of geogenic As. Heavy abstraction in Dhaka creates a risk of encroachment of arsenic-enriched water to Dhaka city shallow aquifers.

Methods

Different geospatial data were collected from within Dhaka city and its immediate surroundings: As measurements from 227 wells, lithologic information from 47 drilling logs and a GIS coverage of surface geology. With data from the drilling logs, two-dimensional subsurface geology maps were interpolated at 5-m depth intervals from 0–100 m below the earth's surface and 10-m intervals from 100–150 m. Four geostatistical risk models were developed using different combinations of surface geology, subsurface hydrostratigraphy and well depth as independent variable. Pixel-wise logistic regression was then applied for each depth layer using a binary coding of As (above the WHO provisional guideline value of 10 μg/L) as the dependent variable. The goodness of fit of the models was checked using receiver operating characteristic (ROC) curves. The area under the curve (AUC) represents the likelihood that the model correctly predicts the actual risk, and an AUC of 70 % or higher is taken to be a good result. Finally, depth-wise risk maps were integrated to produce a summary map of As risk (Fig. 1).

Results

In the study area, seven hydrostratigraphic units (three aquifers and four aquitards) were identified from the borelogs. The uppermost aquifer correlates with the Holocene epoch Bashabo Formation, while the two deeper aquifers are older, i.e. from the Pleistocene Madhupur Formation. Arsenic levels exceeding 10 μg/L were most frequently found in moderately shallow depths of about 25 m below ground. Arsenic levels were negligible between 0 and 10 m, and decreased with depth below 25 m. As was rarely found at more than 100 m below surface.

All four geostatistical models concurred well with the data obtained. The model using only earth's surface information yielded an AUC of 76 %, which increased to merely 77 % when well depth was added. When subsurface geology was included (without surface geology), AUC was higher than 80 %, and the best fit of 85 % was reached using both subsurface and surface geology. Well depth was not significant in this model.

26 depth-wise As risk maps were produced and revealed very low risks of As in any area more than 100 m below surface. The highest risk was found in the Holocene sediments within the 20–40-m depth range. This unit is found mainly outside Dhaka, but also extends into the eastern and southeastern parts of the city.

Conclusions

The different geostatistical logistic regression models produced maps of high and low risk zones matching available data well and allowing prediction of risk in areas lacking sufficient data. The simplest model, using only surface geology, gave results that were nearly as good as the more complicated models using subsurface geology. Preparing subsurface geology maps was time-intensive and required detailed drilling logs that were not always available. In the absence of such data, simple surface geology models are more practical and also yield good results. Well depth is normally available when As concentrations are measured. Model performance was slightly better when depth is included as an independent variable.

The models confirm that As risk is low in Dhaka city and suggest that the rapidly declining groundwater levels in Pleistocene aquifers have not resulted in As migration from surrounding Holocene aquifers. Yet, Holocene sediments found in the southeastern reaches of the city, are at relatively high risk of As contamination. Since few As data were available from these zones, future investigations should target these areas for water quality monitoring.

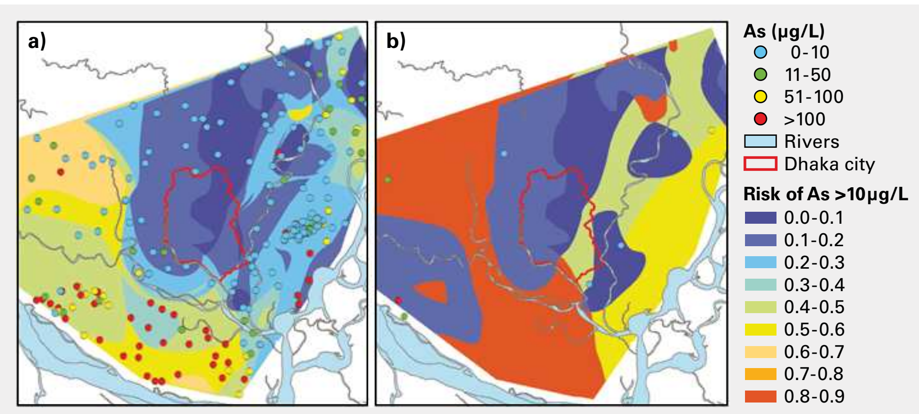

Figure 1: Results from model including surface and subsurface geology: (a) depth-integrated risk map and (b) risk map at 35 m below surface. Dhaka city corporation outlined in red.

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