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Research paper

Effect of river proximity on the arsenic and fluoride distribution in the aquifers of the Brahmaputra Floodplains, Assam, Northeast India

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ABSTRACT

Groundwater samples were collected from the Brahmaputra Flood Plains (BFP) to study the effect of river proximity on the arsenic (As) and fluoride levels (F^-). Arsenic and F^- contamination was found to be higher in the south bank. Higher carbonate weathering was found to elevate the alkalinity in the south bank which in turn appeared to influence the groundwater As and F^- levels. Low NO_3^- levels in the groundwater indicated the existence of a predominantly reducing condition, which is confirmed by low ORP levels in majority of the groundwater samples. Positive correlation between As and Fe, along with close grouping in principal components analysis and hierarchical cluster analysis indicated the involvement of reductive hydrolysis of Fe (hydr)oxides. Principal components analysis showed that reductive hydrolysis was more common in the south bank, which could explain the higher As levels detected in that bank. Higher sedimentation rates on the south bank could also influence the elevated As levels in its groundwater. Co-occurrence of As and F^- was also found to be more likely in the south bank as indicated by hierarchical cluster analysis, the process appeared to be influenced by dissolution of Fe (hydr)oxides. Distance from the river and groundwater As level appear to be related, newer sediments close to the river are more likely to have higher As compared to older sediments away from the river. Fluoride on the other hand appears to have an inverse relation with river proximity, as recharge interrupts rock-water interaction, which is the main pathway for F^- release. Overall occurrence of groundwater As appears to be a more widespread problem in the floodplains, while F^- in groundwater is localised and limited to isolated pockets which promote higher mineral and water interaction over long periods.

1. Introduction

The problem of As and F^- in groundwater has become a serious issue across the world, more so because groundwater is the primary source of drinking water for majority of these people (Harvey et al., 2005). Countries where groundwater As is a severe problem are: Vietnam, Cambodia, China, Nepal, Argentina, Chile, Mexico, United States etc, (Bundschuh et al., 2004; Smedley and Kinniburgh, 2002; Bhattacharya et al., 2002; Smedley et al., 2002, 2003; Ahmed et al., 2004; Kumar et al., 2010a,b). Fluoride on the other hand has been detected in Africa, India, China, Japan, Canada, Turkey etc, (Manji et al., 1986; Brouwer et al., 1988; Apambire et al., 1997; Fantong et al., 2010; Yong and Hua, 1991; Boyle and Changnon, 1995; Oruc, 2008). Endemic fluoride problem has also been reported from developed countries like the USA (Bernstein et al., 1966).

The As problem is particularly severe in the eastern of part of the Indian sub-continent, which includes Bangladesh and Indian parts like the states of West Bengal and Assam, and the Middle Gangetic Plains (MGP) (Kumar et al., 2010a,b; Singh, 2004; Das and Kumar, 2015; Das et al., 2015). The permissible limit for As in drinking water is 10 $\mu g\,L^{-1}$ (WHO, 2008); doses high enough can be outright fatal, while a prolonged exposure can lead to chronic arsenicosis which ultimately progresses to cancer (Liao et al., 2008; Halim et al., 2010). Fluoride on the other hand has been detected mainly in the arid to semiarid regions of the country like Andhra Pradesh, Rajasthan, Gujarat, Uttar Pradesh, and Tamil Nadu (Muralidharan et al., 2002). Presence of F^- over 1.5 $mg\,L^{-1}$ in drinking water can lead to dental and skeletal fluorosis (WHO, 2008).

The release mechanisms of both these contaminants have been studied by different workers across the world. Reductive

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dissolution of metal (hydr)oxides has been proposed as the most probable As release mechanism in aquifers in alluvial settings with reducing conditions (Smedley and Kinniburgh, 2002; Kumar et al., 2010a; Kim et al., 2012). Fluoride release on the other hand is favoured under drier conditions, which promote prolonged rock-water interaction and mineral dissolution, as the primary sources of F^- in groundwater are fluoride bearing minerals like fluorite and fluoro-apatite (Saxena and Ahmed, 2001, 2003). A few regions of the world like Argentina (Gomez et al., 2009), Mexico (Armienta and Segovia, 2008) and Pakistan (Farooqi et al., 2007) have aquifers where the two contaminants have been found to co-exist in the same aquifer, and these areas were found to have arid to semi-arid oxidising conditions.

Although a lot of studies have focussed on the geogenic pollution of As in fluvial plains, yet a co-contamination perspective of As with F^- under such a setting is missing. The effect of As contamination can be clearly observed in previous works like Berg et al. (2008), Kumar et al. (2010a), Shah (2010). Yet the primary objective of these studies was not to observe the influence of the river on As level and contamination in the adjoining areas. Thus systematic studies dealing on the subject of co-contamination perspectives of As and F^- with respect to river proximity are lacking. Presence of newer sediments, recharge conditions which are governed by the river could play important roles in influencing the contamination level of the aquifers with respect to geogenic pollutants like As and F^-. Both As and F^- have been detected in the North-Eastern part of India, and the condition is most severe in Assam (Singh, 2004). Assam is drained by the mighty Brahmaputra River and its numerous tributaries, which have led to the formation of one of the most fertile regions of the world i.e., the Brahmaputra Flood Plains (BFP). The BFP therefore presents us with a good opportunity to study the impact of river on geogenic As and F^- contamination which will further lead more support to the existing works or theories in this field. This study aims to analyse the relation of As and F^- co-occurrence with river proximity, and spatial variation in sampling in the BFP as such a study is lacking not only in this region but also in the entire country.

2. Material and methods

2.1. Study area

The Brahmaputra flood plains (BFP) (Fig. 1) is the eastern most extension of the Indus-Ganga-Brahmaputra flood plain (IGBFP) system, it is also the narrowest portion of the greater IGBFP. The BFP is of tectonic origin, formed due to the compaction of the Indian and the Eurasian plates, which was followed by sedimentation. Sedimentation yield in the Brahmaputra flood plain has been found to be highest in the world (Sinha and Tandon, 2014). The sediment in the BFP is mostly alluvial in nature which has been brought down by the Brahmaputra and its tributaries (Fig. 1) (Singh, 2007). The Indian basement is exposed as residual hills or inselbergs in some regions in Assam (Singh, 2007). The

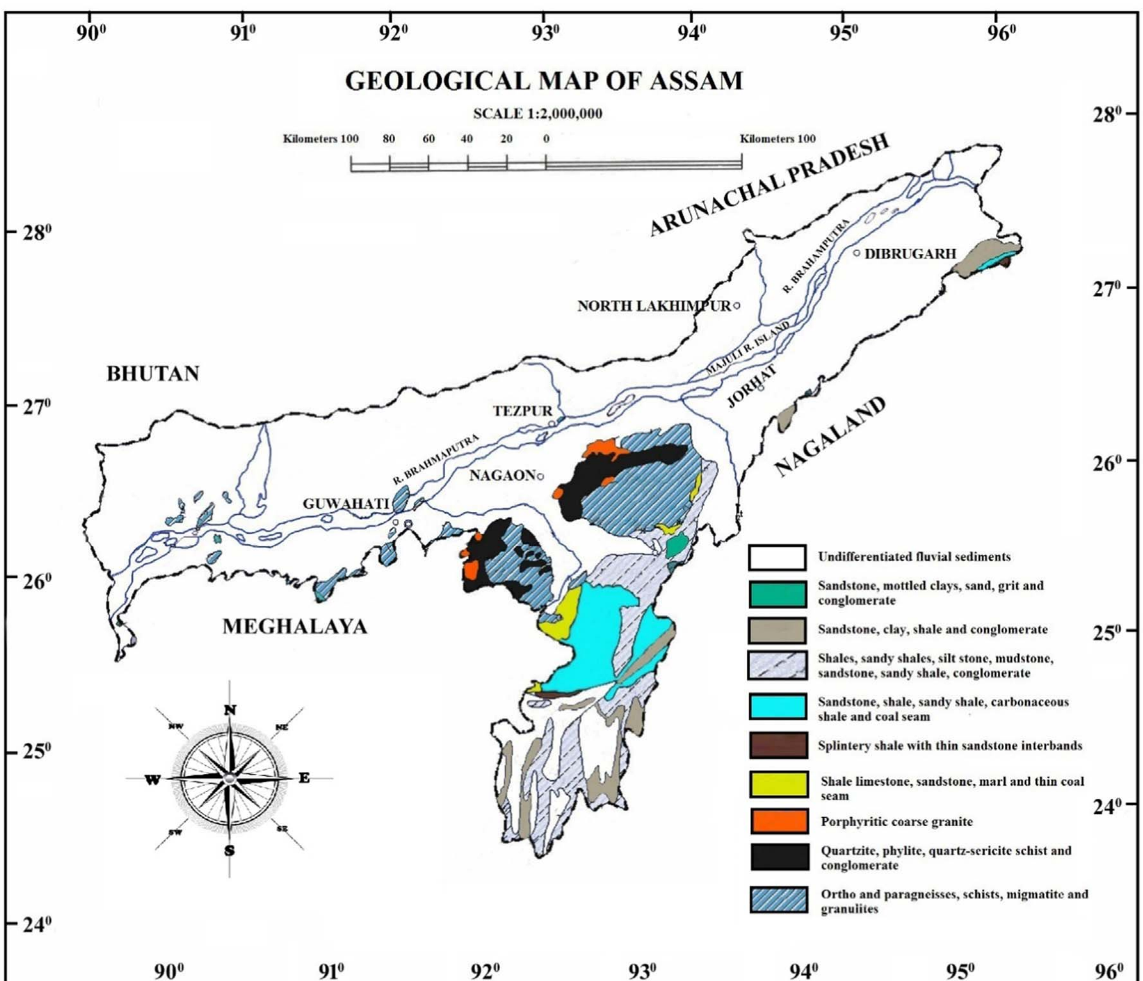

Fig. 1. Geological base map of Assam modified from Geological Survey of India showing the different geological formations.