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Status of groundwater arsenic pollution in Holocene aquifers from parts of the Ghaghara Basin, India: Its relation to geomorphology and hydrogeological setting

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ABSTRACT

A groundwater arsenic (As) survey was carried out for the first time in Faizabad, Gonda, and Basti districts of UP and 38%, 61%, and 42% of tubewells in these districts, respectively have As > 10 μg/l (WHO guideline). Moreover, 15%, 45%, and 26% of tubewells in Faizabad, Gonda, and Basti districts, respectively have As above 50 μg/l, the Indian standards for As in drinking water. About 86%, 69%, and 35% of tubewells in Faizabad, Gonda, and Basti districts respectively tap from shallow depth (21–45 m), and it is worth noticing that 47% As-contaminated (As > 10 μg/l) tubewells in these three districts are located within the depth of 10–35 m in the Holocene Newer Alluvium aquifers. The high content of As (7.11 mg/kg) is recorded in suspended matter sediments of the Ghaghara River as well. Most of the As-contaminated tubewells in Faizabad, Gonda, and Basti districts are located close to abandoned or present meander channels and floodplains of the Ghaghara River. In contrast, tubewells in Faizabad, Ayodhya, and Nawabganj towns are As-safe because of their positions on the Pleistocene Older Alluvium upland surfaces. Deeper tubewells (>50 m) in the Pleistocene Older Alluvium aquifers are suggested as option for As-safe groundwater.

1. Introduction

Arsenic (As) is a common contaminant found in soil and groundwater from both natural and anthropogenic sources. Over last three decades, incidences of high concentrations of As, one of the most hazardous chemical elements, in drinking water have been recognized as a great public health concern in several parts of the world. Millions of tubewells were installed in the Ganges–Brahmaputra–Meghna (GBM) delta complex and other parts of the world in the last few decades (Ravenscroft et al., 2008). Although the major switch from polluted surface water to groundwater in early 1970s helped people to avoid waterborne diseases, but naturally occurring high concentration of dissolved As in groundwater of alluvial aquifers has been causing serious health problems in millions of people for the last three decades. The upper permissible limit of As in drinking water is 10 μg/l in WHO guideline (WHO, 1993) which has been endorsed by Bureau of Indian Standards (BIS, 2003). However, in absence of an alternate source, the permissible limit has been relaxed to 50 μg/l in India. It is generally considered that the mode of occurrence, origin, and mobility of As in sedimentary aquifers in the Bengal Delta and other parts of the world are mainly influenced by local geology, geomorphology, hydrogeology, and geochemistry of sediments and water, as well as anthropogenic activities (Bhattacharya et al., 1997; Nickson et al., 1998; Acharyya et al., 2000; Kinniburgh and Smedley, 2001). The worst As affected regions in Asia are Bangladesh and West Bengal in India (Dhar et al., 1997; Bhattacharya et al., 1997; Nickson et al., 1998; Acharyya et al., 2000; Kinniburgh and Smedley, 2001; Anawar et al., 2003; Acharyya and Shah, 2007, 2010; von Brömssen et al., 2007; Ravenscroft et al., 2008; Shamsudduha et al., 2008). Arsenic pollution in groundwater is also reported from Pakistan, People Republic of China, Taiwan, Vietnam, Laos and Cambodia, and Nepal (Tseng et al., 2000; Sun et al., 2001; Berg et al., 2001; Nickson et al., 2005; Polya et al., 2005; Gurung et al., 2005). Thus As problem is common in several alluvial plains of South and East Asia.

India is the second most populated country in the world, where a large percentage of world's population (17.5%) is living on limited land area (2.4%). The average population density of India is 382 (2011 census), whereas for Uttar Pradesh (UP) state, it is 828 and there is continuously increasing pressure of population in UP. Groundwater As contamination has been reported from the Ganga Plain in the states of Jharkhand, Bihar, and Uttar Pradesh (Chakraborti et al., 2003; Bhattacharjee et al., 2005; Shah, 2008). The Ghaghara River, the focus of present work, is a distributary of the River Ganges and is a significant river in UP with many cities, towns, villages, and hamlets of UP are located on its bank (Fig. 1). The present work aims at groundwater As survey in Faizabad, Gonda, and Basti districts of UP involving tubewells within the Holocene New-

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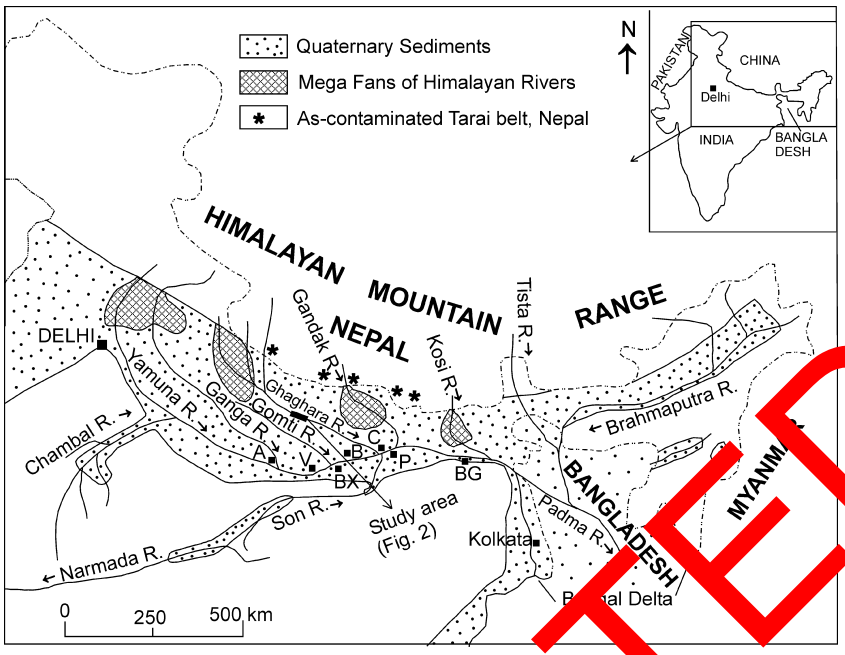

Fig. 1. Quaternary sediments in the Indo-Ganga Basin and Bengal Basin. The study area in the Ghaghara Basin is shown in Fig. 2. Abbreviations: A – Allahabad, V – Varanasi, BX – Buxar, B – Ballia, C – Chappra, P – Patna, BG – Bhagalpur.

er Alluvium aquifers, as well as, the Pleistocene Older Alluvium aquifers. The main objective of study is to investigate the distribution of groundwater As in entrenched channels and flood plains of the Ghaghara River under Quaternary geomorphological setting (Fig. 2).

2. Study area

The Ghaghara River has originated from Matsatung glacier in the Himalayas near Mansarowar Lake in Tibet and traveled a distance of about 1080 km in NW–SE direction, to join the Ganga River. The Ghaghara River adopts a meandering path through the alluvial plains, frequently shifting their courses and forming oxbow lakes. The topography of the area is heterogeneous; varying between upland surfaces, plains areas and low lying small natural bodies, viz., swamp and ponds. The Older Alluvium is located at an elevation of 10–20 m above the river level and constitutes the higher interfluve areas. The Pleistocene Older Alluvium surfaces in the Ghaghara Basin are characterized by yellow-brown colored sediments with profuse calcareous and ferruginous concretions (Fig. 3). The Newer Alluvium forms the river valley terrace and is located at an elevation of 5–10 m above river level. The Holocene Newer Alluvium surfaces are recognized by gray to black colored organic-rich argillaceous sediments in entrenched channels and floodplains of the Ghaghara River (Fig. 3). The area is under humid sub-tropical climate and the annual average rainfall is 1041 mm. Temperature ranges between maximum (47 °C) in summer and minimum (2 °C) in winter.

The distribution of groundwater As in the Ghaghara Basin is prepared based on Survey of India topographic sheets (63J/1, J/2, J/5, and J/6) in 1:50,000 scale, with field checks to identify fluvial landforms and soil characters. The study areas in Faizabad, Gonda, and Basti districts along entrenched channels and flood plains of the Ghaghara River are shown in Fig. 2. In this study, approximately 1500 km^2 areas have been mapped to delineate groundwater As-contaminated and As-safe areas.

3. Geological setting

The Quaternary geology of the Indo-Gangetic plains has been discussed by Pascoe (1964) who sub-divided the sediments into Older Alluvium and Newer Alluvium. This classification was revised by Pathak et al. (1978) as Upper Siwalik (Upper Pliocene to Lower Pleistocene), Older Alluvium (Middle to Upper Pleistocene), and Newer Alluvium (Upper Pleistocene to Recent) in order of superposition. The Siwalik Supergroup is further subdivided into Lower, Middle, and Upper groups ranging in age from Middle Miocene to Early Pleistocene in northern part of the Siwalik Basin forming the Outer Himalaya. The Banda Group in the southern part of the basin corresponds to the Upper Siwalik. The basement and major parts of the Quaternary sediments are concealed under the Ghaghara Basin (Kumar et al., 1996).

The first cycle of Quaternary sedimentation during Upper Pliocene/Lower Pleistocene in the Post-Middle Siwalik Basin came from the southern Peninsula. The sediments formed Bandra Older Alluvium which is characterized by variegated clays followed by the clastic sediments. However, the sediments derived from the Himalayas in the northern part of the basin constitute the Upper Siwalik (Dwivedi et al., 1997).

The valley of Ghaghara River is very wide (5–15 km) with narrow channel (100–200 m during summer). The Ghaghara Valley in the Ganga Plain consists of thick pile of Quaternary sediments. Geomorphologically, the Older Alluvium surfaces i.e. the Varanasi Older Alluvium constitute upland surfaces, which are also recognized as the *Bhangar* surface and are occupying a major part of the area. The Varanasi Older Alluvium consists dominantly of multiple fill polycyclic sequence of sand, silt, and clay (Kumar et al., 1996). In the Ghaghara Basin, the top 3 m part is of silt-clay facies corresponding to suspension load of flood plain environment underlain by arenaceous facies corresponding to channel-fill palaeo-environment. The sub-surface borehole down to a depth of 300 m record a number of calcreate (*kankar*) and argillaceous bands at various levels (Dwivedi et al., 1997).

The river Ghaghara draining the area has developed a second geomorphic unit, the low-lying flood plains – the *Khadar* surface