

Heavy Metals Accumulation in Soil and Agricultural Crops Grown in the Province of Asahi India Glass Ltd., Haridwar (Uttarakhand), India

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Abstract

This investigation was aimed to assess the heavy metals accumulation in soil and agricultural crops viz., Indian mustard (*Brassica juncea* L.), wheat (*Triticum aestivum* L.) and barley (*Hordeum vulgare* L.) irrigated with glass industry effluent. The glass industry effluent was considerably loaded with various plant nutrients and heavy metals. The effluent irrigation significantly ($P < 0.05/P < 0.01$) increased Cd, Cr, Cu, Fe, Mn, Pb, Zn, total bacteria, total fungi, actinomycetes and yeast of the soil used for the cultivation of *B. juncea*, *T. aestivum* and *H. vulgare*. The enrichment of different heavy metals were recorded in the order of $Cr > Pb > Cd > Mn > Zn > Cu > Fe$ for *B. juncea*, $Zn > Cd > Cu > Cr > Pb > Fe > Mn$ for *T. aestivum* and $Zn > Cu > Cd > Fe > Mn > Pb > Cr$ for *H. vulgare* irrigated with glass industry effluent. The translocation of different metals in different parts i.e. root, stem, leaves and fruits were observed in the order of leaves > stem > root > fruit for Cu, Fe, Mn, Pb and Zn; stem > leaves > root > fruit for Cd, root > stem > leaves > fruit for Cr in *B. juncea*, *T. aestivum* and *H. vulgare* irrigated with glass industry effluent. Therefore, glass industry effluent irrigation added heavy metals in the soil and *B. juncea*, *T. aestivum* and *H. vulgare*.

Keywords: Accumulation; Agricultural crops; Enrichment factor; Glass industry effluent; Heavy metals; Soil

Introduction

Contamination of soil and agricultural crops from industrial waste is a result of various types of industrial processes and disposal practices [1-4]. Industries that use large amounts of water for processing have the potential to pollute waterways through the discharge of their waste into streams and rivers, or by run-off and seepage of stored wastes into nearby water sources [5-7]. Other disposal practices which cause water contamination include deep well injection and improper disposal of wastes in surface impoundments. Discharge of industrial effluent without adequate treatment causes severe degradation in the pedosphere, hydrosphere, and atmosphere [8-10]. Effluents from industries contain appreciable amounts of nitrogen (N), phosphorus (P), sodium (Na), potassium (K), calcium (Ca), and magnesium (Mg) along with zinc (Zn), copper (Cu), iron (Fe), manganese (Mn), lead (Pb), nickel (Ni), and cadmium (Cd), and their disposal cause contamination of soil and water environment [2,11-13].

With the rapid enhancement in industrial establishment, there has been substantial increase in the liquid waste which is traditionally discharged either into open land or nearby water courses [14,15]. Industrial effluent is mostly used for the fertigation of agricultural crops, mainly in urban and periurban regions, due to its easy availability, disposal problems and scarcity of irrigation water. In addition, the industrial effluents are the main sources of soil and water contamination [16-18]. Although, effluent irrigation can alleviate water scarcity situations and allows farmers to reduce the purchase of chemical fertilizer and of organic matter that serves as soil conditioner and humus replenishment [10]. However, unregulated irrigation with untreated wastewater poses serious public health risks, as effluent is a major source of heavy metals that cause accumulation in plant parts [13,19,20]. Heavy metals accumulation in agricultural soils is of increasing worldwide concern and particularly in India with the rapid development of industrialization and urbanization [21-23]. The crop plants take up heavy metals and accumulate them in their edible and inedible parts in quantities high enough to cause clinical problems both to animals and human beings consuming these metal-rich plants [4,24,25]. Moreover, a number of serious health problems can develop as

a result of excessive uptake of dietary heavy metals [26,27]. Additionally, the heavy metals such as cadmium (Cd), chromium (Cr), copper (Cu), iron (Fe), nickel (Ni) and zinc (Zn) reaches to the soil through effluent irrigation, and accumulates in plant and vegetable parts, and cause adverse health effects [15,23,28-30]. Keeping in view the present investigation was carried out to the heavy metals accumulation in soil and agricultural crops grown in the Province of Asahi India Glass Ltd., Haridwar (Uttarakhand), India.

Materials and Methods

Study area

Asahi India Glass Ltd. Jhabrera, Roorkee, Haridwar (29°47'50"N 77°48'23"E) was selected for the present study. The glass industry is located about 45 km away from Haridwar at Haridwar Saharanpur via Jhabrera Highway. Asahi India Glass is the largest integrated glass company in India. They manufacture a wide range of international quality automotive safety glass, float glass, architectural processed glass and glass products. The glass industry is using a large quantity of fresh water and discharged huge amount of effluent. The effluent is being used by the farmers in the cultivation of agricultural crops.

Collection of effluent samples and their analysis

The effluent samples were collected from the effluent disposal channel used for the irrigation of agricultural crops in the vicinity of glass industry. Bore well water is considered as control. The samples of

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glass industry effluent and bore well water were collected in thoroughly cleaned plastic containers of 5 liters capacity separately. The samples were brought to the laboratory and were analyzed for various physico-chemical parameters and microbiological viz., total dissolved solids (TDS), electrical conductivity (EC), pH, biochemical oxygen demand (BOD), chemical oxygen demand (COD), total Kjeldahl nitrogen (TKN), phosphate (PO_4^{3-}), sodium (Na^+), potassium (K^+), calcium (Ca^{2+}), magnesium (Mg^{2+}), cadmium (Cd), chromium (Cr), copper (Cu), iron (Fe), lead (Pb), manganese (Mn), zinc (Zn), total bacteria, total fungi, total coliform and yeast following standard methods [31].

Collection of soil samples and their analysis

The soil samples from the surface (0-20 cm) were collected from the effluent irrigated agricultural fields in the vicinity of Asahi India Glass Ltd. The bore well water irrigated soil was taken as control. The samples were brought to the laboratory and dried in clean plastic trays for 7 days at room temperature and then sieved through a 2 mm sieve. The samples were analyzed for various physico-chemical and microbiological parameters viz., viz., EC, organic carbon (OC), TKN, PO_4^{3-} , Na^+ , K^+ , Ca^{2+} , Mg^{2+} , Cd, Cr, Cu, Fe, Mn, Pb, Zn, total bacteria, total fungi, actinomycetes and yeast following standard methods [32].

Collection of agricultural crops samples and their analysis

Glass industry effluent irrigated crops viz., Indian mustard (*Brassica juncea*), wheat (*Triticum aestivum*) and barley (*Hordeum vulgare*) grown in the vicinity of Glass Industry were selected for the present study. Bore well water irrigated *B. juncea*, *T. aestivum* and *H. vulgare* were taken as control. The samples of *B. juncea*, *T. aestivum* and *H. vulgare* from effluent and bore well water irrigated agricultural field were collected in the polythene bags separately. The samples were brought to the laboratory and washed thrice under tap water and followed by distilled water. The crop samples were cut with a sharp knife then air dried and ground and sieved. For the extraction of metals, 10 ml sample

of wastewater, 1.0 g sample of air dried soil/crops was taken in digestion tube. In each sample 3 ml concentrate HNO_3 was added and digested on electrically heated block for 1 hour at 145°C . Then 4 ml of HClO_4 was added and heated to 240°C for an additional hour. The aliquot was cooled, filtered through Whatman # 42 filter paper and the volume was made 50 ml with double distilled water and used for analysis. The metals were analyzed by using atomic absorption spectrophotometer (PerkinElmer Analyst 800 AAS) following standard methods. The enrichment factor for metals accumulated in wastewater irrigated soil and vegetables were calculated by following formula.

$$\text{Enrichment factor} = \frac{\text{Mean content of metal in the sample}}{\text{Mean metal content in the control}}$$

Statistical analysis

The values reported here are means of six values. Data were tested at different significant levels using student t-test to measure the variations between the soil parameters before and after irrigation of these crops with wastewater. One way analysis of variance (ANOVA) was used for data analysis to measure the variations of metals in different parts of these crops before and after glass industry effluent irrigation was calculated with the help of MS Excel, 2013.

Results and Discussion

Occurrence of heavy metals in industrial effluents

The physico-chemical and microbiological properties of glass industry effluent are presented in Table 1. The results revealed that the glass industry effluent was considerably rich in various plant nutrients like TKN (384.75 mg L^{-1}), PO_4^{3-} (145.67 mg L^{-1}), Na^+ (185.65 mg L^{-1}), K^+ (220.90 mg L^{-1}), Ca^{2+} (450.87 mg L^{-1}), Mg^{2+} (230.00 mg L^{-1}) and heavy metals Cd (2.75 mg L^{-1}), Cr (1.26 mg L^{-1}), Cu (6.88 mg L^{-1}), Fe (12.89 mg L^{-1}), Mn (1.54 mg L^{-1}), Pb (2.36 mg L^{-1}) and Zn (8.80 mg L^{-1}). The values of TDS (3640 mg L^{-1}), BOD ($1450.60 \text{ mg L}^{-1}$), COD

Parameter	Borewell water (control)	Composite effluent	BIS disposal standards
TDS (mg L^{-1})	210.50 ± 2.58	3640 ± 3.64	1900
EC (dS cm^{-1})	0.24 ± 0.04	3.24 ± 0.14	-
pH	7.45 ± 0.05	7.85 ± 0.08	5.5-9.0
BOD ₅ (mg L^{-1})	4.59 ± 0.08	1450.60 ± 4.50	100
COD (mg L^{-1})	8.97 ± 0.25	1890.80 ± 5.20	250
TKN (mg L^{-1})	28.90 ± 1.08	384.75 ± 2.96	100
PO_4^{3-} (mg L^{-1})	0.04 ± 0.01	145.67 ± 1.05	-
Na^+ (mg L^{-1})	10.66 ± 0.21	185.65 ± 2.30	-
K^+ (mg L^{-1})	6.80 ± 0.15	220.90 ± 2.40	-
Ca^{2+} (mg L^{-1})	26.90 ± 0.16	450.87 ± 3.74	200
Mg^{2+} (mg L^{-1})	14.66 ± 0.23	230.00 ± 2.66	-
Cd (mg L^{-1})	0.36 ± 0.02	2.75 ± 0.05	2.00
Cr (mg L^{-1})	0.08 ± 0.01	1.26 ± 0.02	2.00
Cu (mg L^{-1})	1.26 ± 0.02	6.88 ± 0.08	3.00
Fe (mg L^{-1})	1.45 ± 0.03	12.89 ± 0.25	1.0
Mn (mg L^{-1})	0.36 ± 0.01	1.54 ± 0.03	-
Zn (mg L^{-1})	2.17 ± 0.54	8.80 ± 0.06	15
Pb (mg L^{-1})	0.24 ± 0.02	2.36 ± 0.04	-
Total bacteria (CFU ml^{-1})	$5.64 \times 10^3 \pm 4.00$	$8.57 \times 10^8 \pm 14.00$	10000
Total fungi (CFU ml^{-1})	$3.75 \times 10^2 \pm 5.00$	$5.23 \times 10^5 \pm 12.00$	-
Total coliform (MPN 100 ml^{-1})	$2.23 \times 10^2 \pm 3.00$	$4.26 \times 10^3 \pm 6.00$	5000
Yeast (CFU ml^{-1})	$1.43 \times 10^2 \pm 2.00$	$3.76 \times 10^3 \pm 7.00$	-

Mean ± SE of six values; BIS- Bureau of Indian Standards

Table 1: Physico-chemical and microbiological characteristics of glass industry effluent.

(1890.80 mg L⁻¹), TKN, Ca²⁺, Cd, Cu, Fe and Zn were observed beyond the prescribed limit of BIS irrigation standards [33]. Moreover, higher values of microbiological parameter total bacteria (8.57 × 10⁸ CFU ml⁻¹), total fungi (5.23 × 10⁵ CFU ml⁻¹), total coliform (4.26 × 10³ MPN 100 ml⁻¹) and yeast (3.76 × 10³ CFU ml⁻¹) were also observed in the glass industry effluent. The higher value of EC (3.24 dS cm⁻¹) is the indicator of more ionic species in the glass industry effluent. The higher values of BOD, COD, TKN and PO₄³⁻ in the glass industry effluent are the indicator of higher organic load of the effluent and it is likely due to the mixing of sewage in the glass industry effluent generated from the staff quarters and offices located in the premises of the glass industry. The higher contents of heavy metals the glass industry effluent is might be associated with silicate minerals using as raw materials in the glass manufacturing and various colouring agents to make the coloured glass panels. Kumar and Chopra [13] also reported higher values of BOD (1256.50 mg L⁻¹), COD (2832.50 mg L⁻¹), Cd (2.98 mg L⁻¹), Cr (1.68 mg L⁻¹), Cu (3.56 mg L⁻¹), Fe (15.25 mg L⁻¹), Pb (0.94 mg L⁻¹), Zn (6.42 mg L⁻¹), total bacteria (9.89 × 10⁷ SPC mL⁻¹) and coliform bacteria (5.69 × 10⁶ MPN 100 mL⁻¹) in the paper mill effluent. Therefore, the glass industry effluent showed higher organic as well as inorganic pollution load.

Occurrence of heavy metals in agricultural soil

Table 2 showed the soil characteristics used in the cultivation of *B. juncea*, *T. aestivum* and *H. vulgare* irrigated with glass industry effluent and bore well water. On perusal of data it is clearly indicated that glass industry effluent significantly (P<0.05/P<0.01/P<0.001) increased EC, OC, TKN, PO₄³⁻, Na⁺, K⁺, Ca²⁺, Mg²⁺, Cd, Cr, Cu, Fe, Mn, Pb, Zn, total bacteria, total fungi, actinomycetes and yeast of the soil used for the cultivation of *B. juncea*, *T. aestivum* and *H. vulgare* compared to bore well water. During the investigation the soil was loamy in texture and no significant change was observed in the soil texture during the study. The pH value is an important parameter, as many nutrients are available only at a particular range of pH for plant uptake. A pH value

of 6.0–8.2 provides predominating bacterial activity and is favorable for maximum yield of crops. The pH of the soil was ranged (7.56-7.68) after irrigation with glass industry effluent. The higher content of OC, TKN and PO₄³⁻ were recorded in the soils used for the cultivation of *B. juncea*, *T. aestivum* and *H. vulgare* which is likely due the more organic nature of glass industry effluent. The higher contents of OC (3.45-4.12 mg Kg⁻¹), TKN (268.58-298.50 mg Kg⁻¹) and PO₄³⁻ (114.67-173.77 mg Kg⁻¹) were recorded in the soil used for the cultivation of *B. juncea*, *T. aestivum* and *H. vulgare*. The higher values of OC, TKN and PO₄³⁻ are the indicator of soil fertility and support the higher population of microbial communities in the soil as earlier reported by Kumar and Chopra [7]. The contents of different heavy metals in the soil used for the cultivation of *B. juncea*, *T. aestivum* and *H. vulgare* were ranged Cd (0.66-0.84 mg Kg⁻¹), Cr (0.24-0.28 mg Kg⁻¹), Cu (4.37-5.84 mg Kg⁻¹), Fe (6.84-7.58 mg Kg⁻¹), Mn (1.38-1.56 mg Kg⁻¹), Pb (0.23-0.29 mg Kg⁻¹), Zn (3.75-4.15 mg Kg⁻¹) after irrigation with glass industry effluent (Table 2). The most contents of heavy metals were recorded in the soil used for the cultivation of *T. aestivum* while the least were found in the soil used for the cultivation of *B. juncea*. Thus it clearly indicated that *B. juncea* was more efficient for the uptake of heavy metals compared to *H. vulgare* and *T. aestivum*. The findings are in line of Chopra et al. [18] who reported higher contents of Cd (4.34 mg Kg⁻¹), Cr (1.65 mg Kg⁻¹), Cu (7.86 mg Kg⁻¹), Fe (10.55 mg Kg⁻¹), Mn (1.87 mg Kg⁻¹) and Zn (8.85 mg Kg⁻¹) in the paper mill effluent irrigated soil. Significant (P<0.05/P<0.01) microbial population in the form of total bacteria (4.85 × 10⁷-7.75 × 10⁹ CFU g⁻¹), total fungi (3.25 × 10⁵-6.35 × 10⁶ CFU g⁻¹), actinomycetes (5.88 × 10³-9.86 × 10⁴ CFU g⁻¹) and yeasts (4.00 × 10⁴-5.65 × 10⁵ CFU g⁻¹) were observed in the soil irrigated with glass industry effluent compared to control soil (bore well water irrigated soil) (Table 2). The findings are in accordance with Beligh et al. [16] who reported significantly higher microbial community in the soil irrigated with olive mill wastewater. The organic carbon and pH are principal components that control the accessibility of heavy metals in the soil. Increasing the soil organic carbon can enhance the soil electrical conductivity and effective cation exchange capacity, which is

Parameter	Borewell water irrigated soil (control)	Glass industry effluent irrigated soil		
		<i>B. juncea</i>	<i>T. aestivum</i>	<i>H. vulgare</i>
EC (dS cm ⁻¹)	2.18 ± 0.05	3.04* ± 0.06	3.40* ± 0.08	3.13* ± 0.06
pH	7.49 ± 0.04	7.56 ± 0.03	7.62 ± 0.04	7.68 ± 0.05
OC	0.56 ± 0.02	3.45** ± 0.10	4.12** ± 0.15	3.87** ± 0.13
TKN (mg Kg ⁻¹)	33.41 ± 3.94	268.58*** ± 4.27	298.50*** ± 1.84	285.18*** ± 2.84
PO ₄ ³⁻ (mg Kg ⁻¹)	55.54 ± 5.72	114.67*** ± 1.86	173.77*** ± 1.24	121.56*** ± 1.95
Na ⁺ (mg Kg ⁻¹)	21.32 ± 2.50	28.96* ± 2.17	33.28* ± 1.64	49.84** ± 1.47
K ⁺ (mg Kg ⁻¹)	169.01 ± 3.06	188.96* ± 1.95	219.97* ± 2.36	210.06* ± 1.06
Ca ²⁺ (mg Kg ⁻¹)	17.73 ± 1.94	118.75** ± 2.36	129.92*** ± 2.05	122.03*** ± 1.16
Mg ²⁺ (mg Kg ⁻¹)	1.72 ± 1.0	12.67*** ± 1.02	16.75*** ± 1.02	18.94*** ± 1.01
Cd (mg Kg ⁻¹)	0.24 ± 0.07	0.66** ± 0.03	0.84** ± 0.03	0.75** ± 0.02
Cr (mg Kg ⁻¹)	0.17 ± 0.06	0.24* ± 16	0.28* ± 16	0.26* ± 0.09
Cu (mg Kg ⁻¹)	2.37 ± 0.35	4.37* ± 0.91	5.84* ± 0.91	5.26* ± 1.07
Fe (mg Kg ⁻¹)	3.13 ± 0.44	6.96* ± 0.75	7.58** ± 0.75	6.84* ± 0.09
Mn (mg Kg ⁻¹)	0.11 ± 0.06	1.38** ± 16	1.56** ± 16	1.43** ± 0.03
Zn (mg Kg ⁻¹)	1.96 ± 17	3.75* ± 0.35	4.15** ± 0.35	4.02** ± 0.08
Pb (mg Kg ⁻¹)	0.07 ± 0.06	0.23** ± 0.02	0.29** ± 0.02	0.25** ± 0.01
Total bacteria (CFU g ⁻¹)	2.56 × 10 ⁶ ± 8.00	7.75 × 10 ⁹ *** ± 6.00	5.69 × 10 ⁸ ** ± 9.00	4.85 × 10 ⁷ ** ± 7.00
Total fungi (CFU g ⁻¹)	1.45 × 10 ⁵ ± 4.00	6.35 × 10 ⁶ * ± 4.00	3.25 × 10 ⁵ * ± 5.00	4.05 × 10 ⁵ * ± 3.00
Actinomycetes (CFU g ⁻¹)	1.67 × 10 ³ ± 5.00	9.86 × 10 ⁴ ** ± 8.00	6.93 × 10 ³ * ± 6.00	5.88 × 10 ³ * ± 7.00
Yeast (CFU g ⁻¹)	3.45 × 10 ⁶ ± 6.00	5.65 × 10 ⁵ * ± 7.00	4.12 × 10 ⁴ ** ± 9.00	4.00 × 10 ⁴ * ± 5.00

Mean ± SE of six values; Significant F -***P-0.1%, **P-1% level, *P-5% level of ANOVA to the control.

Table 2: Effects of glass industry effluent irrigation on soil characteristics used for the cultivation of *B. juncea*, *T. aestivum* and *H. vulgare*.

a reason that may affect both soluble and exchangeable metals [2,34]. However, in the present study, the effects of glass on the soil pH seemed to be one of the promising factors, which affects the availability, and accumulation of Cd, Cr, Cu, Fe, Mn, Pb and Zn. Despite the fact that, the contents of Cd, Cr, Cu and Zn were found to be below the maximum levels permitted for Cd (6.0 mg kg⁻¹), Cr (10.0 mg kg⁻¹), Cu (270 mg kg⁻¹) and Zn (600 mg kg⁻¹) for soil in India [33]. However, there was gradual buildup of these metals in the glass industry effluent irrigated soil and this is likely due to the addition of more organic carbon in the soil which provides more binding sites for the attachment of these metals. Therefore, glass industry effluent irrigation significantly altered the contents of heavy metals in the soil used for the cultivation of *B. juncea*, *T. aestivum* and *H. vulgare*.

Occurrence of heavy metals in agricultural crops

During the present investigation, the contents of heavy metals Cd (3.54-5.09 mg Kg⁻¹), Cr (0.71-2.27 mg Kg⁻¹), Cu (9.73-10.99 mg Kg⁻¹), Fe (10.08-12.89 mg Kg⁻¹), Mn (1.55-3.22 mg Kg⁻¹), Pb (1.27-2.42 mg Kg⁻¹) and Zn (8.28-11.60 mg Kg⁻¹) were ranged in *B. juncea*, *T. aestivum* and *H. vulgare* after irrigation with glass industry effluent (Figures 1-3). The maximum contents of Cd, Cr, Cu, Fe, Mn, Pb and Zn were recorded in *B. juncea* while the least contents of these metals were observed in *T. aestivum* after irrigation with glass industry effluent. The enrichment of different heavy metals were recorded in the order of Cr>Pb>Cd>Mn>Zn>Cu>Fe for *B. juncea*, Zn>Cd>Cu>Cr>Pb>Fe>Mn for *T. aestivum* and Zn>Cu>Cd>Fe>Mn>Pb>Cr for *H. vulgare* after irrigation with glass industry effluent (Figure 4). The translocation of metals in different parts i.e. root, stem, leaves and fruits of *B. juncea* was ranged Cd (0.76-1.65 mg Kg⁻¹), Cr (0.42-0.76 mg Kg⁻¹), Cu (2.09-3.74 mg Kg⁻¹), Fe (2.42-4.08 mg Kg⁻¹), Mn (0.64-0.96 mg Kg⁻¹), Pb (0.44-0.72 mg Kg⁻¹) and Zn (2.12-3.75 mg Kg⁻¹); in *T. aestivum* Cd (0.45-1.12

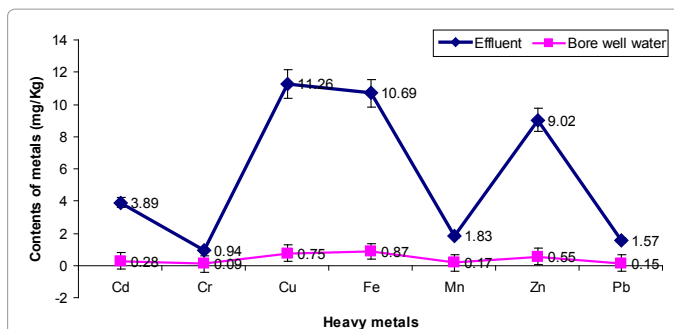


Figure 3: Content of different heavy metals in *H. vulgare* irrigated with glass industry effluent. Error bars are the standard error of the mean.

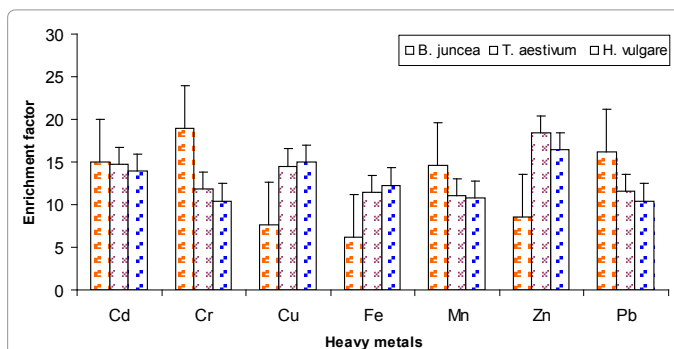


Figure 4: Enrichment factor of different heavy metals in *B. juncea*, *T. aestivum* and *H. vulgare* irrigated with glass industry effluent. Error bars are the standard error of the mean.

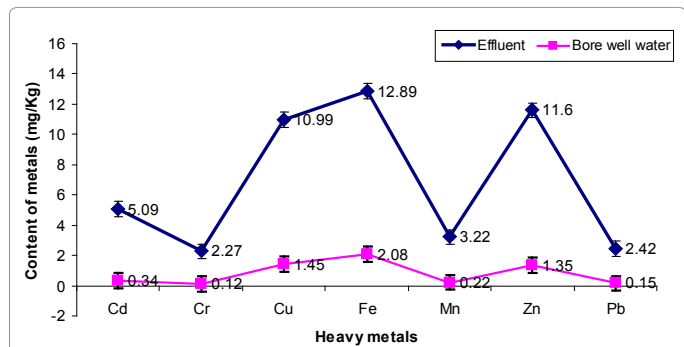


Figure 1: Content of different heavy metals in *B. juncea* irrigated with glass industry effluent. Error bars are the standard error of the mean.

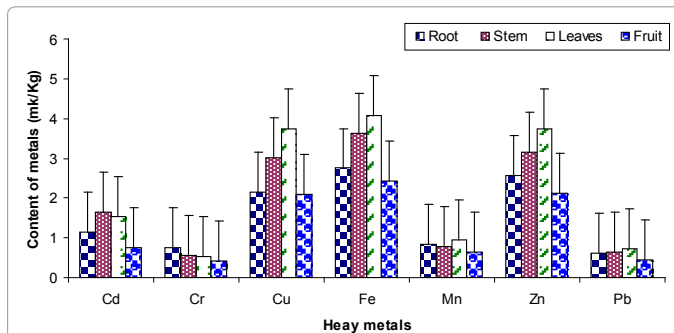


Figure 5: Translocation of heavy metals in different parts of *B. juncea* irrigated with glass industry effluent. Error bars are the standard error of the mean.

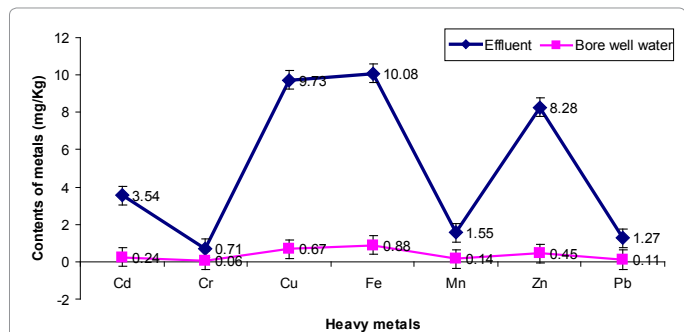


Figure 2: Content of different heavy metals in *T. aestivum* irrigated with glass industry effluent. Error bars are the standard error of the mean.

mg Kg⁻¹), Cr (0.08-0.28 mg Kg⁻¹), Cu (1.88-3.05 mg Kg⁻¹), Fe (1.65-3.12 mg Kg⁻¹), Mn (0.24-0.52 mg Kg⁻¹), Pb (0.21-0.42 mg Kg⁻¹) and Zn (1.38-2.41 mg Kg⁻¹) and in *H. vulgare* Cd (0.54-1.29 mg Kg⁻¹), Cr (0.11-0.36 mg Kg⁻¹), Cu (1.99-3.08 mg Kg⁻¹), Fe (1.96-3.24 mg Kg⁻¹), Mn (0.28-0.58 mg Kg⁻¹), Pb (0.25-0.52 mg Kg⁻¹) and Zn (1.78-2.56 mg Kg⁻¹) irrigated with glass industry effluent (Figures 5-7). The translocation of different metals in different parts i.e. root, stem, leaves and fruits were observed in the order of leaves > stem > root > fruit for Cu, Fe, Mn, Pb and Zn; stem > leaves > root > fruit for Cd, root > stem > leaves > fruit for Cr in *B. juncea*, *T. aestivum* and *H. vulgare* after irrigation with glass industry effluent (Figures 5-7). The accessibility and bioaccumulation of metals are governed by numerous environmental factors viz. pH, solubility, and chemical speciation of the metal, presence of humic substances, presence of other metals, salinity, soil mineralogy, texture, and amorphous Fe and Al contents [2,35]. However, the observed differences in the metal

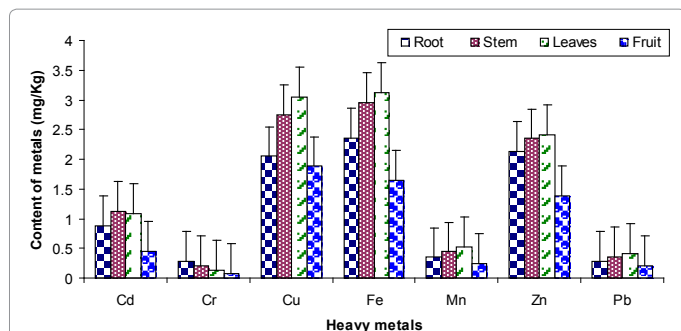


Figure 6: Translocation of heavy metals in different parts of *T. aestivum* irrigated with glass industry effluent. Error bars are the standard error of the mean.

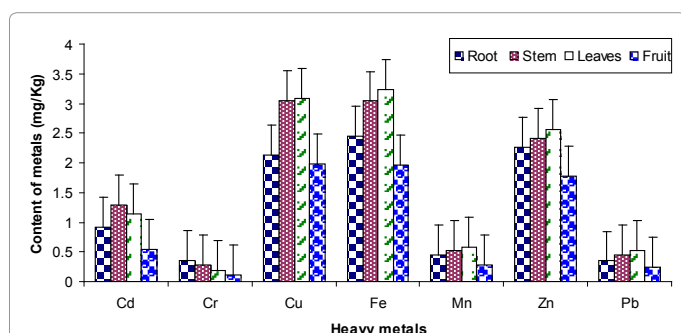


Figure 7: Translocation of heavy metals in different parts of *H. vulgare* irrigated with glass industry effluent. Error bars are the standard error of the mean.

accumulation in the different parts like root, stem, leaves and fruits of the plant suggest different cellular mechanisms of bioaccumulation of heavy metals, which may control their translocation and partitioning in the plant. Cu, Fe, Mn and Zn are associated with the photosynthesis [2,28,36]. The content of Cu, Fe, Mn and Zn was higher in the leaves of *B. juncea*, *T. aestivum* and *H. vulgare* and it is likely due to the higher content of these metals in the glass industry effluent irrigated soil. Cu, Fe and Zn are indispensable for the survival and proliferation of all plants. There is a high demand for Cu, Fe and Zn in the photosynthetic apparatus as a result plants accumulate and translocate Cu, Fe and Zn in their photosynthetic parts [2,36]. Moreover the translocation of Cd, Cr, Cu, Fe, Mn, Pb and Zn are related to the organic matter in the soil, which enhanced their uptake by cultivated plants [2,37].

The contents of Cr were higher in the roots of *B. juncea*, *T. aestivum* and *H. vulgare* than in the aerial parts (i.e., stem, leaves and fruits), indicating that the roots act as barrier for translocation and protect the edible parts from toxic contamination [2]. Deprived translocation of Cr to the shoots and leaves could be due to the sequestration of most of the Cr in the vacuoles of the root cells to render it non-toxic, which may be a natural protective response of this plant [23]. It must be noted that Cr is a toxic and non-essential element to plants and hence the plants may not possess any specific mechanism to transport the Cr [18,34]. The content of Cd, Cr, Cu, Fe, Mn, Pb and Zn were less in the fruits of *B. juncea*, *T. aestivum* and *H. vulgare* and it is likely due to increases in cation-exchange capacity of the soil, which will decrease the uptake of Cd, Cr, Cu, Fe, Mn, Pb and Zn into *B. juncea*, *T. aestivum* and *H. vulgare* plants. Therefore, among *B. juncea*, *T. aestivum* and *H. vulgare*, *B. juncea* was found most efficient compared to *T. aestivum* and *H. vulgare* to translocate and tolerate the metals contents after irrigation with glass industry effluent. Although the contents of Cr, Cu, Mn and

Zn except Cd in *B. juncea*, *T. aestivum* and *H. vulgare* was noted below the permissible limit of FAO/WHO standards for Cd (0.20 mg Kg⁻¹), Cr (2.30 mg Kg⁻¹), Cu (40.00 mg Kg⁻¹) and Zn (60.00 mg Kg⁻¹) [27]. But long-term application of glass industry effluent in the cultivation of *B. juncea*, *T. aestivum* and *H. vulgare* would carry a risk of progressive accumulation of these heavy metals to toxic levels. The findings are in agreement with Chandra et al. [30] who reported the higher content of heavy metals in wheat (*Triticum aestivum* L.) and Indian mustard (*Brassica campestris* L.) irrigated with distillery and tannery effluents.

Conclusions

This study concluded that glass industry effluent irrigation significantly ($P < 0.05/P < 0.01$) changed the soil properties specially increased the contents of different heavy metals viz., Cd, Cr, Cu, Fe, Mn, Pb and Zn in the soil and further in *B. juncea*, *T. aestivum* and *H. vulgare*. The accumulation and translocation of heavy metals were found to be plant part specific and varied from species to species and it is likely due to the uptake efficiency and tolerance capability of different species. The most accumulation of Cd, Cr, Cu, Fe, Mn, Pb and Zn were recorded in *B. juncea* while the least was in *T. aestivum*. The contents of Cr, Cu, Mn and Zn except Cd in *B. juncea*, *T. aestivum* and *H. vulgare* was noted below the permissible limit of FAO/WHO standards but continuous use of glass industry effluent of these crops would increase these metals in these crop plants. Therefore, care should be taken before the use of glass industry effluent in the cultivation of agricultural crops like *B. juncea*, *T. aestivum* and *H. vulgare* crops. Further studies are required on the use of glass industry effluent in the cultivation of different agricultural crops and their health effects after consumption.

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