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Heavy metal dispersion in water saturated and water unsaturated soil of Bengal delta region, India

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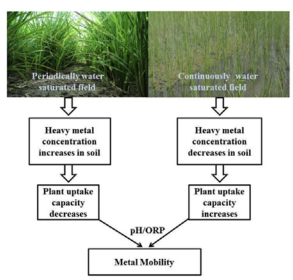
H I G H L I G H T S

- Application of water saturation-unsaturation irrigation practices.
- Effect of pH and ORP on metal mobility and availability.
- Quantitative analysis of metals in soil, water and plant samples by ICP-MS.
- Justification of data by ANOVA and Cluster Analysis.
- Bio-concentration factor and percentage of metals in plant parts.

G R A P H I C A L A B S T R A C T



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1. Introduction

1.1. Study establishment background

Metals, particularly heavy metals are one of the stellar concerns for environmental pollution due to their ability to bio-accumulate and bring forth a cyanogenic effect on the ecosystem. As recommended by 'WHO', a remarkable population in India are under the grasp of Arsenic (As) contamination which has already exceeded by double the threshold value (10 µg L-1) (BGS & DPHE, 2001; Smedley, 2003). According to number of reports, rice cultivated in Asia contains a stupendous amount of lead (Pb) and cadmium (Cd) and is in taken regularly by the natives (Moon et al., 1995; Shimbo et al., 2001; Zhang and Ke, 2004; Cheng et al., 2006). The increasing trend in the population curve, is followed by the enormous requirement of groundwater for purposes like domestic and agricultural activities. However, a hatful of endeavour like silicate minerals application, phosphate and thiourea application have been conducted by different organisations to reduce As concentration in food materials (Seyfferth and Fendorf, 2012; Talukder et al., 2011; Srivastava et al., 2014). In this context, a recent study has shown the exposure of As in children whose origin is in and around the rural areas of Bangladesh (Kippler et al., 2016). The

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accumulation of heavy metals due to human activities usually affects the topsoil layers (Govil et al., 2001) and due to piecemeal cultivation processes, it contaminates the surrounding water level which in turn are absorbed by the plant system (Bhagure and Mirgane, 2011) leading to the venomous effect on our biodiversity on a larger scale (Xian, 1989; Wong et al., 2002). A sound cognition of heavy metal concentration and chemical behavioural properties depend on soil physicochemical characteristics providing careful management to put the bar on toxic metal dispersion. The presence of metals in soil can be categorized into various forms like- 'Dissolved' (in aqueous phase), 'Exchangeable' (in organic and inorganic components), 'Lattice' structure with soil minerals and 'Insoluble' precipitates associated with other soil components. Among these categories, dissolved and exchangeable are accessible to plant system whereas the other two are soil associates. The metal availability is conceived to depend on solid-solution equilibrium with an influence of pH (Lindsay and Lyman, 1979). From earlier interventions, it has been established that the pH and metal availability are inversely related (Sukreeyapongse et al., 2002; Ban and Hesterberg, 2004; Badawy et al., 2002; Wang et al., 2006; Gijs et al., 2007). Apart from pH, organic matter also plays a significant role in heavy metal dispersion and complex formation with soil components (Stevenson, 1982; Antoniadis et al., 2008; McCauley et al., 2009). The proximity of heavy metal in soil with antithetical redox state influences their biological and geochemical cycles with an aid of anthropogenic activities (Lund, 1990).

Unremitting dispersal and accumulation of pollutants may create substantial implication over local agricultural practices where toxic metals can accumulate in the agricultural soil depending on the environmental factors, resulting in food chain contamination (Haygarth and Jones, 1992; Chen et al., 1999) thereby directing to major health hindrances (Needleman, 1980; Mueller, 1994; McLaughlin et al., 1999). This degree of adversity in agricultural soil, hence, should be taken care of (Li et al., 1997). However, accumulation of heavy metal depends on plant species, soil characteristics coupled with enrichment and the ability of the associated plant to absorb the metallic content (Kuhad et al., 1989; Rattan et al., 2005).

1.2. Rice cultivation and field environment

In contrary to other cereals like wheat, barley, maize etc., accumulation of heavy metals in parts of rice plants are much higher (Williams et al., 2007; Duxbury, 2007). Scientists in Bangladesh have done panoptic work on arsenic content in commonly used dietary products, like eggs, meat, fish, fruits, vegetables cereals etc, along with risk assessment (Ahmed et al., 2016). In India, cultivation of Boro rice clasps a strong topographic point in the gross rice production which is supplemented with a varied environment set up than the Amon cultivation during monsoon. Traditionally, the term 'Boro' derives from a Sanskrit verbose 'Borob' which ideally is not a species.

But a seasonal variety of rice, preferably cultivated during the winter-pre summer season around the Gangetic delta basins, saucer-shaped depression, and deltas where waterlogged conditions during monsoon are saturated and un drained during winter which creates an ideal field status for Boro production. This stagnant water of 10–20 cm depth with a periodic alteration of dry field imparts dramatic variation in heavy metal content in the soil-plant system (Singh et al., 2002). The simultaneous flooded and non-flooded circumstances is associated with redox change that affects the mobility of As along with some other metals whose behavioural pattern is redox sensitive as well (Smedley and Kinniburgh, 2002). Flooded soil-water system has a tremendous influence on the biogeochemical cycles of metallic elements by altering redox and pH (Reddy and Patrick, 1976; Masscheleyn et al., 1991; Takahashi et al., 2004; Kirk, 2003; Xu et al., 2008).

Co-precipitation of metals in the presence of another element and sorption to soil particles is an upshot for bioavailability in flooded conditions (Roberts et al., 2007). Periodical change infers to a stop gap application of groundwater irrigation to the subjected field. During the application and after two to four days, the rice field may be persisted with waterlogged condition, which is followed by no waterlog in the rice field for a few days. This cycle of simultaneous change in dry (without water) - wet (waterlog) imparts a variability in the metal chemistry and so their concentration. As Boro cultivation is accompanied by a periodical change of dry-wet conditions, the saturation level of field soil or the percolation rate of water is an important parameter (Wickham and Singh, 1978) dependent on ingredients like soil structure, texture, bulk density, mineralogy, the concentration of salts in aqueous phase, organic matter content etc. The depth of water logged is directly related to percolation rate of water (Sanchez, 1973; Wickham and Singh, 1978) enriched with metallic element contaminating throughout the field soil. This application of dry-wet cycle compared to traditional anaerobic water-saturated fields provides a chemical transformation and diminishes the bioavailability of toxic metals to the soil-plant system (Makino et al., 2000; Zhang et al., 2006; Bing et al., 2010; Liao et al., 2013).

In our present study, a part of Nadia district, West Bengal, India, was spotted where arsenic and other heavy metal aggregation is significantly high (Shrivastava et al., 2014). The metallic content was measured checking the variation of contamination with an application of dry-wet cycle for two experimental fields for two consecutive years. The range of Bioconcentration Factor (BCF) for root and shoot in subjected Boro plants were determined with emphasis on a percentage of metal accumulation in root and shoot separately with respect to the whole plant. The role of pH in mobility and availability of metals were also checked. In further aid to our study, statistical analysis of data was judged by correlation-regression plot and analysis of variance.

2. Material and method

2.1. Sampling area

District Nadia is in the pinnacle among the four districts of West Bengal that produces a bulk volume of crop varieties and thus the agricultural area of this district has a potential risk to be contaminated with a soaring quantity of trace metals dispersed from agro-fertilizers and other anthropogenic sources. The coordinates of Nadia is in between 200 5″ and 240 11″ N latitude and 880 09″ and 880 48″ E longitudes from where our selected study zone Chakdaha block has a coordination of 23001′15.31″ N latitude and 88038′36.86″ E longitude. Chakdaha block is located in the Ganges delta plain and bordered by Hugli River on the west and is 65 km north from Kolkata. Sampling site was Dewli Gram Panchayat of Chakdaha block (Fig. 1).

2.2. Sample collection

In the year 2013 and 2014, samples were collected 3–5 times in a periodical span between February to May (during wintery cultivation) and annual sampling was done to see the effect of temporal variation. Soil samples were collected from each sampling phase at least by 0–20 cm depth using PVC pipes (Geen et al., 2006) and brought to the laboratory for further analysis. They were further categorized as periodically water saturated (i.e. water unsaturated) soil and continuous water saturated soil to distinguish the variation