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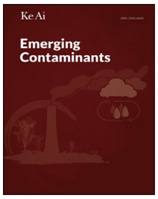

In-situ observation and transport modelling of arsenic in Gangetic plain, India

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ABSTRACT

The focus of this study is to investigate the arsenic movement and impacts on the residual concentrations on groundwater pollution load. The Gangetic plain area in the Ballia, Uttar Pradesh is selected as study area, which is also reported to extreme arsenic pollution in soil-water system. A modelling approach is developed to assess the arsenic flux in partially saturated zone using data of soil texture, soil hydraulic properties and stratigraphy. Soil type, slope, and land-use cover is considered for estimating the transient flux at the top boundary from daily precipitation and evapotranspiration data of the study area. Solute transport in the subsurface is predicted by the mass transfer equation, which is derived by integrating Darcy's law with the equation of mass balance. The arsenic profiles of varying hydrogeological conditions associated with different locations in the study area are presented as breakthrough curves. The results shows that the arsenic transport is dominated by the advective flux and strongly depends on the soil-moisture flow conditions. Which may increases the arsenic load to underlaying groundwater resources. The simulated results suggest that mobility plays a vital role arsenic transport as well as on adsorbed arsenic concentration in subsurface. Likewise, the adsorption isotherms show that the high peak curve for Bairai and low at Sikarderpur. A higher pollution risk is observed in the Belthara Road, whereas a lower vulnerability is computed in the north and northeast regions. This study can help in strategising sustainable groundwater management and protection planning of identified regions of India.

1. Introduction

Arsenic pollution of drinking water is an issue of major concern. Due to its high toxicity to humans, the World Health Organization (WHO) has set a maximum concentration limit of 10 µg/L for arsenic in drinking water [1]. Soils are an aggregate-based structured media that have a multitude of pore domains resulting in varying degrees of advective and diffusive solute and gas transport [1]. Consequently, a spectrum of biogeochemical processes may function at the aggregate scale that collectively, and coupled with solute transport, determine element cycling in soils and sediments. A better understanding is needed to explore how the physical structure impacts biogeochemical processes influencing the fate and transport of As, and temporal changes in speciation and distribution of As through experimental measurement and reactive transport simulations.

Arsenic can exist in many organic and inorganic forms, depending on the origin sources and dominant reactions in soils [2]. Arsenic can form organic compounds by methylation as a biological process, producing both trivalent and pentavalent organo-arsenic compounds [3]. Environmentally significant arsenic compounds are arsenate and arsenite, because they are soluble in water and toxic. Distribution of arsenate and arsenite in the solution and solid phases is largely determined by adsorption and redox reactions in soils. Arsenic in sediments and soils is bound with solid phases at different strengths. The biogeochemistry of arsenic in heterogeneous soil systems is rather complex, comprising a large array of chemical and microbiological reactions, for example, adsorption–desorption, reduction–oxidation, dissolution– precipitation, acid–base reactions, and biomethylation [4]. Those

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reactions are affected by a series of environmental conditions such as pH, Eh, soil constituents, electrolytes, and microbial activity, temperature, and residence time. Traditionally, arsenic sorption studies have been carried out based on batch equilibration experiments conducted within a short period of reaction time.

The vulnerability assessment may be classified as the intrinsic and specific/integrated resource vulnerability. The intrinsic vulnerability depends solely on groundwater which is likely to the effected by imposed contaminant load. While, the specific/integrated vulnerability is determined for a particular pollutant or a certain prevailing human activity [5]. For resource vulnerability only unsaturated zone is considered whereas for source vulnerability, both the saturated and unsaturated zones are considered [6]. Groundwater contamination risk depends not only on vulnerability but also on the contaminant loading on ground surface for entering the subsurface environment [7].

The vulnerability assessment technique has been accepted for its competency to delineate the areas which are more likely, than others, to get contaminated as a result of anthropogenic activities at the surface. Another goal of vulnerability assessment is a subdivision of the area into several units which have different levels of pollution risk. Groundwater contamination can be minimized by delineating and monitoring vulnerable areas of the overlying watershed. Delineating surface areas which are responsible for groundwater contamination is a difficult task due to the involvement of many surface and subsurface parameters which play different roles in polluting groundwater resources. The general concept of groundwater vulnerability is based on the assumption that the physical environment may provide some degree of protection to groundwater against contaminant load making some land areas more vulnerable to groundwater contamination than others. Mostly hydro-geologic factors are used by the researchers for assessing groundwater susceptibility to contamination. These factors are often integrated into groundwater models using multiple methods for predicting susceptible surface areas responsible to groundwater pollution [8].

Assessment of groundwater vulnerability and pollution risk is used as important early tool in decision making and in management of groundwater resource [9]. It also provides a useful framework for effective implementation of contaminant protection programs and control measures [10]. The groundwater vulnerability maps assist to apprise and educate the people and create a general awareness about contamination problem of groundwater [6].

2. Objective

The main focus of this study is to assess the vulnerability and pollution risk of groundwater resources of Ballia District, which, in turn, could be incorporated into groundwater protection planning. The specific objectives are a). *In-situ* observation of arsenic contaminations, b). Lithological investigations, c). Batch scale laboratory experiments to investigate adsorption isotherms and, d) Numerical simulation of arsenic transport using field investigated data.

2.1. Study area

Ballia district, the eastern most part of the Uttar Pradesh lies between 25°23″ and 26°11″ North latitude and 83°38″ and 84°39″ East longitudes (Fig. 1). Total Geographical areas of the district is 2981 sq.km. District headquarter is at Ballia and there are six number of Tehsils namely Ballia (Sadar) Bansdih, Rasra, Belthra, Bairia and Sikanderpur. The district Ballia falls under sub humid climate with grassland vegetation. On the basis of climatic classification with PE index of 44.4. The temperature is maximum in May with 32.25 °C followed by June with 30.75 °C. The coldest month is December (12.15 °C) followed by January (15.9 °C). The humidity is maximum in August (82.5%) following by September (80%). Annual PET of Ballia district on the basis of Varanasi data is 1608.9 mm. The normal annual rainfall is 983 mm while monsoon rainfall is 864.8 mm. Ballia district is underlain by sands of various grades, gravels, silt and clay. These have wide extension. Arsenic above permissible limit in shallow aquifer is found in parts of Ballia district.

3. Materials and methods

The methodology follows the in-situ observation and transport modelling, a standard system for evaluating groundwater pollution risk. The coupled data based and physical pollutant transport modelling to contaminants of an aquifer based on their hydrogeological settings, are effective way to evaluates groundwater vulnerability.

3.1. In-situ observation

The in-situ observation plan was established at five different place of the study area. The sediment and groundwater samples were collected from all the selected locations. The groundwater samples were collected from the hand pump, in use of local communities. Furthermore, the sediment samples were collected from the depth of 25 cm at each location. All the samples were analysed in laboratory for Arsenic concentration as well as other physic-chemical parameters of collected groundwater and sediment samples.

3.2. Lithological investigations

The lithologs of each area was investigated by collecting the soil samples with different depth using core samples analysis. Required lithological data of the study area were obtained from the Central Ground Water Board (CGWB).

3.3. Batch experiments

In this study, a series of six batch sets containing 20 g of oven dried sand with particle size of 0.5–1.0 mm and 40% porosity were prepared under partially saturated condition. The detailed of soil types and texture is listed in Table 1. Various concentrations of Arsenic varying from 5 to 100 ppm were considered in the designed batches (Fig. 2). To maintain the level of saturation the 0.002L groundwater was added. The batch experiments were performed at room temperature (21.6 ± 0.3 °C) by maintaining the initial concentration. To prevent any other microbiological degradation, the effective concentration of $HgCl_2$ used for maintaining sterile conditions. The continuous hourly samples were analyzed using AAS to compute equilibrium break-through curve. To capture the high magnification at pore scale, SEM (Scanning Electron Microscopy) analysis was conducted at 10X.

3.4. Arsenic transport experiments

To investigate the fate and transport of toluene contaminated groundwater, a large scale column setup made of plexi-glass was fabricated. The column was 100 cm in length with an inner

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