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# Groundwater Arsenic Contamination and Associated Health Risks in Bihar, India

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**ABSTRACT:**The extent of groundwater arsenic (As) contamination and associated health-risks were studied in the four villages: Chaukia and Terahrasiya (Vaishali); Mamalkha and Masharu (Bhagalpur) in Bihar, India. Groundwater samples were tested using the standard Silverdiethyledithiocarbamate method at 520nm by Thermo UV-1 spectrophotometer. The As levels in both the districts exceeded the WHO standard of 10µg/L for drinking water with a maximum value of 20µg/L in Vaishali and 143µg/L in Bhagalpur. However, the FAO standard of 100µg/L of As for irrigation water was only exceeded in Bhagalpur. The calculated range of the hazard index (HI) for Vaishali was 0.9 to 10, and for Bhagalpur was 10.40 to 40.47. Both ranges exceed the accepted normal toxic HI of 1.00. The cancer risk was derived as 1-5/1000 people to 5-16/10,000 people in Vaishali, and 7-21/1000 and 5-16/1000 people in Bhagalpur. Prevalence of skin pigmentation was double in Vaishali in comparison to Bhagalpur. The analysis of principal components showed that only two components had a fundamental role in defining variance for cancer risk assessment. A more extensive screening of As contamination of groundwater and a follow-up clinical study are necessary to accurately assess the likelihood of As-related cancers in these districts.

**Key words:** Arsenic,Cancer Risk, Diseases,Vaishali, Bhagalpur, Bihar

## INTRODUCTION

The widespread switch from microbiologically unsafe surface water to microbiologically safe groundwater led millions of people to install their own private hand tube wells (HTW) in Bangladesh and India after an incident related to an acute diarrheal episode. The main reasons for high arsenic (As) contamination in these areas were alteration of the redox condition and the geochemical properties of groundwater. This alteration occurred because of the over-withdrawal of groundwater for drinking and irrigation, which causes the release of As from the minerals (Opar *et al.*, 2007; Phan *et al.*, 2010). The Ganga-Meghna-Brahmaputra (GMB) plain, covering India and Bangladesh, is the highest As-contaminated area in South East Asia affecting more than 500 million people's lives (Hossain *et al.*, 2006). Among more than 70 countries, half of the countries have been recently identified as As-affected areas and it is likely that many other areas with elevated As in groundwater will be found in the future (Bundschuh *et al.*, 2010; Ravenscroft, 2007, 2009). The continuous consumption of As through drinking water and food sources may lead to As poisoning popularly known as *'Arsenicosis'*.

The severity of health effects from As exposure mainly depends on (a) demographic factors like age of the person exposed and gender; (b) socio-economic factors like economic status, education, and awareness; and (c) modifying factors like dose, duration of exposure, genetic susceptibility, health status of the person exposed, nutritional status, route of exposure/inhalation, ingestion, dermal contact, smoking, sex hormones, sunlight exposure, and exposure to pesticides (ATSDR/DTEM, 2006; Maden *et al.*, 2011). The United States National Research Council has reported that, one in 10 people who drink water containing 500µg/L of As may ultimately die from cancers caused by As, including lung, bladder,

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and skin cancer. As health effects range from skin lesions to cancer at values from 10µg/L to up to 2000µg/L of As in drinking water (Table 1).

The groundwater As contamination in Bihar was first reported in Semaria Ojha Patti village of Shahpur, a block of Bhojpur district in 2002 (Chakraborti *et al.,* 2003). In 2007, Nickson et al. reported groundwater As contamination in 50 blocks in 11 districts (Nickson *et al.,* 2007). Currently, the groundwater As contamination has spread to 16 districts, threatening more than 10 million people in Bihar (Ghosh *et al.,* 2007, 2009; Saha, 2009; SOES, 2012). Recently, Singh and Ghosh (2012) estimated that there is a very high health risk in the As-contaminated areas in Maner block of the Patna district. They found that the cancer risk and hazard quotient owing to drinking As-contaminated groundwater was as high as 192 (Singh and Ghosh, 2012). In that area, an average of 142µg/L of As was detected with the highest value of 498µg/L of As measured in the Haldichapra panchayat of Maner block, Patna. However, the highest level of 2182µg/L of As was reported in the Buxar district of Bihar (Fig. 1) (SOES, 2012). Other As affected areas of Bihar, where the level of As in drinking water exceeded 1000µg/L are Bhojpur, Patna, Samastipur, and Bhagalpur districts. More than 50µg/L of As were detected in Vaishali, Saran, Begusarai, Khagaria, Munger, and Katihar districts (Fig. 1). However, other districts like Siwan, Lakhisarai, Darbhanga, Supaul, and Kishanganj were below India's standard of 50µg/L of As for drinking water (Fig. 1). In addition to drinking water, As contamination in soil and food materials has also been reported in the Maner block of the Patna district (Singh, 2011; Singh and Ghosh, 2012). The health of the communities residing in those of As affected areas is at risk through exposure to As through water, soil, and food.

The successive increase in reported cases of new As affected areas from one district and one block in 2002 to 16 districts and 61 blocks in Bihar in 2011, poses a serious threat to the exposed population and creates a challenge for the government of Bihar to start and implement As-mitigation program(s). Out of a total 240,000 water supply hand pumps (public and private) in As affected blocks of Bihar, only 27% (66,623) of the sources were tested for As levels (Nickson *et al.,* 2007). Also, clinical investigations of As exposed populations have not been reported since 2002 after Chakraborti et al. (2003). The present article is an extension of previous work and has used water quality data for cancer risk assessment (Singh, 2011). The goals of this study are (a) to illustrate the extent of groundwater As contamination in the study villages of Vaishali (Chaukia and Terahrasiya) and Bhagalpur (Mamalkha and Masharu) districts of Bihar, India; (b) to derive cancer risk due to consumption of As-contaminated groundwater in the study villages; (c) to examine the other health risk among the study communities; and (d) to evaluate the correlation between the water quality parameters, and the principal components of the variables used for cancer risk assessment.

## MATERIALS & METHODS

A total of 40 water samples (10 samples per village) were collected from HTWs in Vaishali (Chaukia and Terahrasiya) and Bhagalpur (Mamalkha and Masharu) districts (Fig. 1). Each HTW was flushed for ten minutes to get the actual representative

**Table 1. Health problems due to drinking arsenic contaminated water**

| S. No. | Diseases | As in Drinking Water (µg/L) | Country/Region | References |
|---|---|---|---|---|
| 1 | Spontaneous Pregnancy Loss | 10 to 1474 | | Bloom et al., 2010 |
| 2 | Respiratory Complications | 216 | Bangladesh | Islam et al., 2007 |
| 3 | Diabetes | 20 to 400 | | Ganzalez et al., 2007 |
| 4 | Immunological system | 216 | Bangladesh | Islam et al., 2007 |
| 5 | Skin Cancer | >100 | Cordoba, Argentina | Astolfi et al., 1981 |
| 6 | Hepatic Damage | 200 to 2000 | West Bengal, India | Guha Mazumdar et al., 1988 |
| 7 | Recognizable signs of As toxicity | >100 | Cordoba, Argentina | Astolfi et al., 1981 |
| 8 | Skin lesions | <50 | West Bengal, India | Guha Mazumdar et al., 1988 |
| 9 | Arsenic Dermatosis | 200 | West Bengal, India | Chakraborty and Saha (1987) |
| 10 | Neurological disorders | 100 to 2000 | Bangladesh, India | Rahman et al., 2009 |
| 11 | IQ of children | >50 | | Wasserman et al.,2004 |
| 12 | Melanosis/Keratosis | >50 | Bihar, India | Chakraborti et al., 2003 |

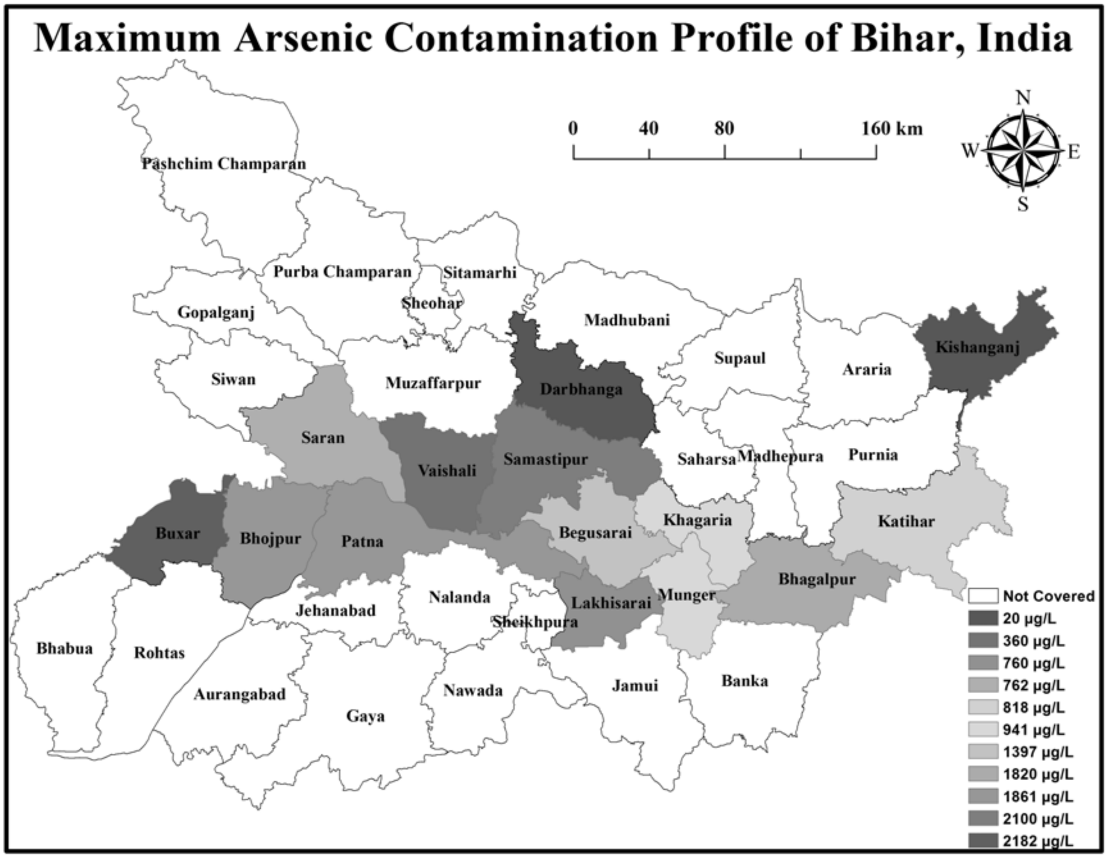


**Fig. 1. Arsenic Contamination Profile of Bihar, India**

(The map was created using Arc GIS 10.1 and the arsenic concentrations data was extracted from SOES 2012; Saha 2009; Ghosh et al., 2007, 2009)

groundwater samples following Nickson's protocol (Nickson *et al.,* 2007). All water samples were tested using UV-Spectrophotometer following the SDDC (Silverdiethyledithiocarbamate) method against a blank at 520nm. The UV-spectrophotometer used for the water samples analyses was calibrated using known concentrations of As standards. A coefficient of 0.99998 was derived for the calibration curve. Known concentrations of As standards were tested in between to check the accuracy of the measurements (Singh, 2011).

A survey in all of the four villages in both of the districts was conducted to estimate per capita consumption of drinking water by the communities. An open and closed ended questionnaire method was used for the survey. Households were selected randomly and children, youth, adults, and elderly people were questioned on per day drinking water consumption. A calibrated glass of 500 ml volume was used to know the correct volume of consumption of water daily. In total, 564 people were surveyed in Vaishali and 308 people in the Bhagalpur district. Detailed methodology is described elsewhere (Singh and Ghosh, 2012).

Cancer risk assessment was conducted by evaluating communities' Ingestion Rate (IR), Average Total Dose (ATD), Chronic Daily Intake (CDI), Cancer Risk (CR) and Hazard Quotient/Hazard Index (HQ/HI). The detailed methodology is described in Singh and Ghosh (2012). The formulas applied are illustrated here:

$$Average\ Total\ Dose\ (ATD)\ (mg) = As_w \times Ingestion\ Rate\ (IR)$$

where $As_w$ = Arsenic concentration of water (mg/L), IR = Water ingestion rate (L/day).

$$Chronic\ Daily\ Intake\ (CDI)\ (mg/kg/day) = ATD(mg) \times Bodyweight(kg)$$

$$Cancer\ Risk\ (CR) = CDI \times Potency\ Factor\ (FP)$$

where PF (oral route) for As is 1.5 (mg/kg/day) (established by USEPA's Integrated Risk Information System-IRIS).

$$HI = CDI/RfD$$

where; RfD is the reference dose for As (mg/kg/day), *i.e.*, $3 \times 10^{-4}$.

A health survey was conducted in the study villages. Responses from the villagers about the health issues including diarrhea, gastric problems, body itching, skin pigmentation, hardening of sole, etc. were noted. Additionally, Relative Risk (RR) and Odds Ratio (OR) were also derived using JMP statistical package. For the RR and OR analysis of the health survey, data was converted into a two-way table. In the JMP software, the fit Y by X analysis tool was selected then the diseases were placed on the Y responses and the names of the villages were placed on the X factor. The count (total population surveyed) was placed under the frequency option. The software was run and the values for RRs and ORs were derived by selecting the RR and the OR options.

Water samples in the sampled villages of both districts were analyzed for As and pH levels. Depths of the installed HTWs were annotated in both areas. All of the 40 water samples were representative of the households surveyed for the health risk analysis. Means of the As concentrations in the water samples, depths of the HTWs, and pH values of the water samples from the sampled villages of Vaishali and Bhagalpur were compared using ANOVA. Principal components analysis was also performed to determine the principal components to derive the variance of cancer risk assessment. All statistical analysis was performed using JMP statistical software version 9.0.

## RESULTS & DISCUSSION

The depth of HTWs in Vaishali ranged from 12.2 m to 15.2 m with a mean value of 13.2 m, whereas in Bhagalpur, HTWs between 12.2 to 32 m were found to be contaminated with As, exhibiting wide spatial variation with a mean value of 22.34 m (Table 2).

The As levels in the groundwater of Vaishali were found within the Indian safe limit of 50µg/L of As for drinking water in both Chaukia and Terahrasiya villages. However, it exceeded by "two fold" the World Health Organization (WHO) standard of 10µg/L of As in the Chaukia village only (Fig. 2). On the other hand, the groundwater of the Bhagalpur district was found highly contaminated with As, ranging from 3µg/L to 143µg/L. The average As concentration in Bhagalpur (50µg/L) was five times that in Vaishali (10µg/L) (Table 2, Fig. 3). In Bhagalpur, 95% of the tested sources were found contaminated with As levels above the WHO standard for drinking water. Furthermore, the As levels were found to be comparatively greater in Masharu than Mamalkha village. In Vaishali, all tested sources were within the prescribed limit of the Food and Agriculture Organization (FAO) for irrigation water set at 100µg/L of As. However, the limit was exceeded in two sources in the Bhagalpur area. The groundwater in Vaishali was available at shallow depths, whereas in Bhagalpur people have to dig to a depth of 32m to install a HTW to extract groundwater (Table 2). It was observed that the physical property of groundwater in both the districts were different from each other. Vaishali's water samples were slightly acidic with a mean pH value of 6.6, whereas in Bhagalpur area water samples were found slightly alkaline with a mean value of 7.7pH (Table 2).

The ANOVA test showed that the mean values of the depth of HTWs, pH values of the drinking water, and As levels in the drinking water tested in both districts were found to be significantly different from each other ($p<.0001$) (Fig. 4-6). A simple linear model was also derived for both districts to understand the correlation and effect of pH and depths on the levels

**Table 2. Statistical expressions of the groundwater data in both districts**

| | Vaishali | | | Bhagalpur | | |
|---|---|---|---|---|---|---|
| | **Depth (m)** | **pH** | **As(µg/L)** | **Depth (m)** | **pH** | **As (µg/L)** |
| Count | 20 | 20 | 20 | 20 | 20 | 20 |
| Mean | 13.18 | 6.5 | 9.7 | 22.34 | 7.74 | 49.8 |
| Median | 12.95 | 6.5 | 9 | 22.9 | 7.9 | 40 |
| Std Dev | 1.12 | 0.5 | 6.63 | 5.35 | 0.3 | 39.98 |
| Std Err Mean | 0.25 | 0.1 | 1.48 | 1.2 | 0.07 | 8.94 |
| Min | 12.2 | 5.5 | 1 | 12.2 | 7 | 3 |
| Max | 15.2 | 7.5 | 21 | 32 | 8 | 143 |
| Lower 95% | 12.65 | 6.2 | 6.6 | 19.83 | 7.6 | 31.09 |
| Upper 95% | 13.7 | 6.7 | 12.8 | 24.84 | 7.88 | 68.51 |

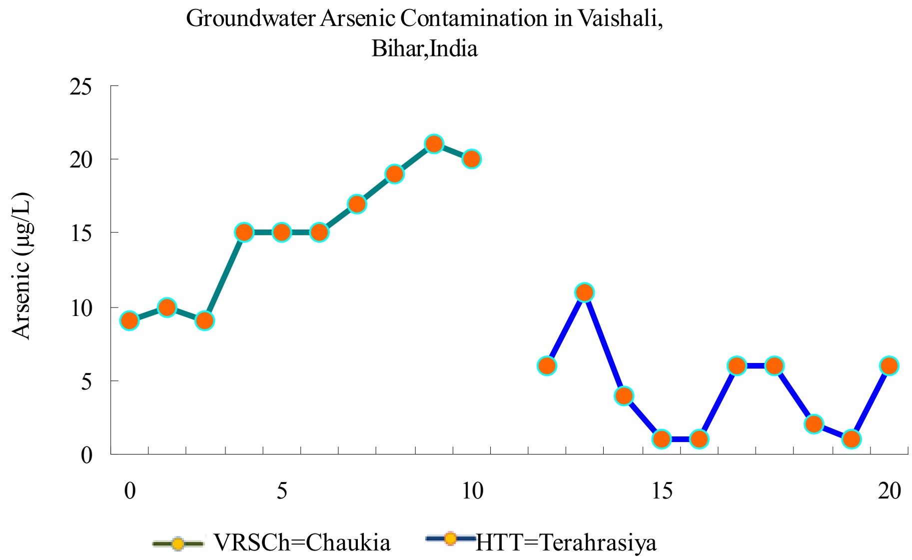


**Fig. 2. Arsenic in Vaishali Groundwater**

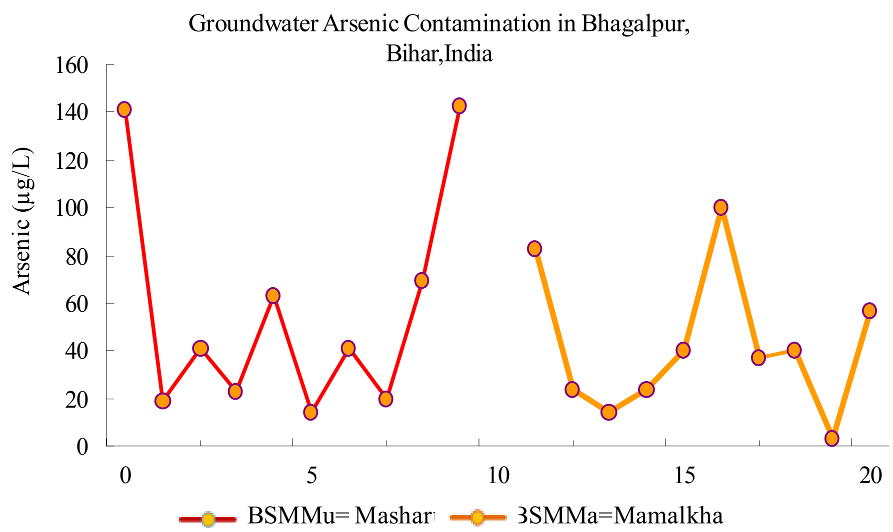


**Fig. 3. Arsenic in Bhagalpur Groundwater**

of As in the groundwater. In both cases, only pH was found to be the most significant predictor for As concentration in the groundwater. The simple linear model showed a very contrasting result for this single predictive variable pH. In the case of Vaishali, the As level was positively correlated with the pH values. The model states that with an increase in one unit of pH value the level of As will increase by 7.5 in Vaishali (Table 3). However, in the case of groundwater of the Bhagalpur, a negative correlation between pH and As was observed. The simple linear model showed that with increase in one unit of pH value, the level of As in the groundwater of Bhagalpur will decrease by 69.75 (Table 3). pH is one of the most important physico-chemical properties of groundwater that influences the concentration of As in groundwater. However, there are other important chemical parameters that play a vital role in As-mobility in groundwater, including organic matter, phosphate, sulfate, carbonic acids, etc. Consequently, a large sample size of groundwater with a detailed physico-chemical analysis is required, which would help suggesting probable mechanism(s) for the contrasting effect of pH on As concentrations in these two districts. A geochemical study of these aquifers would give a more precise explanation for this phenomenon.

A Total of 80 households (20 households in each village) were surveyed, covering a total population of 564 in Vaishali (Terahrasiya=283 and Chaukia=281) and 308 people in Bhagalpur (Mamalkha=159 and

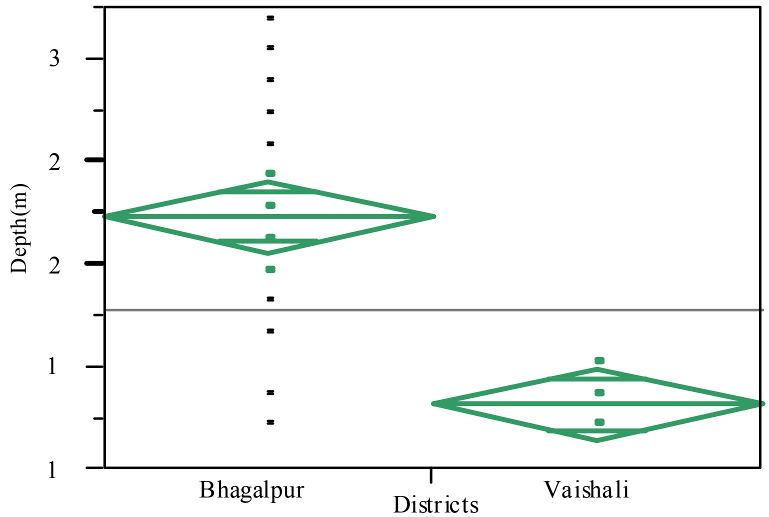


**Fig. 4. ANOVA for depth of HTW**

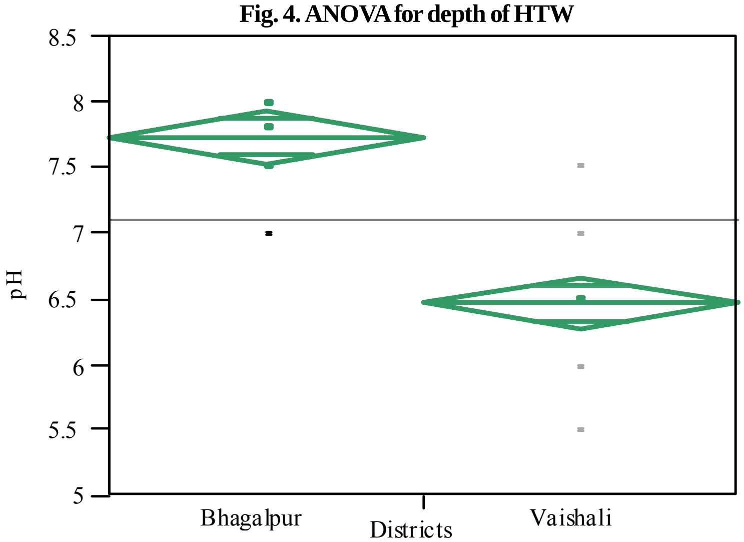


**Fig. 5. ANOVA for pH of water**

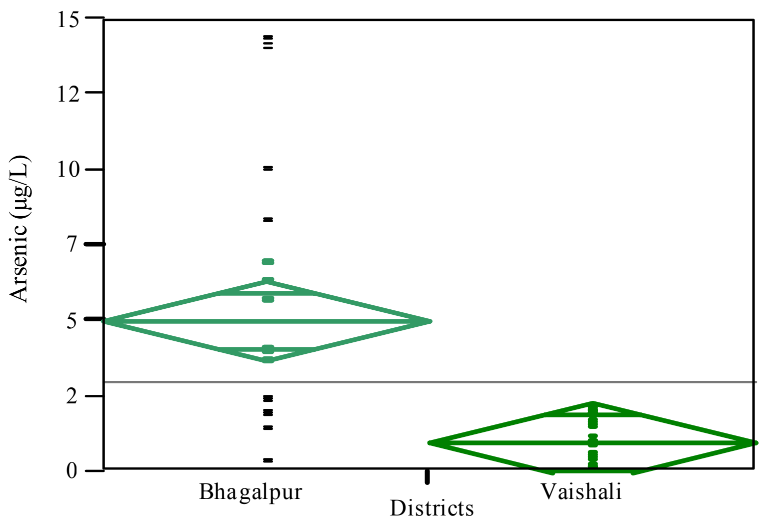


**Fig. 6. ANOVA of Arsenic concentration**

**Table 3. Simple Linear Model for Arsenic Contamination**

| Simple Linear Model | |
|---|---|
| Vaishali | Bhagalpur |
| Arsenic (µg/L) = -39.22222 + 7.5555556*pH<br>(p= 0.0031* @ α=0.05) | Arsenic (µg/L) = 589.67417 - 69.751185*pH<br>(p= 0.0188* @ α=0.05) |

Masharu=149). The per capita consumptions of drinking water by children, youth, adults, and the elderly were recorded; in Chaukia 2.0L/day, 4.80 L/day, 5.60 L/day, and 5.8 L/day; in Terahrasiya 2.4 L/day, 5.0 L/day, 5.2 L/day, and 5.5 L/day; in Mamalkha 2.13 L/day, 5.3 L/day, 5.75 L/day, and 6.31 L/day; and in Masharu 2.20 L/day, 5.6 L/day, 5.4 L/day and 5.2 L/day. The per capita consumption of drinking water was 1.05 times more in Bhagalpur than in Vaishali. However, the difference in the mean values of per capita consumption of drinking water in Vaishali and Bhagalpur was statistically not significant ($R^2$=0.004).

A cancer-risk analysis due to drinking As-contaminated water was performed in both districts. Results showed that the exposed communities in the Chaukia and Terahrasiya villages of Vaishali had high HI values because they consumed As-contaminated drinking water. The HI ranged from 3.43 to 10 and 0.95 to 3.2 respectively; however, it was between 14.5 to 40.5 and 10.40 to 30.8 in Masharu and Mamalkha villages in Bhagalpur respectively (Table 4).

The lower and the upper end of the HI ranges for both the villages of Bhagalpur exceeded the standard toxic risk index 1.00, suggesting that the residents in the Mamalkha and Masharu villages in Bhagalpur might confront more significant adverse toxic health impacts. However, in Vaishali, only the Chaukia village has exceeded the standard toxic risk index 1.00 for all age groups. In Terahrasiya, the HI exceeded only in the age-groups of 5-10 and 40+.

Principal components are eigenvectors of variance-covariance matrix and a method for reducing

**Table 4. Average Total Dose, Chronic Daily Intake Cancer Risk and Hazard Quotient of Respondents in Survey Area due to Drinking Water**

| Districts/ Village | Ages | Age-Mid | Weight (kg) | As in Water (µg/L) | IR(L) | TD (mg/day) | CDI (mg/kg-day) | HQ | Cancer Risk/1000 | Total Pop Surveyed |
|---|---|---|---|---|---|---|---|---|---|---|
| VRSCh | 5-10 | 7.5 | 10 | 15 | 2.0 | 0.03 | 0.003 | 10 | 5 | 105 |
| VRSCh | 11-20 | 15 | 70 | 15 | 4.8 | 0.072 | 0.001 | 3.43 | 2 | 55 |
| VRSCh | 21-40 | 30 | 70 | 15 | 5.6 | 0.084 | 0.001 | 4 | 2 | 93 |
| VRSCh | 40+ | 50 | 70 | 15 | 5.8 | 0.087 | 0.001 | 4.14 | 2 | 28 |
| VHTT | 5-10 | 7.5 | 10 | 4 | 2.4 | 0.01 | 0.001 | 3.2 | 1 | 110 |
| VHTT | 11-20 | 15 | 70 | 4 | 5.0 | 0.02 | 0.000 | 0.95 | 0 | 56 |
| VHTT | 21-40 | 30 | 70 | 4 | 5.2 | 0.021 | 0.000 | 0.99 | 0 | 83 |
| VHTT | 40+ | 50 | 70 | 4 | 5.5 | 0.022 | 0.000 | 1.05 | 0 | 34 |
| BSMMu | 5-10 | 7.5 | 10 | 57 | 2.1 | 0.121 | 0.012 | 40.5 | 18 | 48 |
| BSMMu | 11-20 | 15 | 70 | 57 | 5.3 | 0.304 | 0.004 | 14.5 | 7 | 32 |
| BSMMu | 21-40 | 30 | 70 | 57 | 5.7 | 0.328 | 0.005 | 15.6 | 5 | 55 |
| BSMMu | 40+ | 50 | 70 | 57 | 6.3 | 0.36 | 0.005 | 17.1 | 8 | 24 |
| BSMMa | 5-10 | 7.5 | 10 | 42 | 2.2 | 0.092 | 0.009 | 30.8 | 14 | 31 |
| BSMMa | 11-20 | 15 | 70 | 42 | 5.6 | 0.235 | 0.003 | 11.2 | 5 | 27 |
| BSMMa | 21-40 | 30 | 70 | 42 | 5.4 | 0.227 | 0.003 | 10.8 | 5 | 57 |
| BSMMa | 40+ | 50 | 70 | 42 | 5.2 | 0.218 | 0.003 | 10.4 | 5 | 31 |

VRSCh=Chaukia VHTT=Terahrasiya BSMMu= Masharu BSMMa=Mamalkha the dimensionality of multivariate data sets. An example is the six cancer risk variables that were used to derive cancer risk in this study. Since many of the cancer risk variables are positively or negatively correlated, some of the variables essentially contain the same information. PCA helps finding a new orthogonal coordinate system of uncorrelated variables to represent the original cancer risks data. Each coordinate direction (principal vector) is articulated as a linear combination of the original variables. The first principal vector is in the direction of greatest variance in the original data set. The eigenvalues associated with each direction are a measure of the variance accounted for by that direction. Each succeeding principal vector is orthogonal to the preceding vectors and is in the direction of the greatest variance not accounted for by the previous vectors. PCA also provides an opportunity to reduce the dimensionality of the data by ignoring the vectors associated with small eigenvalues that account for the least amount of variance. To execute PCA analysis, the data were standardized using the JMP statistical package for zero mean. Thereafter, unit variance and the variance-covariance matrix were calculated (Table 5).

According to the derived covariance matrix, a very high positive significant correlation between Age-mid and weight and IR was found (Table 5). The correlation suggests that with an increase in age-mid the weight and the IR will increase significantly. Furthermore, a very high positive correlation between weight and IR was also derived. However, a strong negative correlation between weight and CDI was observed (Table 5). Additionally, as was expected, a very strong positive correlation between As in water and TD and CDI was observed, as TD and CDI directly depend on the As concentration in the sources. Other variables didn't show any significant correlation. The principal components on covariance have been represented in Table 6.

The eigenvalues in the first two components were found to be greater than one. Additionally, the first two principal components explain about 90% of the variances (Table 6). The first PC was essentially age-mid; it explains about 50% of the variance. The second PC was primarily weight (kg); it cumulatively explains 90% of the variance. The first PC contrasts CDI with other constituents of the component and the second PC contrasts age-mid and weight with the other constituents of the component (Table 7). A scree-plot was derived to confirm the number of PC; the bend that appears on the scree-plot suggests that the variance will fundamentally be explained by the two PC.

The first PC of cancer risk was marked by significant loadings of age-mid, weight, IR, and CDI. High loadings of the four constituents and a strong positive correlation between age-mid and weight and IR (Table 5) indicate mid-age increase in weight and IR. The second PC of cancer risk was marked by significant loadings of As in water, TD, and CDI. High loadings of the three constituents and a strong positive correlation between As in water and TD and CDI (Table 5) indicate the concentration of As increase in TD and CDI.

Health interviews and examinations yielded evidence and reports of diarrhea, gastric problems, body itching, skin pigmentation, hardening of sole, and other diseases. In Chaukia (Vaishali), out of the total surveyed population (n=281), about 0.35% of the population were found suffering from diarrhea; 3.9%

**Table 5. Covariance matrix**

| | Age-Mid | Weight (kg) | As in Water (µg/L) | IR(L) | TD (mg/day) | CDI (mg/kg-day) |
|---|---|---|---|---|---|---|
| Age-Mid | 1.00000 | 0.64444 | -0.00000 | 0.72197 | 0.27509 | -0.33142 |
| Weight (kg) | 0.64444 | 1.00000 | -0.00000 | 0.97244 | 0.37681 | -0.54495 |
| As in Water (µg/L) | -0.00000 | -0.00000 | 1.00000 | 0.08418 | 0.87576 | 0.75712 |
| IR(L) | 0.72197 | 0.97244 | 0.08418 | 1.00000 | 0.47699 | -0.48076 |
| TD(mg/day) | 0.27509 | 0.37681 | 0.87576 | 0.47699 | 1.00000 | 0.36430 |
| CDI(mg/kg-day) | -0.33142 | -0.54495 | 0.75712 | -0.48076 | 0.36430 | 1.00000 |

**Table 6. Principal Components**

| Particulars | Eigenvalue |
|---|---|
| PC-1 | 3.0165 |
| PC-2 | 2.3573 |
| Percent | 90 |
| Prob>ChiSq | <.0001* |

**Table 7. Loading Matrix of PC of variables used for cancer risk assessment**

| Constituents | Prin1 | Prin2 |
|---|---|---|
| Age-Mid | 0.80634 | -0.00593 |
| Weight (kg) | 0.95866 | -0.03891 |
| As in Water (µg/L) | 0.03029 | 0.99716 |
| IR(L) | 0.98361 | 0.05559 |
| TD (mg/day) | 0.43821 | 0.86158 |
| CDI (mg/kg-day) | -0.53557 | 0.78486 |

of the population had gastric problems; 2.1% of the population had body itching; 1.8% of the population had skin pigmentation; 0.7% of the population had hardening of sole; and 1.8% of the surveyed population were suffering from other diseases (jaundice, typhoid, tuberculosis, and asthma). In Terahrasiya (n=283), 0.7%, 4.2%, 2.5%, 2.5%, 1.4%, and 1.8% of the population were suffering from diarrhea, gastric problems, body itching, skin pigmentation, hardening of sole, and other diseases (jaundice, dysentery, tuberculosis, piles, and heart problem), respectively (Table 8).

In Masharu (Bhagalpur), out of the total surveyed population (n=159), 0.6%, 6.3%, 3.1%, 3.1%, and 1.9% of the population were suffering from diarrhea, gastric problems, body itching, skin pigmentation, hardening of sole, and other diseases (tuberculosis, body-ache, and black tongue), respectively. However, in Mamalkha (Bhagalpur) (n=149), 5.4%, 3.4%, .67%, and 1.34% of people were suffering from gastric problems, body itching, skin pigmentation, and other diseases (heart problems and hysteria), respectively (Table 8).

Relative Risks (RR) and Odds Ratio (OR) analysis were performed to see the relative risks of different diseases among the surveyed population in the studied villages. The RR value for the diarrhea in Terahrasiya was greater than one (RR=2), which indicates that the Terahrasiya village is more likely to get diarrhea than the Chaukia village. Similarly, in the case of gastric problems, body itching, skin pigmentation, and hardening of soles, the ORs were more than 1 (1.1, 1.2, 1.4, and 2, respectively). Subsequently, the Terahrasiya

**Table 8. Health Survey Results in Vaishali and Bhagalpur Districts of Bihar, India**

| Sl. No. | District | Block | Panchayat | Village | Drh | Gas | BdI | PnB | HdS | Oth | Total Population Surveyed |
|---|---|---|---|---|---|---|---|---|---|---|---|
| 1 | Vaishali | Raghopur | Saraipur | Chowkia | 1 | 11 | 6 | 5 | 2 | 5 | 281 |
| 2 | Vaishali | Hajipur | Terahrasia | Terahrasia | 2 | 12 | 7 | 7 | 4 | 5 | 283 |
| 3 | Bhagalpur | Sabour | Mamalkha | Masharu | 1 | 10 | 5 | 5 | 2 | 3 | 159 |
| 4 | Bhagalpur | Sabour | Mamalkha | Mamalkha | 0 | 8 | 5 | 1 | 0 | 2 | 149 |

Drh= Diarrhea Gas= Gastric BdI= Body Itching PnB= Pigmentation on body HdS= Hardening of Sole Oth= Others

**Table 9. Relative health risks and odds ratios in Vaishali**

| | N = 283 | N = 281 | | | | |
|---|---|---|---|---|---|---|
| | VHTT | VRSCh | RR | 95% CI | OR | 95% CI |
| Diarrhea | 2 | 1 | 2 | (0.181098-21.77645) | 0.5 | (0.04524-5.56542) |
| Gastric Problem | 12 | 11 | 1.1 | (0.486075-2.413869) | 0.92 | (0.399066-2.121235) |
| Body Itching | 7 | 6 | 1.2 | 0.394238-3.403882) | 0.86 | (0.285459-2.592482) |
| Pigmentation | 7 | 5 | 1.4 | (0.446496-4.327913) | 0.714 | (0.223985-2.277844) |
| Hardening of Sole | 4 | 2 | 2 | (0.366675-10.7552) | 0.5 | (0.090843-2.751989) |
| Others | 5 | 5 | 1 | (0.290648-3.392134) | 1.007 | (0.288371-3.518195) |
| Pigmentation Prevalence | 2.47% | 1.78% | | | | |

VRSCh=Chaukia VHTT=Terahrasiya

village was more likely to get these diseases than the Chaukia village (Table 9).

The ORs for all the diseases except 'others' were found to be less than one (Table 9) and the 95%CI includes one, hence the ORs were not statistically significant in Terahrasiya and Chaukia. In the case of other diseases, the OR was found to be about one (OR=1.007), which shows that the two villages were equally likely to get 'other' diseases. However, the 95%CI includes one; therefore, it was not statistically significant (Table 9). The skin pigmentation prevalence was found to be 1.4 fold greater in the Terahrasiya village than the Chaukia village in the Vaishali district.

In the Bhagalpur district, the RR values for diarrhea and hardening of sole were found to be '0', revealing that Mamalkha was less likely to get diarrhea and hardening of sole than the Masharu. In the case of incidence of gastric problems, skin pigmentation, and other diseases, the RR values were found to be less than one (0.9, 0.2, and 0.7, respectively), revealing that the village of Mamalkha was less likely to get gastric problems, skin pigmentation, and 'other' diseases (Table 10).

The ORs for diarrhea and hardening of sole diseases in both the villages of the Bhagalpur district were '0'. However, in the case of gastric problems (OR=1.183), skin pigmentation (OR=4.805), and 'other' diseases (OR=1.413), the ORs were more than one, which indicates that the village of Mamalkha was more likely to get these diseases than the village of Masharu. Since the 95% CI includes one in all of the cases, it was not statistically significant (Table 10). In Bhagalpur, the only health difference observed between the two villages was a five-fold greater prevalence of skin pigmentation in the surveyed communities of Masharu than the communities of Mamalkha.

When the RR and OR were consolidated at district level, it was evident that the Bhagalpur district was more likely to get gastric problems and body itching problems than the Vaishali district (Table 11).

**Table 10. Relative health risks and odds ratios in Bhagalpur**

| | N = 149 | N = 159 | | | | |
|---|---|---|---|---|---|---|
| | **BSMMa** | **BSMMu** | **RR** | **95% CI** | **OR** | **95% CI** |
| Diarrhea | 0 | 1 | 0 | 0 | 0 | 0-0 |
| Gastric Problem | 8 | 10 | 0.9 | (0.346241-2.104858) | 1.183 | (0.453922-3.082507) |
| Body Itching | 5 | 5 | 1.1 | (0.315271-3.611911) | 0.265 | (0.265171-3.297289) |
| Pigmentation | 1 | 5 | 0.2 | (0.025277-1.805596) | 4.805 | (0.554795-41.61879) |
| Hardening of Sole | 0 | 2 | 0 | 0 | 0 | (0-0) |
| Others | 2 | 3 | 0.7 | (0.12055-4.198283) | 1.413 | (0.232869-8.579404) |
| Pigmentation Prevalence | 0.67% | 3.14% | | | | |

BSMMu= Masharu BSMMa=Mamalkha

**Table 11. Relative health risks and odds ratios in Vaishali and Bhagalpur districts**

| | N = 308 | N = 564 | | | | |
|---|---|---|---|---|---|---|
| | **Bhagalpur** | **Vaishali** | **RR** | **95% CI** | **OR** | **95% CI** |
| Diarrhea | 1 | 3 | 0.6 | (0.063764-5.843029) | 1.64 | (0.17004-15.8502) |
| Gastric Problem | 18 | 23 | 1.4 | (0.785742-2.613762) | 0.685 | (0.363677-1.290019) |
| Body Itching | 10 | 13 | 1.4 | (0.624981-3.174706) | 0.703 | (0.304635-1.622693) |
| Pigmentation | 6 | 12 | 0.9 | (0.34705-2.415487) | 1.094 | (0.406592-2.944673) |
| Hardening of Sole | 2 | 6 | 0.6 | (0.123944-3.005998) | 1.645 | (0.330045-8.200574) |
| Others | 5 | 10 | 0.9 | (0.315786-2.654628) | 1.094 | (0.370502-3.229501) |
| Pigmentation Prevalence | 4.03% | 7.55% | | | | |

## CONCLUSION

The concentrations of As in drinking water exceeded the WHO standard of 10μg/L in both the Vaishali and the Bhagalpur districts. Only in Bhagalpur did the concentrations of As exceed the FAO standard of 100μg/L for irrigation water. Potable groundwater was available in greater shallow depths in Vaishali than in Bhagalpur. Both CR and HI exceeded the minimum and the maximum acceptable range in the study areas, increasing cancer susceptibility in exposed populations. Only two principal components were adequate to explain about 90% of the variance in cancer risk assessment. Age-mid and weight were found to be the significant variables to explain the cancer risk. The RR of gastric problem and body itching was greater in Bhagalpur than Vaishali; however, among the ‘other’ diseases category, Vaishali had a greater RR than Bhagalpur. The prevalence of skin pigmentation was found to be about two-fold in Vaishali than that of Bhagalpur. The pH values and the As concentrations in both districts were significantly different from each other. The authors of this study suggest further screening of drinking water sources for As contamination. Rigorous research on the geochemistry of the As-contaminated aquifers is required to reveal the mechanism of As-mobility in the areas. Additionally, systematic clinical study in the As exposed populations should be given priority, seeing that since 2002 (after Chakraborti *et al.,* 2003) no such study has been reported. More importantly, socio-economic studies should be given importance to understand the modifying factors for As exposure among the As exposed communities in the studied districts and other As affected areas in the state.

## REFERENCES


ATSDR/DTEM, (2006). Agency for Toxic Substances and Disease Registry, Division of Toxicology and Environmental Medicine .ToxFAQs: CABS™/Chemical Agent Briefing Sheet Arsenic.

Astolfi, E., Maccagno, A., Fernandez, J. C. G., Vaccara, R. and Stimola, R. (1981). Relation between arsenic in drinking water and skin cancer. Biological Trace Element Research, **3**, 133-143.

Bloom, M. S., Fitzgerald, E. F., Kim, K., Neamtiu, I. and Gurzau, E. S. (2010). Spontaneous pregnancy loss in humans and exposure to arsenic in drinking water. International Journal of Hygiene and Environmental Health, **213**, 401-413.

Bundschuh, J., Litter, M. I. and Bhattacharya, P. (2010). Targeting arsenic-safe aquifers for drinking water supplies. Environmental Geochem Health, **32**, 307–315.

Chakraborti, D., Mukherjee, S. C., Pati, S., Sengupta, M. K., Rahman, M. M. and Chowdhury, U. K. (2003). Arsenic groundwater contamination in middle Ganga plain, Bihar, India: A future danger. Environ Health Perspective, **111**, 1194-201.

Chakraborty, A. K. and Saha, K. C. (1987). Arsenical dermatosis from tube well water in West Bengal. Indian J. Med. Res., **85**, 326–334.

Ghosh, A. K., Singh, S. K., Bose, N. and Singh, K. (2009). Arsenic hot spots detected in the state of Bihar (India) a serious health hazards for estimated human population of 5.5 Lakh. Assessment of Ground Water Resources and Management, edited by AL. Ramanathan, Prosun Bhattacharya, A. K. Keshari, jochen Bundschuh, D. Chandrashekharam, S. K. Singh, Published by I. K. International Publishing House Pvt. Ltd., New Delhi, ISBN: 978-81-906757-2-7, 62-70.

Ghosh, A. K., Singh, Shatrunjay K., Bose, N., Singh, Sushant K., Singh, A., Chaudhary, S. Mishra, R., Roy, N. P. and Upadhyaya, A. (2007). Study of arsenic contamination in ground water of Bihar (India) along the River Ganges. International workshop on arsenic sourcing and mobilization in Holocene Deltas. Department of Science and Technology, Government of India, on 12-13 December, 83-87.

González, J. A. C., Razo, L. M. D.,Vargas, G. G., Salazar, F. S. and Pena, J. E. (2007). Inorganic arsenic exposure and type 2 diabetes mellitus in Mexico. Environmental Research, **104 (3)**, 383–389.

Guha Mazumder, D. N., Haque, R., Ghosh, N., De, B. K., Santra, A., Chakraborty, D. and Smith, A. H. (1998). Arsenic levels in drinking water and the prevalence of skin lesions in West Bengal, India. International Journal of Epidemiology, **27**, 871-877.

Hossain, M. A., Mukherjee, A., Sengupta, M. K., Ahmad, S., Das, B., Nayak, B., Pal, A.,Rahman, M. M. and Chakraborti, D. (2006). Million dollar arsenic removal plants in West Bengal, India: Useful or Not? Water Quality Resource Journal Canada, **41 (2)**, 216-225.

Islam, L. N., Nabi, A. H. M. N. and Rahman, M. M. (2007). Association of respiratory complications and elevated serum immunoglobulin with drinking water arsenic toxicity in human. J Environ Sci Health, **42**, 1807–14.

Maden, N., Singh, A., Smith, L. S., Maharjan, M. and Shrestha, S. (2011). Factors associated with Arsenicosis and arsenic exposure status in Nepal: Implications from community based study. Journal of Community Health, **36 (1)**, 76-82.

Nickson, R., Sengupta, C., Mitra, P., Dave, S. N., Banerjee, A. K., Bhattacharya, A., Basu, S., Kakoti, N., Moorthy, N. S., Wasuja, M., Kumar, M., Mishra, D.S., Ghosh, A., Vaish, D. P., Srivastava, A. K., Tripathi, R. M., Singh, S. N., Prasad, R., Bhattacharya, S. and Deverill, P. (2007). Current knowledge on the distribution of arsenic in groundwater in five states of India. Journal of Environmental Science and Health Part A, Toxic/Hazardous Substances and Environmental Engineering, **42 (12)**, 1707-1718.

Opar, A., Pfaff, A., Seddique, A. A., Ahmed, K. M., Graziano, J. H. and Geen, A. V. (2007). Responses of 6500 households to arsenic mitigation in Araihazar, Bangladesh. Health and Place, **13**, 164–172.

Phan, K., Sthiannopkao, S., Kim, K. W., Wong, M. H., Sao, V., Hashim, J. H., Mohamed, Yasin M. S. and Aljunid, S. M. (2010). Health risk assessment of inorganic arsenic intake of Cambodia residents through groundwater drinking pathway. Water Research, **44 (19)**, 5777-5788.

Rahman, M. M., Naidu, R. and Bhattacharya, P. (2009). Arsenic contamination in groundwater in the Southeast Asia region. Environmental Geochemistry and Health, **31**, 9-21.

Rahman, M. M., Ng, J. C. and Naidu, R. (2009). Chronic exposure of arsenic via drinking water and its adverse health impacts on humans. Environmental Geochemistry and Health, **31**, 189-200.

Ravenscroft, P. (2007). Predicting the global distribution of arsenic pollution in groundwater. In Royal Geographical Society annual international conference, Department of Geography, Cambridge University< http://phys4. harvard. edu/~ wilson/arsenic/conferences/2007_RGS (Vol. 1).

Ravenscroft, P., Brammer, H. and Richards, K. S. (2009). Arsenic pollution: a global synthesis. Wiley-Blackwell, U.K.

Saha, D. (2009). Arsenic groundwater contamination in parts of middle Ganga plain, Bihar. Current Science, **97 (6)**, 753-755.

Singh, S. K. (2011). Arsenic contamination in water, soil, and food materials in Bihar. Lambert Academic Publishing, Germany.

Singh, S. K. and Ghosh, A. K. (2012). Health risk assessment due to groundwater arsenic contamination: Children are at high risk. Human and Ecological Risk Assessment, An International Journal, **18 (4)**, 751-766.

SOES, (2012). School of Environmental Studies, Groundwater arsenic contamination in middle Ganga plain, Bihar, India: A Future Danger? School of Environmental Science, Jadavpur University, Kolkata, India.

Wasserman, G. A., Liu, X., Parvez, F., Ahsan, H., Litvak, P.F., Geen, A. V., Slavkovich, V., LoIacono, N. J., Cheng, Z., Hussain, I., Momotaj, H. and Graziano, J. H. (2004). Water arsenic exposure and children’s intellectual function in Araihazar, Bangladesh. Environmental Health Perspectives, **112 (3)**, 1329-1333.