Journal of Hydrology 378 (2009) 105–118

Contents lists available at ScienceDirect

Journal of Hydrology

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

Geological controls on groundwater chemistry and arsenic mobilization: Hydrogeochemical study along an E–W transect in the Meghna basin, Bangladesh

M. Aziz Hasan [a,b], Prosun Bhattacharya [a,*], Ondra Sracek [d,e], Kazi Matin Ahmed [b], Mattias von Brömssen [a,c], Gunnar Jacks [a]

[a] KTH-International Groundwater Arsenic Research Group, Department of Land and Water Resources Engineering, Royal Institute of Technology, SE-100 44 Stockholm, Sweden
[b] Department of Geology, University of Dhaka, Dhaka 1000, Bangladesh
[c] Ramböll Sweden AB, Box 4205, SE-102 65 Stockholm, Sweden
[d] Ochrana podzemních vod (OPV s.r.o., Protection of ground water Ltd.), Bělohorská 31, 169 00 Praha 6, Czech Republic
[e] Department of Geology, Faculty of Science, Palacký University, 17. Listopad 12, 771 46 Olomouc, Czech Republic

ARTICLE INFO

Article history:
Received 19 February 2009
Received in revised form 18 August 2009
Accepted 4 September 2009

This manuscript was handled by L. Charlet, Editor-in-Chief, with the assistance of Bernhard Wehrli, Associate Editor

Keywords:
Groundwater chemistry
Holocene and Pliocene aquifers
Redox conditions
Transect
Meghna basin
Bangladesh

SUMMARY

Hydrogeochemical investigations along an E–W transect in the middle Meghna basin show groundwater chemistry and redox condition vary considerably with the change in geology. Groundwater in the Holocene shallow (<150 m bgl) alluvial aquifer in western part of the transect is affected by high arsenic concentration (As > 10 μg/l) and salinity. On the other hand, groundwater from the Pliocene Dupi Tila sandy aquifer in the eastern part is fresh and low in As (<10 μg/l). The Holocene shallow aquifers are high in dissolved As, HCO_3^-, Fe and dissolved organic carbon (DOC), but generally low in SO_4^{2-} and NO_3^-. High HCO_3^- concentrations (250–716 mg/l) together with high DOC concentrations (1.4–21.7 mg/l) in these aquifers reflect active sources of degradable natural organic matter that drives the biogeochemical process. There is generally de-coupling of As from other redox-sensitive elements. In contrast, the Pliocene aquifers are low in As, HCO_3^- and DOC. Molar ratio of HCO_3^-/H_4SiO_4 suggests that silicate weathering is dominant in the deeper Holocene aquifers and in the Pliocene aquifers. Molar ratios of Cl^-/HCO_3^- and Na^+/Cl^- suggest mixing of relict seawater with the fresh water as the origin of groundwater salinity. Speciation calculations show that saturation indices for siderite and rhodochrosite vary significantly between the Holocene and Pliocene aquifers. Stable isotopes (δ^2H and $\delta^{18}O$) in groundwater indicate rapid infiltration without significant effects of evaporation. The isotopic data also indicates groundwater recharge from monsoonal precipitation with some impact of altitude effect at the base of the Tripura Hills in the east. The results of the study clearly indicate geological control (i.e. change in lithofacies) on groundwater chemistry and distribution of redox-sensitive elements such as As along the transect.

Introduction

The Bengal Basin, comprising Bangladesh and the eastern part of India, is the largest sedimentary basin located at the tip of the Bay of Bengal. The basin accumulates a huge thickness of sediment (∼16 km) derived from the Himalayan and Indo-Burman Range (Uddin and Lundberg, 1998) by the Ganges–Brahmaputra–Meghna (GBM) river systems constituting one of the largest delta complexes known as the Ganges- or Bengal delta. The unconsolidated alluvial sediments in the delta plains and flood plains of the basin forms the most prolific aquifer system and serves as the main source of drinking, household and irrigation demand of water. But with the occurrence of arsenic (As) above WHO guide line value of 10 μg/l in the groundwater of shallow alluvial aquifers of Bangladesh and West Bengal province of India (Bhattacharya et al., 1997, 2002a; Nickson et al., 1998; Acharyya et al., 1999; BGS/DPHE 2001; McArthur et al., 2001; Ahmed et al., 2004; Ravenscroft et al., 2005), the use of groundwater for drinking and irrigation purposes has created a great concern for public health in this region (Chakraborti et al., 2004). Knowing the fact of As poisoning in groundwater, people in the rural areas are still largely dependent on groundwater as the surface water has greater risk of pollution with pathogens and various inorganic pollutants. The cost involved for the treatment of polluted surface water is not affordable for the poor rural people. An estimated population of about 85 million is exposed to As toxicity from drinking groundwater in the affected regions of Bangladesh and India (Michael and Voss, 2008).

Several researchers from various national and international organisations have carried out detailed hydrogeological and geochemical studies mostly on a local scale e.g. a village or an upazila

* Corresponding author. Tel.: +46 8 790 7399; fax: +46 8 790 6857.
E-mail address: prosun@kth.se (P. Bhattacharya).

0022-1694/$ - see front matter © 2009 Elsevier B.V. All rights reserved.
doi:10.1016/j.jhydrol.2009.09.016

(subdistrict) to understand the occurrence and genesis of As in groundwater (Harvey et al., 2002; Swartz et al., 2004; Zheng et al., 2004; Nath et al., 2005, 2008; Bhattacharya et al., 2006; von Brömssen et al., 2007; Hasan et al., 2009). However, little has so far been done to investigate the problem on a regional scale particularly along transects (van Geen et al., 2006; Mukherjee and Fryar, 2008). A hydrogeological and geochemical investigation along an E–W transect in the middle Meghna basin have been done in the present study. The Meghna basin, more specifically a sub-basin of the Bengal Basin, in south east Bangladesh is one of the most severely affected areas of Bangladesh where 60–90% of domestic hand tube wells (HTWs) are pumping water with As above Bangladesh drinking water standard (BDWS) of 50 μg/l (BGS/DPHE 2001; BAMWSP, 2002). Besides As, salinity in groundwater is another problem for drinking and irrigation purposes in the area. The study area includes six upazilas viz. Daudkandi, Chandina, Muradnagar, Debidwar, Burichang, and Comilla Sadar of Comilla district along an E–W transect in the middle Meghna basin stretching nearly 50 km and covering an area of about 1500 sq km (Fig. 1). The main objective of the paper is to understand the controls of geology and hydrogeology on the geochemical processes in relation to As mobilization and salinity in groundwater on a regional scale.

Geomorphic and hydrogeologic setting

Geomorphology and regional geology

The study area stretches from the base of the Tripura Hills in the east to the Meghna River in the west. It slopes gently from an average elevation of 10 m above sea level (asl) along the base of the Tripura Hills to the flood plains of the river Meghna with an elevation of less than 3 m except for the north–south trending low hill range called the Lalmai Hills. The area can be broadly divided into three geomorphic units (Fig. 2a) according to Morgan and McIntire (1959) and Bakr (1977).

Lalmai Hills – A north–south trending low hill range of 17 km long and 1–2.4 km wide with an average height of 30 m asl. The hills are covered by the Pleistocene Madhupur Clay Formation which is underlain unconformably by the Pliocene Dupi Tila Formation. Madhupur Formation consists of reddish brown hard and plastic clay while Dupi Tila Formation is composed of unconsolidated yellowish brown medium to coarse sand.

Tippera Surface – A relatively elevated (3–10 m asl) flat land lies between the Tripura Foot Hills in the east and Meghna Flood Plain in the west. It is made up of recent alluvial deposits consisting of clay, silt, silty loam and sand. However, Bakr (1977) further classified the Tippera Surface into two geomorphic units viz. Chandina Deltic Plain, between Lalmai Hills in the east and Meghna Flood Plain in the west, and Lalmai Deltaic Plain, the area between Lalmai Hills and Tripura Foot Hills. The Lalmai Deltic Plain is an uplifted terrace (Lalmai terrace) as indicated by surface presence of Madhupur Clay at some places.

Meghan Flood Plain – A low lying (<3 m asl) flat area composed of clay, silt and fine sand deposited by the present day river Meghna and its tributaries. It is characterized by meander channels, old levees, ox-bow lakes, and back swamps.

The delta plains and flood plains of the Meghna basin comprise a blanket of recent alluvial deposits (Fig. 2b), except in the Lalmai Hills where Pleistocene Madhupur Clay and Pliocene Dupi Tila sands are exposed (Alam et al., 1990). It is assumed that the Madhupur Clay covers an extensive area from the base of the Tripura Hills to the uplifted Madhupur Tract in the far west. However, the Madhupur Clay is either eroded by the incised channels or buried deep under the recent alluvial deposits in the valleys (Bakr, 1977).

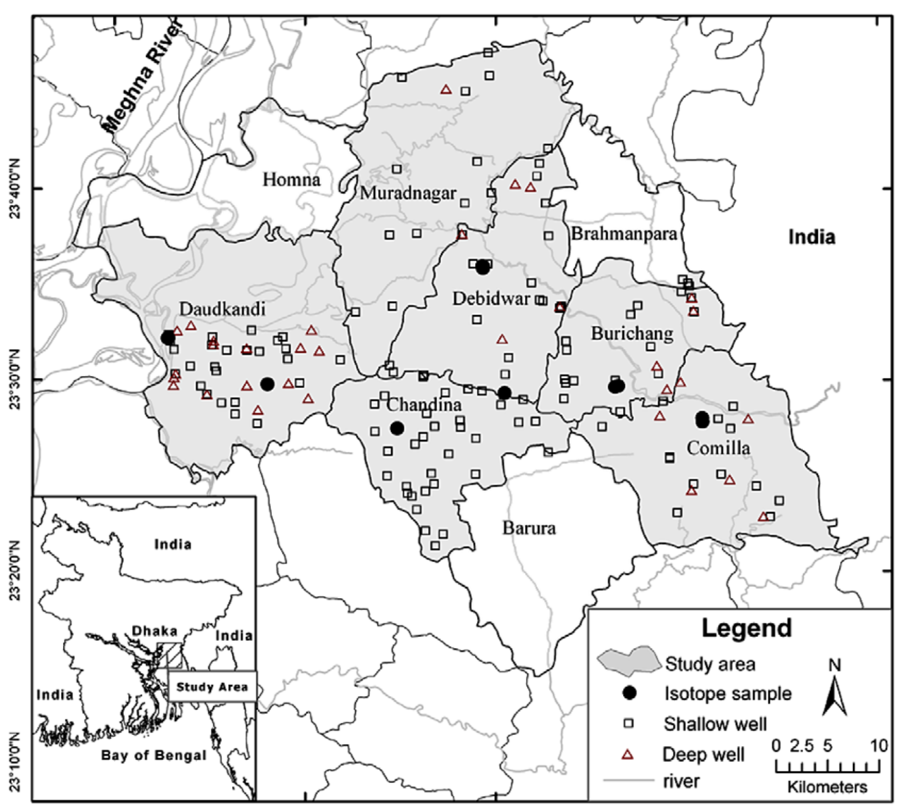

Fig. 1. Map of the study area, groundwater sampling locations, and geological section line (E–W).