Journal of Hydrology 518 (2014) 363–372

Contents lists available at ScienceDirect

Journal of Hydrology

journal homepage: www.elsevier.com/locate/jhydrol

Status of groundwater arsenic contamination in all 17 blocks of Nadia district in the state of West Bengal, India: A 23-year study report

Mohammad Mahmudur Rahman [a,b], Debapriya Mondal [a,c], Bhaskar Das [a,d], Mrinal Kumar Sengupta [a], Sad Ahamed [a], M. Amir Hossain [a], Alok Chandra Samal [b], Kshitish Chandra Saha [e], Subhash Chandra Mukherjee [f], Rathindra Nath Dutta [g], Dipankar Chakraborti [a,*]

[a] School of Environmental Studies (SOES), Jadavpur University, Kolkata 700 032, India
[b] Centre for Environmental Risk Assessment and Remediation (CERAR), University of South Australia, Mawson Lakes Campus, Mawson Lakes, South Australia, SA 5095, Australia
[c] School of Environment & Life Sciences, University of Salford, Salford, United Kingdom
[d] School of Mechanical and Building Sciences, VIT University, Vellore 632 014, Tamil Nadu, India
[e] Department of Dermatology, School of Tropical Medicine, Kolkata, India
[f] Departments of Neurology, Medical College, Kolkata, India
[g] Department of Dermatology, Institute of Post Graduate Medical Education and Research, SSKM Hospital, Kolkata, India

ARTICLE INFO

Article history:
Available online 5 November 2013

Keywords:
Groundwater
Arsenic
Nadia district
Biological samples
Arsenical dermatitis
Arsenical neuropathy

SUMMARY

A comprehensive study was conducted in Nadia, one of the nine arsenic (As) affected districts in West Bengal, India to determine the extent and severity of groundwater As contamination and its health effects in particular, dermatological effects and neurological complications. We collected 28,947 hand tube-well water samples from all 17 blocks of Nadia district and analyzed for As by the flow injection-hydride generation atomic absorption spectrometer (FI-HG-AAS). We found 51.4% and 17.3% of the tube-wells had As above 10 and 50 μg/L, respectively and observed that groundwater of all 17 blocks contained As above 50 μg/L with maximum observed level of 3200 μg/L. We estimated that about 2.1 million and 0.6 million people could be drinking As contaminated water above 10 and 50 μg/L, respectively, while 0.048 million could be at risk of drinking As-contaminated water above 300 μg/L, the concentration predicted to cause overt arsenical skin lesions. We screened 15,153 villagers from 50 villages and registered 1077 with arsenical skin lesions resulting in a prevalence rate of 7.1%. Analyzing 2671 biological samples (hair, nail and urine), from people with and without arsenical skin symptoms we found 95% of the samples had As above the normal level, indicating many people in Nadia district are sub-clinically affected. Arsenical neuropathy was observed in 33% of 255 arsenicosis patients with 28.2% prevalence for predominant sensory neuropathy and 4.7% for sensorimotor. As groundwater is still the main source of drinking water, targeting low-As aquifers and switching tube-well from unsafe to nearby safe sources are two visible options to obtain safe drinking water.

1. Introduction

Since 1988, our team, at School of Environmental Studies (SOES) dedicated to research on As contamination of groundwater, have reported occurrences of high As concentrations, not only in West Bengal (Chakraborti et al., 2009; Rahman et al., 2001; Chowdhury et al., 2001; Das et al., 1995) but also in other areas (Uttar Pradesh, Bihar, Jharkhand, West Bengal, Assam) of the Ganga–Brahmaputra (GB) plain and most of the areas of Padma–Meghna–Brahmaputra (PMB) plain of Bangladesh (Chakraborti et al., 2003, 2004, 2010). The GMB plain comprises an area of 569,749 km^2, with a population of over 500 million. We also reported that the groundwater in Manipur valley of Manipur state, one of the seven North Eastern Hill states in India is also As contaminated (Chakraborti et al., 2008). Despite over two decades of research in West Bengal, we identify additional affected villages with every new survey.

Based on our study of all 19 districts of West Bengal, analyzing 140,150 hand tube-well water samples we identified 48.1% tube-wells had As concentrations above 10 μg/L (the WHO and the Bureau of Indian Standard acceptable limit) and 23.8% above 50 μg/L (the standard value of As in many developing countries) (Chakraborti et al., 2009). Hence, we have classified them into three categories: Highly affected, mildly affected, and As safe. Nine districts (Malda, Murshidabad, Nadia, North 24 Parganas, South 24 Parganas, Bardhaman, Howrah, Hoogly and Kolkata), where concentrations more than 300 μg/L of As was found in tube-wells are categorized as highly affected (135,555 water samples

* Corresponding author. Fax: +91 33 24141 6266.
E-mail address: dcsoesju@gmail.com (D. Chakraborti).

0022-1694/$ - see front matter
http://dx.doi.org/10.1016/j.jhydrol.2013.10.037

analyzed from these nine districts). The five districts (Koch Bihar, Jalpaiguri, Darjeeling, North Dinajpur and South Dinajpur) where (2923 samples analyzed) As concentrations were between 10 and 50 μg/L, are called mildly affected. The rest five districts (Bankura, Birbhum, Purulia, Medinipur East and Medinipur West), where As concentrations (1672 samples analyzed) were below 10 μg/L are termed as unaffected or As safe. Out of these highly affected nine districts of West Bengal, five (South 24 Parganas, North 24 Parganas, Nadia, Murshidabad, and Malda) are most widely affected, and from our preliminary survey of these five districts, we identified patients with arsenical skin lesions from 371 villages in 40 blocks (total blocks surveyed for arsenicosis patients 55). We have already reported detail findings of As contamination and health effects from two highly As-contaminated districts, Murshidabad (Mukherjee et al., 2005; Rahman et al., 2005a, 2005b, 2005c, 2005d) and North 24 Parganas (Rahman et al., 2003).

In this article, we report our findings on groundwater As contamination from Nadia district. Previously, in 1991, we detected As contamination only in 6 villages of 4 affected blocks (Karimpur I, Karimpur II, Nabadwip and Chakdaha) of Nadia district (SOES Report, 1991). In 1996, based on the analysis of 706 water samples, we reported that 8 out of 17 blocks of Nadia district were As contaminated (Mandal et al., 1996) and during 2001 and 2002, we further circulated two reports (SOES Report, 2001, 2002) to the Government of West Bengal to take immediate action in Nadia district. Besides us, Public Health Engineering Department (PHED), Government of West Bengal, with the support of UNICEF analyzed 29,640 tube-wells by silver diethyldithiocarbamate (SDDC) method from all 17 affected blocks of Nadia district and reported that 26% of the samples had As greater than 50 μg/L and 41.2% of the samples had As between 10 and 50 μg/L (Nickson et al., 2007). Recently, Guha Mazumder et al. (2010) reported highest level of As concentration in drinking water to be 1362 μg/L based on a study conducted from 37 As-affected villages in all 17 blocks of Nadia district involving 10,469 subjects from 2297 households. The prevalence rate of arsenicosis was found to be 15.4% and chronic lung disease was found in 207 (12.8%) subjects while peripheral neuropathy was observed in 257 (15.9%) cases (Guha Mazumder et al., 2010).

Considering the extent of As contamination in Nadia district, we present herewith the up to date research, from all the 17 blocks of Nadia district, on: (i) As concentrations in hand tube-wells; (ii) estimation of the population drinking As-contaminated water at different concentration levels; (iii) relationship of As concentrations with Fe concentrations and depth of tube-wells; (iv) As concentrations in biomarkers; and (v) health effects to humans in particular to dermatological effects and neurological complications based on our surveys.

2. Materials and methods

2.1. Description of the study area

Nadia district is situated in the eastern bank of the river Bhagirathi. The geographical extent lies with latitude of 22°41′23″N and longitude of 72°51′24″E, which covers an area of about 3927 km^2. According to 2001 Census, it has a population of 4.6 million (2.4 million males and 2.2 million females). The district consists of 17 blocks, and each block has several gram panchayets (GP, cluster of villages), and each GP has several villages. Officially, there are 1250 inhabited villages/wards in Nadia district. In these 17 blocks, there are 10 municipalities and people living in municipalities have piped line public water supply schemes mostly using groundwater, whereas, people living in blocks mostly uses the hand tube-wells. Total population of 17 blocks is 3.8 million and that of 10 municipalities 0.8 million.

2.2. Sample collection and As analysis

Tube-well water samples were collected and analyzed between 1991 and 2013, with an objective to cover the whole area and representative population of Nadia district. We also collected biomarkers (hair, nail, urine and skin scales) from victims with arsenical skin lesions and from those living in As-affected villages, based on water analysis, but having no arsenical skin lesions. This study has been approved by the office of the Principal and Chairman; Institutional Ethics Committee (IEC), Medical College Kolkata, India and the Ethics committee, Jadavpur University, Kolkata. All subjects consented, for themselves and their young children, to medical evaluation and photography before providing biological samples.

The method of water and biomarker sample collections, the digestion procedures for hair, nail, and skin scale and methods of analysis are reported earlier (Chatterjee et al., 1995; Das et al., 1995; Samanta et al., 1999). Briefly, water samples were collected in prewashed with nitric acid: water (1:1) polyethylene bottles and one drop of nitric acid: water (1:1) was added for 10 ml of collected sample as preservative. Spot urine samples were also collected in pre-washed polyethylene bottles and immediately after collection, the samples were stored in salt ice mixture and later on return to the laboratory kept at −20 °C until analyzed. Hair and nail samples were cut using stainless steel blade and stored in zip lock bag until analyzed. Skin scales samples were only collected from the people suffering from hyperkeratosis and keratosis by stainless steel blade and stored in plastic zip lock bag until analyzed.

Water, hair, nail, skin scale samples were analyzed after digestion for As by the flow injection-hydride generation atomic absorption spectrometry (FI-HG-AAS) method. A detail of the instrumentation has been reported previously (Chatterjee et al., 1995; Das et al., 1995; Samanta et al., 1999). For urine samples, only inorganic As and its metabolites [(As(III), As(V), MMA(V) and DMA(V)] were measured with no chemical treatment. Under the experimental condition of FI-HG-AAS, arsenobetaine and arsenocholine do not produce a signal (Chatterjee et al., 1995). Hair, nail and skin scale samples were analyzed for total As after digestion using a simple digestion method (Samanta et al., 1999). Briefly, 0.02–0.05 g of sample was taken in a 25-ml beaker and then 4 ml concentrated HNO_3 and 2 ml (30% v/v) H_2O_2 were added. The beaker was placed on a hot plate at 80–90 °C. Heating was continued with time to time addition of a known volume of concentrated HNO_3 until the color turned from deep brown to pale yellow. On reaching a final volume of about 1 ml, heating was discontinued. After cooling, 2–3 ml of water was added, and the solution was filtered through a Millipore filter and finally made up to 5 ml and then analyzed.

About 5% water samples, randomly selected from the samples collected for As analysis, were also analyzed for iron (Fe) concentrations by spectrophotometry (Shimadzu double beam spectrophotometer Model UV-150-02). For a very small subset of samples ($n = 35$, collected from only two blocks, Chakdah and Haringhata II) we were able to perform multi-element analysis using ICP-MS (Agilent 7500ce) analyzing for Sodium (Na), Calcium (Ca), Potassium (K), Magnesium (Mg), Manganese (Mn), Copper (Cu), Zinc (Zn), Co (Cobalt), Chromium (Cr), Nickel (Ni), Cadmium (Cd), Lead (Pb) along with As and Fe.

2.3. Probable estimation of the population drinking As-contaminated water at different concentration levels

To estimate the number of people who could be probably drinking As-contaminated water at different concentration levels we used a systematic approach, described previously in details (Chakraborti et al., 2009; Rahman et al., 2003, 2005a). Briefly,