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Metal contamination of soil and translocation in vegetables growing under industrial wastewater irrigated agricultural field of Vadodara, Gujarat, India ☆

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ABSTRACT

The present investigation was carried out to evaluate metals concentration in ten vegetable crops growing in mixed industrial effluent irrigated agricultural field near Vadodara, Gujarat, India. Differential accumulation and translocation of various metals in selected vegetables plant species was observed. A higher concentration of metals were found in order of Fe > Mn > Zn > Cd > Cu > Pb > Cr > As in soil irrigated with industrial effluent than soil irrigated with tube well water; however, the concentration of As, Cr and Pb found below detection limit in tube well water irrigated soil. Metal accumulation in root and top of vegetables varied significantly both in relations to metal concentration in the soil and the plant genotype. Among ten vegetable species studied five vegetable species, i.e. Spinach, Radish, Tomato, Chili and Cabbage growing in mixed industrial effluent irrigated agricultural field showed high accumulation and translocation of toxic metals (As, Cd, Cr, Pb and Ni) in their edible parts, thus, their cultivation are unsafe with respect to possible transfer in food chain and health hazards. However, it is suggested that vegetable crops restricting toxic metal in non-edible port may be recommended for cultivation in such metal contaminated agricultural field.

1. Introduction

Metals are intrinsic component of the earth crust; however, today soil contamination with heavy metals is an environmental problem on a global scale and it is becoming increasingly important as industrialization increases (Salvatore et al., 2009). Industrial activities such as mining, electroplating and manufacturing of essential commodities produce huge volume of wastewater as effluent that contains heavy metals and other toxicants, which deteriorate the quality of aquatic system where it is discharged (Tiwari et al., 2008). Metals are extremely persistent in the environment; as they are non-degradable and thus readily accumulated at toxic levels. Metals can also accumulate in the soil at toxic levels due to long term application of wastewater (Bohn et al., 1985). Apart from discharges from several industrial areas, metals continuously enter into the water source consumed by human beings and animals, endangering their growth and health (Freedman and Hutchinson, 1981; Sigel, 1986). In many areas these discharges are used by local formers for irrigating their crops, thus introducing these pollutants to the crops (Warning et al., 1996). Very often plant chemical composition is modified without damage being easily visible, and plants grown in contaminated soils contain higher quantities of metals than plants grown in un-contaminated soils (Van and Zwart, 1997; Yusuf et al., 2003; Nadal et al., 2005). In this changing scenario reuse of domestic and industrial wastewater in agriculture for irrigating crops appears to be a lucrative option due to appreciable amount of plant nutrients present in this water (Rattan et al., 2005). A number of studies from developing countries have reported heavy metal contamination in wastewater and wastewater irrigated soil (Cao and Hu, 2000; Nan et al., 2002; Singh et al., 2004; Mapanda et al., 2005; Tiwari et al., 2008). In many developing countries including India, farmers are irrigating their crop plants with industrial effluents (Kaushik et al., 2005; Rattan et al., 2005; Abbas et al., 2007; Tiwari et al., 2008) having high level of several toxic metals (Cu, Cd, Cr, Zn, Fe, Ni, Mn and Pb) (Kumar and Chandra, 2004; Abbas et al., 2007; Tiwari et al., 2008) due to the non-availability of alternative sources of irrigation water. Several researchers have been documented use of diluted industrial effluents/sludge has growth and productivity enhancing effects on crop plants (Quartacci et al., 2006; Abbas et al., 2007; Bose and Bhattacharyya, 2008; Chandra et al., 2008). However, loading of heavy metals often leads to degradation of

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soil health and contamination of food chain mainly through the vegetables grown on such soils (Rattan et al., 2002). The process of metal uptake and accumulation by different plants depend on the concentration of available metal in soils, solubility sequences and the plant species growing on these soils (Andersson, 1977).

Vegetable constitute an important component of human diet since they contain carbohydrates, proteins, as well as vitamins, minerals and trace elements (Dastane, 1987). One important dietary uptake pathway could be through vegetable crops irrigated with metal contaminated waste water. In the Umariya town of district Vadodara, Gujarat, India, a 100 Km long channel has been constructed for the discharge of effluents from several industrial units specially pharmaceuticals, pigments, petrochemicals, dye, paints, pesticides, chemical, lubricants, etc. The effluent channel is designed for effluent collection from various industrial estates and finally discharged in to the Arabian Sea. Local farmers across the channel use this waste water to irrigate their agricultural fields for growing crops due to scarcity of fresh water for irrigation. The vegetables generally grown in the area of Umariya are Spinach (*Spinacia oleracea* L), Radish (*Raphanus sativus*), Tomato (*Lycopersicon esculentum*), Cress (*Lepidium sativum*), Dill (*Peucedanum graveolens*), Coriander (*Coriandrum sativum*), Chili (*Capsicum annum*), Cabbage (*Brassica oleracea* var capitata), Brinjal (*Solanum melongena*) and Okra (*Hibiscus esculentus*) by local farmers. However, there are very limited empirical information from India for heavy metal contents in soil and irrigation water and its accumulation and translocation to crop plants especially in vegetables form such metal contaminated agricultural field. It is of prime importance to know the degree of translocation of heavy metals from soils to plants used as food crops, and studies on the absorption of metals by food plants grown on soils to a safe level as not to cause phytotoxicity symptoms are of great practical interest. Indeed, edible plants produced from such soils could expose unknown consumers to the risk of ingesting high doses of metals that exceed the law and that, in the long-term, could cause cases of subacute or chronic intoxication (Salvatore et al., 2009).

The present study was selected in this agriculture field to establish direct relationship of level of metals in such contaminated agricultural field and the vegetable crops growing there in. The main objective of present studies is to quantify the level of metals concentration in soil and their translocation in vegetables to evaluate health hazards and which may be helpful in making policies for growing safe vegetables in these contaminated areas.

2. Materials and methods

2.1. Study area

The area selected for present study was around effluent discharge channel located at Umariya, Vadodara, Gujarat (India). A number of industrial units are located in the adjacent area. Most of the treated and untreated industrial effluents are being discharged through this effluent channel. Several acres of agricultural land irrigated by channel effluent water and local farmers cultivate various types of crop of economic importance, including seasonal vegetables. As per the information given by the local farmers we have identified the above area where, waste water irrigation has been a common practice for many years and irrigation water can only be sourced to treated or untreated industrial effluent.

2.2. Sampling and analysis of industrial effluent and tube well water

For physico-chemical and metal analysis, effluent samples were collected in clean acid washed glass bottles from channel near to both ETP discharge point, Umariya, Vadodara, Gujarat, India and tube well water from the area situated 2 Km away from the channel in triplicate of capacity 500 ml that was being used for irrigation purposes, 2 ml of concentrated HNO_3 was added to the water to avoid microbial utilization of heavy metal and other nutrients. The bottle containing samples were brought to the laboratory and digestion was completed within a week. Measurement of pH, electrical conductivity (EC), total dissolved solids (TDS) and salinity was done in both effluent and tube well water instantly by using HACH portable water quality laboratory system (DREL/2010). The concentration of chloride, fluoride, sulphate, sulphide, calcium, phosphate, potassium, sodium, magnesium, nitrate, ammonical and total nitrogen in effluent and tube well water were measured in the laboratory as per guideline given in APHA (2002). Total, inorganic and organic carbon contents were analyzed by Total Organic Carbon Analyzer (TOC-VCSH, TNM-1; Shimadzu Corporation, Japan). For the estimation of metal concentration (As, Cd, Cr, Cu, Fe, Mn, Ni, Pb and Zn) in tube well water and mixed industrial effluent water samples (50 ml) were digested with $HClO_4$:HNO_3 (1:4 v/v) at 80 °C and filtered through whatman No. 42 filter paper and final volume was made up to 15 ml with milli-Q water. The concentration of various metals was measured by using Inductively-Coupled Plasma Spectrometer, Perkin Elmer Corporation (ICP Optima 3300 RL).

2.3. Soil sampling and analysis

Soil samples were collected in triplicate from the agricultural field situated near channel and irrigated with mix industrial effluent and tube well water. Ten composite surface soils (0–20 cm) samples from both soil were collected randomly on which the test crop plants were grown separately. Soil samples were oven dried at 70 °C and grind into fine powder using pestle and mortar and passed through 1 mm sieve and stored at room temperature before analysis of soil properties and metal content. Well-mixed samples of 2 gm each were taken in 250 ml glass beaker and digested with 8 ml of aqua regia on a sand bath for 2 h. After evaporation to near dryness, the samples were digested with nitric acid, filtered and diluted to 50 ml with distilled water (Ming and Ma, 2001). Filtrate samples were analyzed for determination of As, Cd, Cr, Cu, Fe, Mn, Ni, Pb and Zn by Inductively-Coupled Plasma Spectrometer, Perkin Elmer Corporation (ICP Optima 3300 RL).

2.4. Collection and analysis of vegetable crops

Total ten vegetable crops, i.e. Spinach (*Spinacia oleracea* L), Radish (*Raphanus sativus*), Tomato (*Lycopersicon esculentum*), Cress (*Lepidium sativum*), Dill (*Peucedanum graveolens*), Coriander (*Coriandrum sativum*), Chili (*Capsicum annum*), Cabbage (Brassica oleracea var capitata), Brinjal (*Solanum melongena*) and Okra (*Hibiscus esculentus*) seasonally grown in the agricultural field of Umariya by local farmers were collected, for each species five samples were collected randomly at their maturity stage and seasons in plastic bags and brought to laboratory. Samples were firstly wiped with 0.01 N HCl and then washed with tap water followed by rinsing with deionised water. The various plant parts viz., tops and roots were separated and dried in forced-drought oven at 70 °C for 48 h and were grind by a cross beater grinding mill. For measurement of metal concentration (As, Cd, Cr, Cu, Fe, Mn, Ni, Pb and Zn), all the samples were digested with $HClO_4$:HNO_3 (1:4 v/v) and diluted with milli-Q water. Total As in the samples was analyzed following Abedin et al. (2002). Samples were digested in 1 ml of concentrated HNO_3 on a heating bath at 180 °C for 1 h and subsequently at 200 °C to evaporate the samples to dryness. The residue was taken up in 10 ml of 10% HCl (w/v) containing 10% KI (w/v) and 5% ascorbic acid (w/v). Metal concentrations were measured on the Inductively-Coupled Plasma Spectrometer, Perkin Elmer Corporation (ICP Optima 3300 RL).The standard reference materials of Fe, Zn (BND 1101.02; provided by the National Physical Laboratory, New Delhi, India), Cd, Cr, Cu, Pb (EPA quality control samples; Lot TMA989) were used for the calibration and quality assurance. Analytical data quality of the metals was ensured through repeated analysis ($n=3$) of standard reference samples and the results were found to be within $\pm 2.03\%$ to $\pm 2.95\%$ of certified values. The mean recovery was about 96–98.5% for different metals. The blanks were run in triplicate to check the precision of the method with each set of samples. The detection limits for Fe, Zn, Cd, Cr, Cu, Pb and As were 0.3, 0.2, 0.9, 0.5, 0.9, 1.5 and 0.3 ppb, respectively.

2.5. Statistical analysis

All experiments were carried out in triplicate, to confirm the variability of data and validity of results, all data were subjected to analysis of variance (ANOVA) and for group wise comparison of means Duncan's multiple range test (DMRT) was applied to see the significant level amongst various treatments (Gomez and Gomez, 1984).

2.6. Translocation factor (TF)

Translocation factor is calculated as the ratio of metal concentration in aerial parts plants and metal concentration in plant root, i.e.

$$TF = (C_{aerial}/C_{root}),$$

where, C_{aerial} is the conc. in plant's aerial part and C_{root} is the conc. in plant's root.