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Multiple Groundwater Contamination in the Mid-Gangetic Plain, Bihar (India): A Potential Threat

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ABSTRACT

Drinking water in Bihar (India) experiences multiple contaminations (arsenic, fluoride, nitrate, iron, and fecal coliform) challenges. This study focuses on developing an effective water-management decision-support tool by studying contaminated drinking water areas in the Mid-Gangetic Plain in the Bihar state of India. The major goals of the study are: mapping of the sampling density deficit index (SDDI) and mapping the pollution prevention priority index (PPPI). Based on the SDDI, approximately a 1000 drinking water sources in each district is needed to be tested to know a clear drinking water quality profile. Based on the PPPI, Saran, Bhojpur, Jehanabad, Nawada, Sheikhpura, and Munger districts should be given priority in groundwater-mitigation policies.

Introduction:

Ensuring potable drinking water to millions of lives across the globe is a prime concern for most of the political, socioeconomic, scientific, technological, and engineering think-tanks, contamination of drinking water from several toxic metals and pathogenic microbes is common (WaterAid 2007, Bain, Cronk et al. 2014). Consequently, water related adversities pose major impediments to achieve green socioeconomic growth (Schwarzenbach, Egli et al. 2010, Bhatti, Koike et al. 2012, Onda, LoBuglio et al. 2012, Grey, Garrick et al. 2013). About 28% of the global population uses unsafe drinking water, out of which more than 6 million people are without improved drinking water sources in Asia (Onda, LoBuglio et al. 2012). India is one of the South Asian countries, severely suffering from water quality challenges. Meeting the drinking water needs of a rural population of more than 700 million people in India, spread over 15 diverse ecological regions could be a challenging and nerve-wracking task (WaterAid 2007). Moreover, the heterogeneous level of awareness, socioeconomic development, low literacy rates, high poverty, cultural practices, and rituals add to the complexity of the task. Despite an estimated more than \$22 billion spent to provide safe drinking water in the last six decades in India, lack of safe and secure drinking water continues to be a major hurdle and a national economic burden (Bhatti, Koike et al. 2012). Half of the Indian population still defecates in open environments. As a result, about 38 million communities are affected by waterborne diseases annually and 1.5 million children are estimated to die of diarrhea alone in the country (WaterAid 2007, Cronin, Prakash et al. 2014). The resulting economic burden is estimated at \$600 million a year (WaterAid 2007). In addition, these diseases affect education and result in a loss of about 180 million work day annually in the country (WaterAid 2007).

In India, more than 33% of the groundwater resources are unfit for consumption (Cronin, Prakash et al. 2014). About 30% of the districts (201 out of 675) have some degree of groundwater fluoride contamination, affecting >400 million people's lives, in Rajasthan, Karnataka, Bihar, Madhya Pradesh, and West Bengal states in India (Chakraborti, Das et al. 2010, Cronin, Prakash et al. 2014). About 70.4 million people reported to be affected with groundwater arsenic-contamination in six states, including Bihar, Uttar Pradesh, Jharkhand, Assam, Manipur, and West Bengal (Nickson, Sengupta et al. 2007, Chakraborti, Das et al. 2010, Cronin, Prakash et al. 2014). An estimated 0.3 million of individuals were suffering from various stages of arsenicosis in the country (WHO 2010). The concentrations of nitrate in drinking water, primarily induced by agricultural activities, exceeded the Indian safe limit of 45mg/L in 11 states of India. Another serious issue is the higher concentration of iron in drinking water in the country. About 12 states are widely affected with elevated levels of iron in India: the highest affected populations are in Assam, Bihar, Chhattisgarh, Kerala, and Orissa (Chakraborti, Das et al. 2010, Cronin, Prakash et al. 2014). The other major concern for a safe drinking water supply in the country is bacteriological contamination. About 40% of the tested drinking water sources were contaminated with bacteria, confined in the Gangetic Plain areas in India (Chakraborti, Das et al. 2010). Manifestation of coliform, higher than the standard set by the Government of India, at 10 coliform counts per 100 ml of drinking water, and occurrences of zooplankton and other bacteria warrant mitigation policies (Jessoe 2013). The problem of multiple contamination of drinking water is more prevalent in the rural India, where about 80% of the population resides.

This multifarious groundwater contamination challenge impact socioeconomically deprived rural inhabitants in India. There is also a serious scarcity of research essentially focused on multiple groundwater contamination in the country and other parts of the world. According to the Agency for Toxic Substances and Disease Registry (ATSDR) (ATSDR 2011), the toxicity ranking of arsenic is 1, fluoride is 211 (fluorine), and nitrate is 220. Although there have been reports in literature of individual toxicity of arsenic, fluoride, and nitrate, there is very little known about the effects of the combined exposure to these toxicants (Chouhan and Flora 2010). In a recent study by Pohl et al. (2009), the ATSDR chemical mixture risk assessment only applied to 380 binary combinations of chemicals. Out of these combinations, none of the combinations explain about any interaction effect of arsenic, fluoride, and nitrate to each other includes additive effects (=), synergism (greater than additive effects), or antagonism (less than additive effects) (Pohl, Mumtaz et al. 2009). Development of water filtration units, to purify multiple contaminations, creates a significant challenge for water filtrations corporations .Furthermore, lack of reliable information on the habitation wise water quality data on various contaminants, lack of guideline for minimum number of drinking water sources to be tested (sampling density) in a habitation, and lack of decision-making tools to prioritize mitigation policies, led to failure of water management efforts. Several water filters were designed and tested in the arsenic and fluoride affected areas at regional and at the national levels. However, in most cases, filters failed to meet all the requirements for cleaning contaminated water in the areas. Additionally, water-filters failed to remove contaminants below the prescribed standards, failed to purify contaminants other than the targeted metals, and the performance of the filters was badly impacted by the presence of other chemicals such as iron and phosphate (Ahmed, Minnatullah et al. 2006, Chiew, Sampson et al. 2009). Nonetheless, scientists and engineers are still struggling to find effective mitigation technologies for multiple contaminants. Lack of guideline of sampling density i.e., minimum number of samples to be tested per square mile adds to the water quality monitoring and mitigation policies as well.

Based on the above research gaps and insights, the current research is designed to address the following questions: a) what is the current groundwater sampling density of the project area; and b) what is the current status of multiple groundwater contamination in the project area. Based on the results, we propose i) mapping of the sampling density deficit index to prioritize areas for the required number of groundwater samples to be tested, to get a representative groundwater contamination profile of the area; and ii) mapping the pollution prevention priority index to prioritize areas based on its current multiple groundwater contamination profile, where mitigation policies are an urgent need.

Study Site:

We selected Bihar for the case study, which is located in the Mid-Gangetic Plain (MGP) in India. Bihar is the second worst arsenic-affected state of India, which shares its boundary with Bangladesh, Nepal, and West Bengal, three of the most arsenic-affected areas in the world, and experience multiple groundwater contamination problems (Singh and Ghosh 2012, Singh, Ghosh et al. 2014, Singh and Vedwan 2014). The first case of the groundwater arsenic-contamination and Arsenicosis incidences were reported in 2003(Chakraborti, Mukherjee et al. 2003). In the consecutive years numerous habitations were found contaminated with arsenic levels greater than the World Health Organization (WHO) standard of 10µg/L and the Bureau of Indian Standard (BIS) of 50µg/L (Ayoob and Gupta 2006, Nickson, Sengupta et al. 2007, Saha 2009, Singh 2011, Singh, Ghosh et al. 2014). Elevated levels of arsenic in the soil and in the food chain, and health risks associated with the consumption of arsenic through water and foods were also reported in the state (Singh, Ghosh et al. 2014). The first reported case of high concentrations of fluoride and nitrate was in the southern district Rohtas of Bihar (Ray, Rao et al. 2000). Later, groundwater fluoride and nitrate contamination greater than the BIS standard was reported in a total of 266 and 503 blocks (out of 534) in 22 and in 9 districts (out of 37), respectively (Mishra and Shaw 2009). Fluoride in the food chain, and several cases of fluorosis was also reported in the state (Ranjan and Yasmin 2014, Yasmin, Ranjan et al. 2014). Concentrations of Iron more than the BIS standard of 1mg/L were reported in 19 (out of 37) districts (CGWB, 2010).

Methodology:

We extracted district wise groundwater contamination data on arsenic, fluoride, iron, nitrate, and fecal coliform, from the official website of the Department of Drinking Water and Sanitation, Government of India. The attributes of the groundwater contamination data used for this study were: total number of water sources tested, number of tested water sources not contaminated, and number of water sources contaminated with iron, arsenic, fluoride, nitrate, and fecal coliform. The data were entered into a Microsoft Excel Spreadsheet 2010 for further analysis. Maps were created using ArcGIS version 10.1(ESRI 2012). The sampling density were calculated following a preferred one water sample per square mile to be tested (Winkel, Berg et al. 2008). Based on the number of contaminants in each district, and considering the ATSDR (2011) toxicity level of the contaminants, pollution prevention priority index were derived, adapting the "composite vulnerability index" method described by Singh and Vedwan (2014). The pollution prevention priority index, followed by the mapping help prioritize the areas, where and what type of water management efforts would be needed.

Results and Discussion:

A sampling density deficit index map is shown in Figure 1, which explicates the minimum number of water samples required to be tested in each district. A majority of the districts (24 districts) had sampling density deficit between 97% and 98%; 10 districts between 95% and 97%; and only three districts had sampling density deficit of 95%. The state still has an average 96% of sampling density deficit (Figure 1).

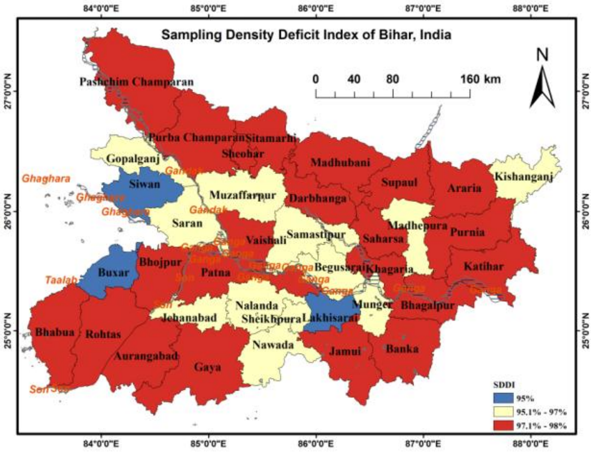
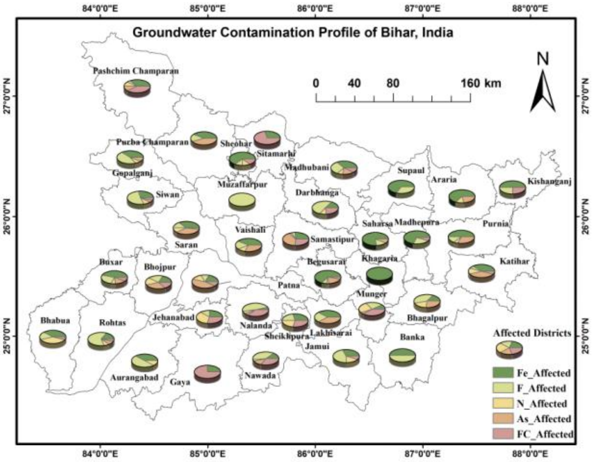


Figure: 1. Sampling density deficit index for groundwater in Bihar, India

Therefore, to derive a representative groundwater contamination profile of the state, more than 35000 groundwater sources should be tested, with an average of about 950 groundwater sources in each district. Out of the total of 532 community blocks in Bihar, about 42% blocks were contaminated with iron; 32% blocks were contaminated with fluoride; 13% bocks were contaminated with nitrate; 19% blocks were contaminated with arsenic; and 18% of the community blocks were contaminated fecal coliform. Four districts were 100% contaminated with iron; ten districts were ≥50% contaminated with iron in the state (Figure 2). None of the district was 100% fluoride contaminated. A total of 11 districts were ≥50% contaminated with fluoride. Only four districts were safe from fluoride contamination (Figure 2).



Note: Fe: Iron; F: Fluoride; N: Nitrate; As: Arsenic; FC: Fecal coliform

Figure: 2. Groundwater contamination profile of Bihar, India

Similar to fluoride contamination, none of the districts was 100% contaminated with nitrate, four districts were ≥50% contaminated with nitrate, and a total of 11 districts were 100% safe from nitrate contamination in the state (Figure 2). Only one district was 100% exposed to fecal coliform contamination and four districts were ≥50% contaminated with fecal coliform. However, a total of 13 districts were 100% free from fecal coliform contamination (Figure 2).

Multiple groundwater contamination analysis showed that a total of 180 community blocks (out of 532) were contaminated with only one contaminant: 23 community blocks were contaminated with only arsenic in seven district; 48 blocks were contaminated with only fluoride in 14 districts; 82 blocks were contaminated with iron in 27 districts; eight blocks were contaminated with nitrate in six districts; and 19 blocks were contaminated with only fecal coliform in 10 districts.

A total of 286 community blocks were contaminated with a combination of two contaminants. Out of these 286 community blocks, only one block was contaminated with arsenic and fecal coliform in only one district; eight blocks with fluoride and arsenic in four districts; five blocks with fluoride and nitrate in four districts; 29 blocks with iron and arsenic in 11 districts; 38 blocks with iron and fluoride in 20 districts; 13 blocks with iron and nitrate in eight districts; five blocks with nitrate and arsenic in four districts; 16 blocks with fluoride and fecal coliform in four districts; 19 blocks with iron and fecal coliform in 11 districts; and one block was contaminated with nitrate and fecal coliform in only one district.

A total of 44 blocks were contaminated with a combination of three contaminants. Out of these 44 blocks, eight blocks were contaminated with iron, arsenic, and fecal coliform in two districts; five blocks were contaminated with iron, fluoride, and fecal coliform in six districts; five blocks were contaminated with iron, fluoride, and nitrate in five districts; three blocks were contaminated with iron, nitrate and arsenic in two districts; two blocks were contaminated with iron, nitrate and fecal coliform in one district; two blocks were contaminated with fluoride, arsenic and fecal coliform in two districts; three blocks were contaminated with fluoride, nitrate and arsenic in three districts; eight blocks were contaminated with fluoride, nitrate and fecal coliform in four districts; and eight blocks were contaminated with iron, fluoride and arsenic in four districts.

A total of 19 blocks were contaminated with a combination of four contaminants. Out of the total 19 blocks, four blocks were contaminated with iron, fluoride, arsenic, and fecal coliform in three districts; seven blocks were contaminated with iron, fluoride, nitrate, and arsenic in six districts; six blocks were contaminated with iron, fluoride, nitrate, and fecal coliform in three districts; one block was contaminated with iron, nitrate, arsenic, and fecal coliform in one district; and one block was contaminated with fluoride, nitrate, arsenic, and fecal coliform in only one district. Only two blocks in two districts were contaminated with a combination of all the five contaminants.

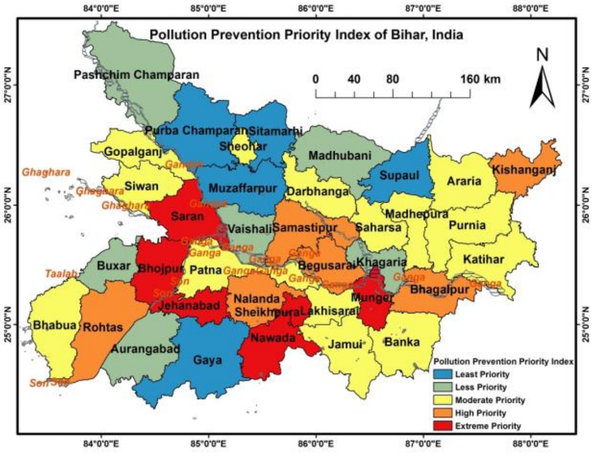


Figure: 3. Pollution priority index of Bihar, India

We derived four extreme pollution prevention priority districts, where water management efforts are immediately required. Six districts were at the scale of high priority; fourteen districts were at the scale of moderate priority; three districts were at the less priority level; and five districts were at the pre-priority level (Figure 3). Most of the districts adjacent to the River Ganges fall under the categories of either extreme or high priority areas. The districts that should be given extreme priority for groundwater mitigation policies or, interventions were Saran, Bhojpur, Jehanabad, Nawada, Munger, Rohtas, Nalanda, Samastiput, Begusarai, Bhagalpur, and Kishanganj.

Conclusion:

This preliminary result validates that the drinking water in Bihar is severely affected with multiple contamination, which could be a potential threat to millions of underprivileged people, and therefore warrants immediate mitigation policies. The health risk due to the consumption of individual groundwater contaminants like arsenic, fluoride, nitrate, etc., has been extensively investigated and reported. However, the synergistic effects of multiple groundwater contaminants have not been appropriately addressed. Some studies have shown that combined exposure to arsenic and fluoride leads to distinct damage on the nervous system of offspring, with decreased learning and memory ability (Chouhan and Flora 2010). Chinoy and Shah have reported altered histology of the cerebral hemisphere following combined arsenic-fluoride exposure, wherein the effects produced by arsenic are more prominent as compared to fluoride (Shah and Chinoy 2004). Additionally, genotoxic effects of combined exposure to arsenic and fluoride have also been reported to be more pronounced as compared to their individual exposure. The toxicological effects of fluoride can be enhanced by arsenic (Chouhan and Flora 2010). There are other poverty-related factors behind inequalities in child mortality, including poor nutrition and access to affordable healthcare. Children who are malnourished are more likely to suffer from diarrhea and longer lasting sickness episodes (WaterAid 2007). Inadequate sanitation remained, however, continuing a cycle of water-borne disease and poverty (Ayoob and Gupta 2006, Chakraborti, Das et al. 2010). The communities are forced to spend a significant amount of their wages on health, because of lack of health system services (WaterAid 2007). About 1000 drinking water samples in each district need to be tested for multiple contaminations. Water-filters capable of filtering multiple contaminations should be developed and distributed among the exposed communities with a subsidized rate, as the exposed communities are socioeconomically marginalized. The research is ongoing; we are developing a decision support tool to prioritize pollution prevention policies for improved and effective mitigation policies, awareness campaigns, and outreach.

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