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Accumulation and health risk of heavy metals in sugarcane irrigated with industrial effluent in some rural areas of Uttarakhand, India

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ABSTRACT

This study presents the results of heavy metal analysis in soils and sugarcane being irrigated using paper mill industrial effluent. Sampling was done in a total of 10 rural areas of district Udham Singh Nagar, Uttarakhand, India and level of chromium (Cr), copper (Cu), lead (Pb), nickel (Ni), cadmium (Cd), zinc (Zn), iron (Fe), and magnesium (Mg) in soil and plant was then analyzed using atomic absorption spectrophotometer (AAS). The concentrations ($mg\,kg^{-1}$) of heavy metal in soils was 24.10–67.58, 0.01–0.28, 21.34–50.35, 0.63–72.0, 32.3–43.0, 202.2–209.6, 565.1–566.9, 0.23–12.90 in topsoil and 26.0–71.98, 0.01–0.26, 21.45–50.99, 28.38–68.76 31.62–40.21, 200.46–204.11, 565.08–566.95 and 0.01–1.30 in subsoil for Cr, Cd, Cu, Zn, Ni, Mg, Fe and Pb, respectively. In the edible part of sugarcane concentration ($mg\,kg^{-1}$) of Cr, Cu, Cd, Pb, Zn and Ni was 10.54–60.22, 3.56–22.38, 0.001–0.15, 0.01–1.11, 4.55–48.9, and 1.87–4.42, respectively. Cr and Ni content in sugarcane were higher than the guideline value of World health Organization (WHO)/Food & Agriculture Organization (FAO) and Indian Standards (IS). The bioconcentration factor (BCF) was found in the ranges of 0.06 to 0.95 for all metals. The BCF trend for the present investigation was Mg > Cr > Cd > Fe > Pb > Cu > Zn > Ni. Sugarcane juice is consumed by rural people, thus the human health risk was measured using the concentration of total heavy metals in sugarcane juice using estimated daily intake (EDI) and total hazard quotient (THQ). The total EDI was $2.1 \times 10^{-1}\,mg^{-1}\,kg^{-1}\,day^{-1}$ in adults and $2.2 \times 10^{-1}\,mg^{-1}\,kg^{-1}\,day^{-1}$ in children in this region. THQ values were less than 1 (safe limit) but long-term consumption of contaminated sugarcane juice can create serious human health issues in this region. Results suggest anthropogenic load of heavy metal in cultivated lands of rural areas of this region.

1. Introduction

The agriculture sector is the major user of fresh water resources in India, but sustainable water availability is highly questionable not only for this sector but for other sectors like industries and domestic supply. In a concern to conserve freshwater supplies, the recovery and reuse of wastewaters presents a valid and affordable solution to meet the demands. Several countries across the globe, with limited resources of freshwater, have selected reuse/recycling of wastewater to deal with the water crisis (Angelakis et al., 1999; Xu et al., 2014). Irrigation with treated wastewaters has become one of the major substitutes to maintain the existing resources of water and improve the existing urban water supplies in many cities (Biggs and Jiang, 2009). In addition, of being a source of irrigation water, these wastewaters contain substantial amounts of plant nutrients that can benefit the soil by adding the N, P, many other essential plant micronutrients

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(Duncan et al., 2009; Martinez et al., 2011) and organic matter (Liu et al., 2005). However, such wastewater also contains the significant amounts of heavy metals and other industrial toxicants which can pose serious threats to the chemical quality of soil and crops (Tripathi et al., 1997; Khan et al., 2008a; Sharma et al., 2009; Balkhair and Ashraf, 2015). Few empirical studies from India have indicated heavy metal contamination in the soils due to wastewater irrigation and its further transfer to vegetable crops (Tripathi et al., 1997; Sharma et al., 2007, 2008, 2009; Khillare et al., 2011). Few heavy metals (As, Cd, Cr, Cu, Pb, Ni, Zn, etc.) found commonly in most of urban wastewater and utility of such water for soil irrigation cause heavy metal enrichments in soils. Excessive accumulation of heavy metals in soil causes effect on food quality and health safety (Muchuweti et al., 2006).

Food chain translocation of heavy metal is one of the consequences of soil contaminated with heavy metals (Khan et al., 2008b; Nasreddine and Parent-Massin, 2002; Türkdoğan et al., 2003). Crops grown on the metal-contaminated soils accumulate metals in excessive quantities enough to cause health hazards in human beings consuming these metal rich plants. The dietary intake is considered as the main route of exposure to heavy metals in population living in the vicinity of contaminated sites (Tripathi et al., 1997). Heavy metal uptake by plants depends on the form in the soil and on the plant species. The ingestion of some metals, e.g. Cd, Cu, Ni and Pb leads to depletion of some essential nutrients in the body, which in turn causes physiological disorders like – decrease in immunological defenses, intrauterine growth retardation (caused by Al, Cd, Mn and Pb), psychosocial dysfunctions, disabilities and a high prevalence of upper gastrointestinal cancer (Iyengar and Nair, 2000; Türkdoğan et al., 2003). Some heavy metals, such as Cd and Pb are considered to be a cancer causing agent (Trichopoulos et al., 1997).

This study aimed to investigate the level of heavy metals in soils and in standing crop in some rural areas located around the vicinity of an industrial unit in Udham Singh Nagar district, Uttarakhand, India. Due to scarcity of water, the farmers of this area have been using effluent (mainly discharged by a local paper mill) without any dilutions to irrigate their crops. The level of heavy metals (Cr, Cu, Cd, Pb, Ni, Zn, Fe and Mg) in soil (top- and sub-soil) of crop-field and in standing crop, i.e. sugarcane was estimated. Using the results of analysis the health risk in human, due to consumption of heavy metal contaminated plants, was also calculated for local human population residing in this area.

2. Materials and methods

2.1. Study site

The study area is located in the Udham Singh Nagar district, Uttarakhand, India. The prosperous district of Udham Singh Nagar is endowed with a very fertile land. The agriculture is the mainstay and few industries are also located in this part of the State. The average rainfall in this area is 1296.85 mm. The main soil type of this area is deep loams and sandy and the major food crops cultivated in this region are: rice, wheat, barley, sugarcane and vegetables (tomato, pea, etc.). A large public-owned pulp and paper mill – Century Pulp and Paper Mill is located in this area which is considered to be one of the largest paper mills in the country. The main unit of the industry is located at *Lalkuan*. The paper mill is one of the largest water consuming industries therefore; supply of water in this mill is made through boreholes. As per report of central groundwater board, the groundwater is of good quality and all parameters well within the permissible limits. As per the land use map the industry is surrounded by dense reserve forest on the western side, urban settlement on the Northwest side and agricultural land on the eastern and southern side. The major agriculture crop grown in the adjoined areas of industry are: sugarcane, wheat, rice, barley, etc. The treated or partially treated wastewater from the industry is disposed through a large open wastewater channel in surrounding areas and the majority of its quantity is being utilized directly (without any dilution) by local farmers to irrigate their food crops. The industry is located around 7 km far from crop fields. The wastewater drain is around 9–10 km long and finally meets to a local dried river bed. However, the economic status of farmers of this area is not good therefore; most of farmers cannot afford the cost of installing boreholes in their farms to fetch groundwater for irrigation purposes. No surface water body is available to support irrigation system in this area. Framers prefer industrial effluent, which is available freely in plenty form, to irrigate their crops. To analyze the chemical characteristics, a sample of industrial effluent was collected from effluent outlet point of the industry and then analyzed for different chemical characteristics by following standard methodology as described by APHA-AWWA-WPFC (1994). The overall characteristics of industrial wastewater available for the irrigation purposes are presented in Table 1.

Table 1 – Physico-chemical parameters of the industrial effluent being used for crop irrigation purposes.

Parameters	Observed value (mean ± S.D)	Permissible limit[a] (EPR, 1986)
pH	5.12 (0.06)	–
EC (ds m^{-1})	1.43 (0.15)	–
Na (mg L^{-1})	88.07 (11.82)	–
K (mg L^{-1})	44.12 (2.20)	–
Cr (mg L^{-1})	48.41 (1.3)	2
Cu (mg L^{-1})	7.36 (1.6)	3.0
Cd (mg L^{-1})	1.21 (3.21)	2.0
Pb (mg L^{-1})	1.11 (1.06)	0.1
Ni (mg L^{-1})	3.54 (1.13)	3.0
Zn (mg L^{-1})	50.91 (2.12)	5.0
Mg (mg L^{-1})	116 (0.41)	–
Fe (mg L^{-1})	212 (1.12)	–

[a] Standard for effluent discharge to inland surface water.

2.2. Soil and plant sampling

The Soil in the study area is calcareous, moderately productive and suitable for extensive cultivation of high yielding variety of crops like rice and sugarcane. The soil samples were collected from crop fields located at the *Shantipuri* village which is 7–8 km far from the main industrial unit setup. A total of 30 samples of each soil sub-group (top soil – 0–15 cm and sub soil – 15–35 cm) from 10 different locations of this study area were collected. The random sampling was done in crop fields from different localities. From single sampling area a total of three samples of soils (top- and sub-soil) were collected by following the standard methodology as described by (Carter and Gregorich, 2008). A gap between two sampling's filed was maintained in order to avoid duplicity in sampling sites. The sampled soil was stored in contamination free fresh