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Arsenic contamination in agricultural soils of Bengal deltaic region of West Bengal and its higher assimilation in monsoon rice

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HIGHLIGHTS

- Arsenic in soils in arsenic elevated ground water contaminated sites during monsoon rice cultivation.
- Heavy metal(liod)s accumulation in the agricultural soils irrigated with contaminated groundwater in winter.
- Heavy metal(liod)s dispersion in the agricultural soils with rain water in monsoon.
- Estimate the Potential Ecological Risk, Bio-concentration Factor, Translocation Factor of heavy metal(liod)s.
- Estimate the Maximum Allowable Daily Level of arsenic through rice consumption and its effect on plants and human.

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ABSTRACT

In the Bengal deltaic region, the shallow groundwater laced with arsenic is used for irrigation frequently and has elevated the soil arsenic in agricultural soil. However, the areas with seasonal flooding reduce arsenic in top layers of the soils. Study shows arsenic accumulation in the deeper soil layers with time in the contaminated agricultural soil (19.40 ± 0.38 mg/kg in 0–5 cm, 27.17 ± 0.44 mg/kg in 5–10 cm and 41.24 ± 0.48 mg/kg in 10–15 cm) in 2013 whereas depletion in 2014 and its buildup in different parts of monsoon rice plant in Nadia, India. Principal Component Analysis and Cluster Analysis were performed, and Enrichment Factor was calculated to identify the sources of arsenic in the soil. Potential Ecological Risk was also calculated to estimate the extent of risk posed by arsenic in soil, along with the potential risk of dietary arsenic exposure. Remarkably, the concentration of arsenic detected in the rice grain showed average value of 1.4 mg/kg in 2013 which has increased to 1.6 in 2014, both being above the permissible limit (1 mg/kg). These results indicate that monsoon flooding enhances the infiltration of arsenic in the deeper soil layer, which lead to further contamination of shallow groundwater.

1. Introduction

Nadia district of West Bengal remains evergreen with seasonal field crops being cultivated throughout the year for its plenty of groundwater and type of soil available (new alluvium). But as a major concern, it is one of the nine districts in West Bengal where groundwater contains arsenic above the prescribed limit by World Health Organization (WHO) of 10 μg/l [9,56]. Long term irrigation practices with As laden groundwater accumulates As in the upper surface of soil, affecting the topsoil strongly [43,47,65,7,52,53]. Temporal variability may cause As diffusion into floodwater [51] and lateral removal with receding floodwater or As transport to deeper soil layer by infiltration [36].

In West Bengal, approximately 47% of the gross rice area is grown under rainfed condition [3]. Monsoon rice is typically grown from July to October and it accounts for 69% of the overall rice space. Rice plants also accumulate As in their different parts (root, shoot and grain) and thus results to phytotoxicity [41,54].

In 1980 International Agency for Research on Cancer (IARC) classified inorganic arsenic (iAs) as a carcinogen, but the long-term toxic effects have been known since the nineteenth century [31]. Arsenic is by far one of the most toxic elements in the environment [16] and is responsible for the highest risks of morbidity and mortality worldwide, both because of its toxicity and the number of people exposed [28]. Arsenic mobility in the soil is mainly controlled by

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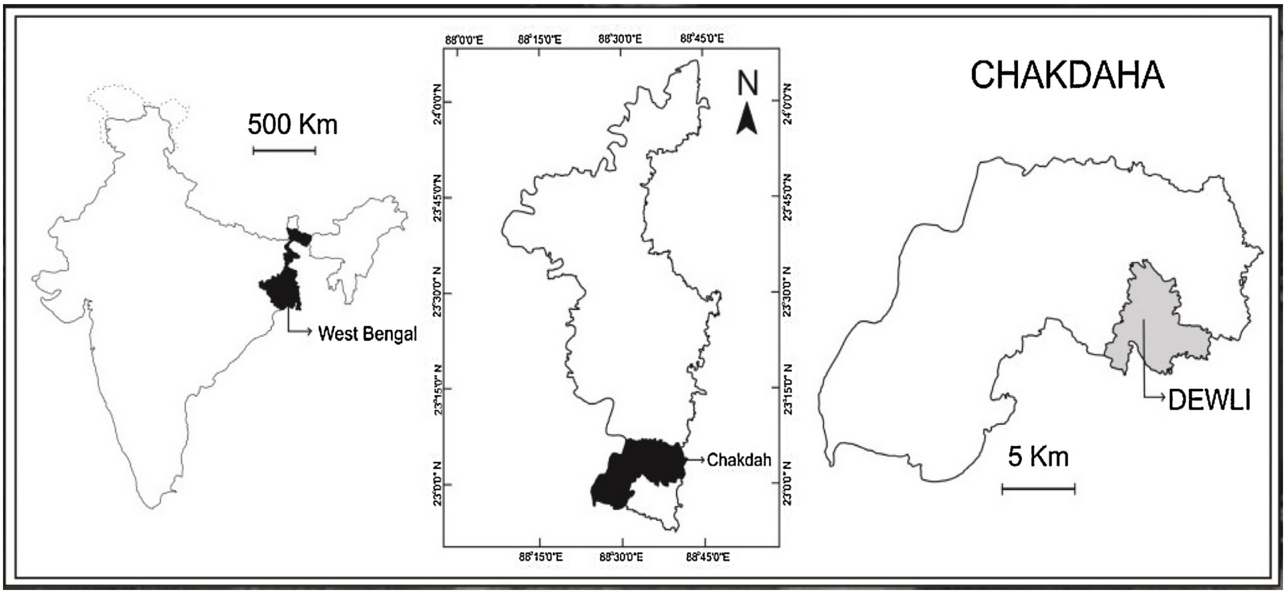

Fig. 1. Map of the study area (Drawn using CorelDRAW Graphics Suite X6).

redox condition. Under aerobic condition, As pentavalent (AsV) is predominated while arsenic trivalent (AsIII) predominate under anaerobic condition [20]. In paddy field or soil surface, arsenic is present in oxidized form (AsV) over the top soil. In monsoon season when flooding occurs and create an anaerobic condition over the soil, the pentavalent arsenic may change into trivalent arsenic form. Arsenite (AsIII) have great affinity with water at neutral pH and is easily soluble in water. Arsenite easily diffuses with floodwater and removes with receding floodwater. Mobility of arsenic also depends on iron oxide. Fe redox chemistry is one of the main factors for regulating As mobility [38].

Typically the concentrations of As in non-contaminated soils vary from 0.1 to 10 mg/kg [34]. But due to the intensive irrigation practices in the area, the extent of soil contamination has increased to a level that even the monsoon fed rice grown in the agricultural fields are heavily affected with arsenic and other heavy metals [29].

The reason for elevated As content in flooded rice is the reducing surroundings of submerged soils, which ends up in dissolution of As and, therefore, an exaggerated As phytoavailability [35,61,4]. In general, the bioavailability of As in soil is powerfully influenced by the chemical and physical characteristics together with the character of minerals and clay content, organic matter, texture, pH and Eh [10], cation-exchange capability (CEC) [45] and presence and concentration of oxides and hydroxides of metal, Al and Mn, soil phosphate concentration, rhizosphere iron plaque formation, microorganism activity and rice selection as well as the plants growth characteristics etc [44].

In agricultural field, arsenic is mobilized in reducing environments in the form of As (III), where the Fe (III) – oxyhydroxides simply gets dissolved and reduced to Fe (II) [46,51]. This leads to the uptake of As by the crops and its subsequent transfer to human and other life forms. It has been established that the possible As exposure from the consumption of rice cultivated on the contaminated fields can be substantial, particularly for the population on a subsistence rice diet [69]. Not only that, the increasing of soil and plant arsenic levels can have a more significant effects on human nutrition by decreasing the content of other important nutrients, such as, Se, Ni, and Zn in rice grains [66].

At places, as a result of repeated application of heavy metals contaminated water for irrigation, the speciation of heavy metals are influenced strongly and hence the metals eventually leach into soil solution and pollute the groundwater reserve [13]. Plants thus uptake these mobile ions present in the soil solution which is largely determined by the total quantity of the ions in the soil [49,53]. It is clear that arsenic present in irrigation water and soil leads to higher level of arsenic in rice plant root, leaf and stem [5]. Excessive content of these metals in edible part, beyond Maximum Allowable Daily Limit (MADL) leads to a number of health disorders affecting human beings and animals adversely [6,32,68]. Certainly the exposure of humans to arsenic causes health impairments ranging from stomach pain and circulatory problems to skin, lung, bladder, and kidney cancer [68,19,10].

A thorough study on the status of arsenic contamination is urgently needed to assess the risk for human and environmental health associated with the potential increase of soil arsenic levels in rice paddies. This would also help in the development of mitigation measures for providing food security of the arsenic exposed population. Thus, the objective of the present study was to study the heterogeneity of soil arsenic concentrations in different soil layers of the rice paddy fields. Also, a specific attention on the temporal variability over the cycles of paddy cultivation and the subsequent effects of monsoon flooding was investigated.

2. Material and methods

2.1. Sampling site description

The sampling site (latitude 23°01′15.31" N and longitude 88°38′36.86" E), comes under Nadia district of West Bengal (Fig. 1). The site has a history of long term use of As contaminated groundwater for irrigation purpose [49,9]. Agriculture is the primary occupation of the area and farmers in the village use the arsenic contaminated groundwater for various purposes especially for irrigation of the traditional continuously flooded rice paddies. The level of arsenic in the groundwater frequently exceeds the World Health Organisation (WHO) Guidelines for drinking water quality (10 μg/l) and the Food and Agricultural Organisation (FAO) Permissible Limit for Irrigation Water (100 μg/l) [18,68]. The study area is also of great concern due to its area coverage and population density.

The study was carried out for a period of three months from August-October, 2013 and 2014. For the present study three plots each 80 × 30 m, were taken. Out of which one plot was taken as the

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