Potential for Arsenic Contamination of Rice in Bangladesh: Spatial Analysis and Mapping of High Risk Areas

Zev Ross[1], John M. Duxbury[1], Debi Narayan Rudra Paul[2], Stephen D. DeGloria[1]

[1]Cornell University, Department of Crop and Soil Sciences, 904 Bradfield Hall; Ithaca, NY 14853; [2]Bangladesh Rice Research Institute, Gazipur 1701, Bangladesh

Abstract

Knowledge of the location and severity of arsenic contamination in Bangladesh is required to develop land and resource management strategies to reduce both human exposure to arsenic and arsenic contamination of food and water supplies. While the threat posed by directly drinking arsenic contaminated water has been well documented, the potential for exposure through secondary sources is not as well-understood. Given that rice accounts for 70% of an average adult's caloric intake in Bangladesh, the potential for exposure to arsenic through rice consumption must be considered in environmental health investigations.

The present study provides a spatial assessment of the risk of arsenic contamination of rice based on the use of arsenic contaminated groundwater for irrigation in Bangladesh. Specifically, we evaluate the potential risk of arsenic contamination of *boro* rice based on the average arsenic concentration of groundwater and the proportion of *boro* rice irrigated with groundwater by *upazila*. The potential consequences of exposure to high arsenic groundwater are elevated levels of arsenic in rice grain and straw and, possibly, over time, accumulation of arsenic in soil to levels that are toxic to rice. These outcomes raise the possibility of increased human exposure to arsenic as well as food security concerns if rice yields are reduced.

Potential high risk areas for arsenic contamination of rice were identified using spatial analysis and modeling. Existing country-wide data on groundwater arsenic contamination, winter (*boro)* rice production and irrigation methods were used to identify areas where high production of groundwater irrigated *boro* rice corresponds to areas with high arsenic contamination of groundwater. Our general approach was to combine data on groundwater arsenic concentrations, *boro* rice production and use of groundwater for irrigation to identify areas of the country with both high arsenic in groundwater and high production of groundwater irrigated rice. The resolution of the analysis was limited to the *upazila*-level by the production and irrigation databases.

The *boro* rice production data were multiplied by the percent irrigated by groundwater to obtain the total production of groundwater irrigated *boro* rice (in 1000s of tonnes) in each *upazila*. The arsenic point database was aggregated "up" from the point data to the *upazila* level using block kriging methods rather than simply taking the average of the data points in each *upazila*. This approach has the advantage that it makes use of both the values at nearby locations in addition to the overall spatial pattern in the measured data.

Unlike many other kriging methods, block kriging does not explicitly require data to be normally distributed. The arsenic data exhibits a long right tail, however, a comparison with predictions based on log-transformed data as well as a comparison with predictions based on a model computed by removing extreme values (greater than 500 µg L^{-1}) suggests that kriging the untransformed data is appropriate and not unduly influenced by large values. Rather than impose a transformation and risk the "exaggerated" error in the back-transformation, we kriged the *untransformed* arsenic data. To evaluate the uncertainty in the kriged point predictions we also computed a map of prediction standard errors and used these to identify and eliminate from the analysis *upazila* with particularly unreliable estimates. In order to achieve area wide estimates by *upazila* we used block kriging in which point kriged estimates within *upazila* were arithmetically averaged.

Results show that seventy-six percent of the total irrigated *boro* rice is grown in *upazila* where mean groundwater arsenic concentrations are below 50 µg L^{-1}, the Bangladesh health standard. Seven percent, however, is grown in areas with mean concentrations greater than 100 µg L^{-1}, primarily in south-central and western-central Bangladesh. Mitigation strategies are suggested for the areas considered to be at risk for arsenic contamination of *boro* rice.

This spatial analysis and mapping of arsenic contamination risk for *boro* season rice is, to our knowledge, the first attempt to identify and map high risk areas for potential arsenic contamination of rice consumed by a large population. It is a first step in the assessment of risk of human exposure to arsenic through the food system. Fortunately for Bangladesh, much of the *boro* rice production using groundwater for irrigation is in the northern part of the county where arsenic concentrations are generally below the WHO drinking water standard of 10 µg L^{-1}. Additionally, greater use of surface water for irrigation and lower levels of *boro* rice production moderate the risk for contamination in the central area where groundwater arsenic levels are high.

The inability to include soil arsenic concentrations in the analysis and the level of spatial resolution are important limitations to the current study. A systematic determination of soil arsenic content across Bangladesh, similar to that done for groundwater, should be undertaken. The combination of soil and groundwater arsenic data layers would provide a more accurate representation of risk for arsenic contamination of *boro* rice, and could extend the analysis to the *aman* season rice.

We emphasize that the risk analysis presented here assumes that the arsenic content of groundwater leads to a buildup of arsenic in soils and that these parameters are important drivers of the arsenic content of rice. On this basis, our analysis suggests several strategies to avoid contamination of both rice and soils with arsenic. These are:

1. Further develop surface water resources for those *upazila* in the central part of the country that have high levels of arsenic in groundwater.
2. Avoid production of *boro* rice where groundwater arsenic levels are high and this is the only source of irrigation water. Other cereal crops such as maize and wheat, which require far less water could be substituted for rice in the winter season.

Modern water conserving technologies, such as using raised beds and furrow irrigation in place flood irrigation, would further reduce arsenic loading to soil.

3. Expand *boro* rice production in the northern part of the country where groundwater arsenic levels are low.

Such changes would require substantial investment in infrastructure for use of surface water and policies that control where *boro* rice is grown. However, the long-term pay-off from avoiding soil contamination with arsenic cannot be overstated and reaches to the core of agricultural sustainability in Bangladesh.