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# Arsenic mobilization in the aquifers of three physiographic settings of West Bengal, India: Understanding geogenic and anthropogenic influences

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## HIGHLIGHTS

- Geomorphic and landform feature controls the distribution of arsenic in groundwater.
- Local land use is a potential source of dissolved organic carbon in groundwater.
- Anthropogenic activity controls the release of arsenic in groundwater.
- Multiple geochemical processes are responsible for arsenic release in groundwater.

## ARTICLE INFO

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## ABSTRACT

A comparative hydrogeochemical study was carried out in West Bengal, India covering three physiographic regions, Debagram and Chakdaha located in the Bhagirathi-Hooghly alluvial plain and Baruipur in the delta front, to demonstrate the control of geogenic and anthropogenic influences on groundwater arsenic (As) mobilization. Groundwater samples ($n = 90$) from tube wells were analyzed for different physico-chemical parameters. The low redox potential (Eh = −185 to −86 mV) and dominant As(III) and Fe(II) concentrations are indicative of anoxic nature of the aquifer. The shallow (<100 m) and deeper (>100 m) aquifers of Bhagirathi-Hooghly alluvial plains as well as shallow aquifers of delta front are characterized by $Ca^{2+}$—$HCO_3^-$ type water, whereas $Na^+$ and $Cl^-$ enrichment is found in the deeper aquifer of delta front. The equilibrium of groundwater with respect to carbonate minerals and their precipitation/dissolution seems to be controlling the overall groundwater chemistry. The low $SO_4^{2-}$ and high DOC, $PO_4^{3-}$ and $HCO_3^-$ concentrations in groundwater signify ongoing microbial mediated redox processes favoring As mobilization in the aquifer. The As release is influenced by both geogenic (i.e. geomorphology) and anthropogenic (i.e. unsewered sanitation) processes. Multiple geochemical processes, e.g., Fe-oxyhydroxides reduction and carbonate dissolution, are responsible for high As occurrence in groundwaters.



## 1. Introduction

Arsenic (As) is a naturally occurring carcinogenic metalloid. The distribution of As is widespread throughout the world, especially in Southeast Asia [1–10]. Among the As-contaminated regions of Southeast Asia, Bengal Delta Plain (BDP) has been considered as the worst affected area with respect to large spatial coverage and

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exposure on human health [11,12]. In BDP, As in groundwater usually exceeds WHO recommended guideline value ($10\,\mu g\,L^{-1}$) as well as Indian National drinking water standard ($50\,\mu g\,L^{-1}$). Currently, scientific community and policy makers are working toward finding long-term sustainable solutions for mitigation.

The occurrences of As in groundwater in West Bengal have been widely reported from the districts of Maldah, Murshidabad, Nadia, North & South 24 Parganas, Burdwan, Howrah and Hooghly, and more recent observations from Kolkata, Koch Bihar, North & South Dinajpur districts [13]. The affected districts include one hundred and eleven blocks and more than three thousand villages [14]. The high As groundwater in West Bengal stretches ~400 km (Maldah district in the north to South 24 Parganas district in the south) and was typically characterized by heterogeneous and patchy distribution of hot spots, interspersed with low/safe As-areas [15,16].

In West Bengal, previous studies have demonstrated the role of depositional behavior of aquifer sediments on the geochemical processes leading to the release of high As concentrations in the groundwater [8,17]. The processes of As mobilization is mainly governed by the complex biogeochemical interactions regulated by a number of physical, chemical and biological factors, such as sedimentological settings, sedimentation history, groundwater abstraction, adsorption and desorption behavior of sediments, dissolved organic carbon and microbes [2,3,9,18–28]. Such biogeochemical interactions can further be complicated by the local anthropogenic activities, such as unsewered sanitations, domestic wastes and ponds [30–32]. However, only a few studies [33–35] have attempted to demonstrate the controlling behavior of regional scale lithological and hydrological variations on As release processes by comparing As-contamination scenarios in different physiographic settings of the delta plain. The effect of different local factors including land use pattern toward As release to groundwater have not been demonstrated in details. Thus there are considerable knowledge-gaps to our scientific understanding of the cumulative controlling mechanism of geogenic and anthropogenic factors in release of As into groundwater of the deltaic basin.

The objective of this study is to elucidate the mechanism of As release into groundwater of three physiographic settings of deltaic West Bengal, India. The study areas are Debagram and Chakdaha located within the Bhagirathi-Hooghly alluvial plain and Baruipur located within the Delta front (head of Bay of Bengal). We examined the salient hydrogeochemical features of groundwater in drinking water wells. The role of geomorphology and land use including the influence of anthropogenic activities (e.g. sanitation, pond, domestic wastes, etc.) on As release processes were also examined.

## 2. Study areas

### 2.1. Location and climate

The study areas, Debagram and Chakdaha are situated in the northern and southern part of the Nadia district, respectively, and Baruipur is situated in the South 24 Parganas district of West Bengal, India (Fig. 1). The study areas have tropical climate with annual rainfall ranges between 1295 and 3945 mm. The temperature ranges between 16 and 42 °C and average relative humidity is >65%. The study areas have three distinct seasons: summer (February to May), monsoon (June to September) and winter (October to January). The bulk of the rainfall (82%) takes place during monsoon periods due to moisture-laden winds from the Bay of Bengal. The local conventional rainfall contributes during pre-monsoonal (16%) and winter (2%) periods.

### 2.2. Physiography and geomorphology

The state of West Bengal can be divided into six macro-physiographic regions: (i) laterite upland and barind tract; (ii) upper delta plain (UDP); (iii) valley margin fan; (iv) marginal plain; (v) lower delta plain (LDP), and (vi) delta front [36]. The upper- and lower-delta plain is surrounded by the river Ganges-Padma, river Bhagirathi-Hooghly, and the Bay of Bengal in the east, west and south, respectively.

The major geomorphic units of the delta plain can be divided into two distinct divisions: (i) the UDP of meander belts of river Bhagirathi-Hooghly in the north, and (ii) the LDP and the delta front with several tidal creeks in the south. A series of meander

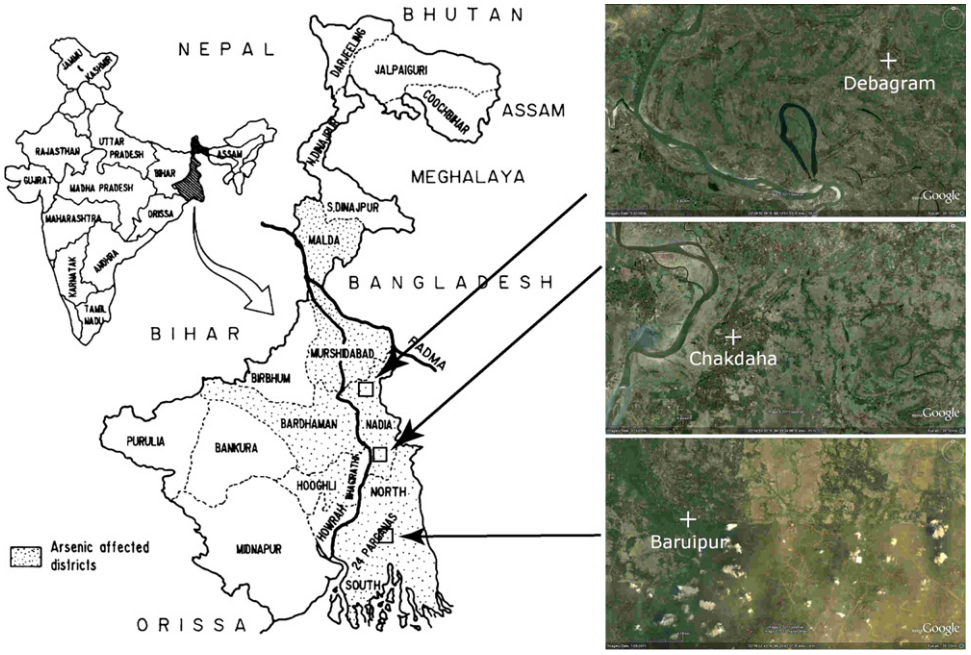


**Fig. 1.** Map of the study areas (1: Debagram; 2: Chakdaha; 3: Baruipur) in West Bengal, India showing arsenic affected districts. Map also shows Google Earth imagery of the areas surrounding three study areas. The central study area locations were marked with a cross in each of the Google Earth imagery. The GPS coordinates (WGS 84) of the sampled groundwater have been given in Table S1.

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