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Arsenic risk analysis of Bangladesh using geographical information system

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Introduction

Arsenic contamination of ground water is a widely prevalent phenomenon in Bangladesh. It is a form of groundwater pollution due to naturally occurring high concentrations of arsenic in deeper levels of groundwater. Arsenic contamination of groundwater in Bangladesh was discovered by the School of Environmental Studies (SOES) in 1992 (Dhar et al., 1997). The natural contamination of tube wells has led to widespread human exposure to arsenic through drinking water (Dhar et al., 1997). Since consumption of cereals and vegetables is a significant route of human exposure to arsenic, use of groundwater for irrigation of crops raises the question of arsenic uptake in food. The impact of arsenic-contaminated irrigation on rice is especially important as rice is the major staple food, and it may be grown in soil where irrigation has introduced arsenic from groundwater. Arsenic contamination in irrigation would be a toxic to rice leading to reduced yields (Paul, B.K. et. al. 2000). Shallow aquifers (20–70 m) generally have the highest levels of arsenic. The present study dealt with the map of irrigation land coverage, population, arsenic contamination of ground water and then converted the map into the Geographical Information System (GIS) data and maps, and then utilized the arsenic effect on irrigated land coverage and arsenic impact on population. Six categories of arsenic contamination maps were used to assess the levels of arsenic in different areas of Bangladesh. A risk map for administrative districts of Bangladesh was developed using both irrigation and population maps, interacting with groundwater arsenic concentration map (developed by Jakaria 2000).

Methodology

Data Preparation and Analysis

An arsenic contamination map was prepared on the basis of arsenic contamination levels. Six categories of arsenic contamination were defined: 1. uncontaminated (0 – 10 ppm), 2. low contamination (10 – 50 ppm), 3. contaminated (50 – 150 ppm), 4. highly contaminated (150 – 500ppm), 5. severely contaminated (500 – 1000 ppm), 6. extremely contaminated (1000 – 2000ppm). We obtained population and irrigation categorized maps, developed by the Bangladesh Bureau of Static and Bangladesh Agriculture Department. We superimposed these maps onto the base groundwater contamination map and converted them in to GIS data. The Population map employs five categories: 1. population density <500 persons/km^2, 2. 501 - 1000 persons/km^2, 3. 1001 – 1500 persons/km^2, 4. 1501 – 2000 person/km^2, 5. >2000 persons/km^2. The irrigation map employs four categories defined in terms of extent of area irrigated: 1. <25%, 2. 25 – 50%, 3. 50 – 75%, 4. 75 – 100%.

Hazard maps

We developed a model that required two hazard maps, using the interaction of arsenic groundwater contamination categories with first population density and second irrigation extent. The schematic concept of the model is shown in Figure 1. Islam and Sado (2000 and 2002) developed the concept of a ranking matrix defined by multiplication to determine a flood hazard and flood risk map. In this study, their concept of a ranking matrix was used to develop the two hazard maps and the final risk map. To generate the two hazard maps, we superimposed the district-based map categorizing arsenic concentration in groundwater (6 categories) on respectively the district-based map showing population concentration (5 categories) and the map showing irrigation extent (4 categories). This exercise generated 30 hazard ranks in the former and 24 in the latter map. Finally, the hazard ranks were aggregated into three categories: arsenic-population matrix aggregated ranks – low (1 – 6), medium (8 – 15), high (16 – 24); arsenic-irrigation – low (1 – 9), medium (10 – 18), high (20 – 30) shown in Table 1.

Table 1 Categories of hazard rank using ranking matrix

		Arsenic Contamination Category					
		1	**2**	**3**	**4**	**5**	**6**
Population Category	**1**	1	2	3	4	5	6
	2	2	4	6	8	10	12
	3	3	6	9	12	15	18
	4	4	8	12	16	20	24
	5	5	10	15	20	25	30

a) Categories of arsenic-population hazard map

		Arsenic Contamination Category					
		1	**2**	**3**	**4**	**5**	**6**
Irrigation Category	**1**	1	2	3	4	5	6
	2	2	4	6	8	10	12
	3	3	6	9	12	15	18
	4	4	8	12	16	20	24

b) Categories of arsenic-irrigation hazard map

Risk analysis

High level of arsenic in water for drinking or cooking or in irrigated fields may lead to serious health problems, such as melanosis, leuko-melanosis, hyperkeratosis, black foot disease, hepatomegaly, neuropathy and cancer (Khan and Ahamed, 1997). In this study, the arsenic vulnerability data were prepared in the form of GIS data using the arsenic vulnerability map which was developed by Jakaria (2000) on the basis of the presence of arsenic in soil and water, and arsenic patients. Jakaria's map used three categories:

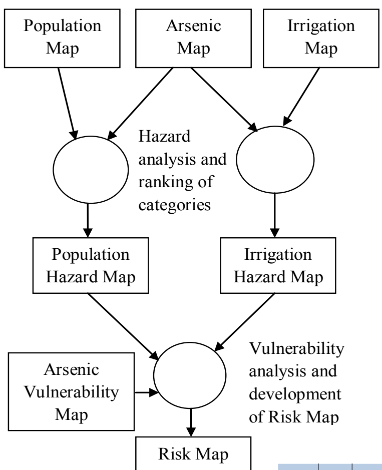
1. arsenic found with high arsenic levels in soil and ground water and in patients' blood,
2. arsenic found in soil and groundwater and
3. arsenic not detected.

In order to quantify the arsenic risk, the two hazard maps were set against vulnerability data (from Jakaria's map) by using Eq. 1 and developed two risk maps for arsenic-population effect and arsenic-irrigation effect.

$$Risk = vulnerability \times hazard \qquad (1)$$

These two maps were categorized into three categories 1, 2 and 3 by using the score of the risk. Finally, a risk map was developed by considering the interactive effect of two risk maps using the ranking matrix of two-dimensional multiplication modes (shown in Fig. 1) with six risk ranks; 1, 2, 3, 4, 6 and 9 drawn from the 3 x 3 ranking matrix for the administrative districts of Bangladesh. The final result is shown in Figure 2.

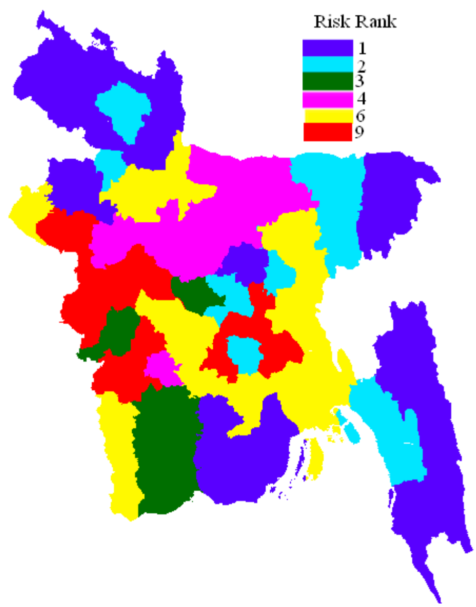
Figure 1: Flowchart of the model and ranking matrix



HR	1	2	3
1	1	2	3
2	2	4	6
3	3	6	9

Ranking Matrix

Figure 2: Arsenic contamination risk map for administrative district



Conclusions

Arsenic risk assessment was performed using arsenic contamination levels against both population density and irrigation density, defined for the administrative districts of Bangladesh. This risk map may help the responsible authorities to better comprehend the arsenic effect on the country's population and food. The general public may become more aware of the risk of arsenic in different districts of the country.

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