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COMPARATIVE ANALYSIS OF SOIL PHYSICOCHEMICAL PROPERTIES AND CHROMIUM CONTENT IN SEWAGE AND TUBEWELL WATER-IRRIGATED FIELDS: A STUDY IN MALERKOTLA AND MANDI GOBINDGARH, PUNJAB

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ABSTRACT

Surface (0-15 cm) and sub-surface (15-30 cm) soil samples were collected from fields irrigated with sewage water and tube well water at ten sites each in Malerkotla and Mandi Gobindgarh towns of Punjab. The samples were analyzed for physicochemical properties, DTPA-Cr, and total Cr contents. In Malerkotla, the pH of sewage water-irrigated fields was lower (mean value of 8.14 in the surface and 8.12 in the sub-surface layer) compared to tube well water-irrigated fields (mean value of 8.18 in the surface and 8.29 in the sub-surface layer). In Mandi Gobindgarh, the pH of sewage water-irrigated fields was even lower, with mean values of 7.99 in the surface and 8.08 in the sub-surface soil, while the mean pH of tube well water-irrigated surface soil was 8.17 and 8.29 in the sub-surface soil, decreasing with depth. The electrical conductivity and organic carbon content of sewage water-irrigated soils were observed to be higher in Mandi Gobindgarh compared to Malerkotla. The calcium carbonate content was 1.04% higher in tube well-irrigated soils of Malerkotla compared to Mandi Gobindgarh. The cation exchange capacity of Mandi Gobindgarh was 1.69 times higher than that of Malerkotla. The mean DTPA-Cr in both soils was higher in Malerkotla compared to Mandi Gobindgarh, but the total Cr content was 1.14% higher in Malerkotla. Correlation coefficients of DTPA-Cr and total Cr contents with soil properties showed that organic carbon, pH, calcium carbonate, and clay contents were significantly correlated with DTPA-Cr. Partial regression analysis revealed that pH, organic carbon, cation exchange capacity, silt, and calcium carbonate content significantly explained the variability in DTPA-Cr and total Cr contents.

Keywords: Chromium content, Correlation coefficients, Sewage water, Soil properties

The accumulation of heavy metals in soils poses significant concerns for agricultural production, impacting soil health, crop growth, food quality, and environmental well-being. These metals can accumulate to toxic levels, adversely affecting human life quality. Wastewaters from domestic, commercial, and industrial sources often flow into sewers, eventually reaching water bodies and being utilized for irrigation. Farmers are often attracted to these waters due to their nutrient content. However, continued use of sewage water for irrigation can lead to soil enrichment with heavy metals, posing risks of toxicity.

Malerkotla, a small yet prominent town in the Sangrur district of Punjab, hosts a limited number of industries such as steel and chilled roll production. Waste from these industries, combined with domestic wastewater, enters drainage systems. Mandi Gobindgarh, another small industrial town, is renowned for its iron, steel, and related industries, which also discharge effluents into open drains. In the natural environment, chromium exists primarily in two forms: Cr (III) and Cr (VI). Cr (VI) is more toxic, associated with reduced plant growth and altered morphology, while Cr (III) is comparatively less toxic and mobile. The indiscriminate discharge of industrial and sewage effluents onto agricultural lands has become a significant source of chromium contamination in sewage-irrigated soils. With this in mind, the objective of this study was to explore the relationship between various soil properties and chromium content in soils irrigated with sewage water and tubewell water.

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MATERIALS AND METHODS

Surface (0-15 cm) and sub-surface (15-30 cm) soil samples were collected from ten villages in Malerkotla town, where sewage water has been used for irrigation for many years. These villages include Ahmedgarh (1), Ahmedgarh (2), Mehtabpur (1), Chhipar (1), Jarg road-Malerkotla (1), Secular Public School (1), Jarg road-Malerkotla (2), Harjinder Nagar-Jamalpura (1), Amar colony-Malerkotla (1), and Eidgaah Railway Station-Malerkotla (1). Additionally, soil samples were collected from the same villages at ten different sites where only tube well water was used for irrigation.

Surface and sub-surface soil samples were also collected from Mandi Gobindgarh town, where sewage water was used for irrigation at ten different sites, namely Tooran (2), Kumbarh (3), Badali (5), and Fatehpur (1).

The values given in brackets indicate the number of sites. Soil samples from the same layers were collected from ten different sites in the same villages, where only tube well water was used for irrigation.

The soil samples were processed and analyzed for pH, electrical conductivity, organic carbon, calcium carbonate, and cation exchange capacity using standard methods (Page, 1982). Texture was determined using the International Pipette method (Piper, 1966). Available chromium in the samples was determined using the DTPA method (Lindsay and Norvell, 1978). Soil samples were also analyzed for total chromium content after digestion with HF and $HClO_4$ in Teflon beakers. Chromium analyses in soil extracts were done using ICAP-AES (100ml).

Correlation coefficients between DTPA-extractable chromium and total chromium with different soil properties were determined for both soil layers in sewage water and tube well water-irrigated soils to explain the significance of particular properties in identifying chromium-contaminated sites. Regression coefficients were calculated using SPSS 16.0 statistical software to describe the individual and combined influence of various soil properties on DTPA-extractable chromium in both soil types.

RESULTS AND DISCUSSION

Soil properties

Malerkotla

Sewage water irrigated soil

In Malerkotla, the pH of sewage water-irrigated soils ranged from 7.72 to 8.80 in the surface layer and 7.44 to 8.33 in the sub-surface layer, with mean values of 8.14 and 8.12, respectively (Table 1). Electrical conductivity (EC) varied from 0.09 to 0.39 dSm^{-1} in the surface layer (mean value 0.23 dSm^{-1}) and 0.07 to 0.40 dSm^{-1} in the sub-surface layer (mean value 0.25 dSm^{-1}). Soil organic carbon (SOC) ranged from 0.46 to 0.79 percent and 0.21 to 0.52 percent in the surface and sub-surface layers, with mean values of 0.69 and 0.37 percent, respectively (Table 1).

Calcium carbonate content ranged from nil to 1.44 percent in the surface layer and nil to 2.0 percent in the sub-surface layer, with mean values of 1.02 and 1.13 percent, indicating an increase in the sub-surface layer. Cation exchange capacity (CEC) ranged from 8.09 to 10.90 Cmol kg^{-1} in the surface layer and 6.61 to 10.13 Cmol kg^{-1} in the sub-surface layer, with mean values of 9.42 and 8.80 Cmol kg^{-1}, respectively (Table 1), indicating a decrease in the sub-surface layer. DTPA-Cr ranged from 0.015 to 0.045 mg kg^{-1} in the surface layer and 0.013 to 0.045 mg kg^{-1} in the sub-surface layer, with mean values of 0.03 mg kg^{-1} in both layers. Total Cr ranged from 38.5 to 71.7 mg kg^{-1} in the surface layer and 23.0 to 45.8 mg kg^{-1} in the sub-surface layer, with mean values of 51.0 and 36.2 mg kg^{-1}, respectively, indicating a decrease in the sub-surface layer.

Tube well water irrigated soil

The pH of this soil ranged from 7.75 to 8.52 in the surface layer and 7.87 to 8.67 in the sub-surface layer, with mean values of 8.18 and 8.29, respectively (Table 1). Electrical conductivity (EC) varied from 0.08 to 0.29 dSm^{-1} in the surface layer and 0.09 to 0.31 dSm^{-1} in the sub-surface layer, resulting in mean values of 0.21 and 0.19 dSm^{-1}, indicating a numeric decrease in mean soil EC in the sub-surface layer.

Table 1. Physico-chemical properties of surface and sub-surface soils irrigated with sewage water and tube well water in Malerkotla, Punjab

Soil Property	Sewage water irrigated (SWI)		Tube well water irrigated (TWI)	
	0-15 cm	15-30 cm	0-15 cm	15-30 cm
pH	7.72 – 8.80 (8.14)	7.44 – 8.33 (8.12)	7.75 -8.52 (8.18)	7.87 – 8.67 (8.29)
EC (dS m^{-1})	0.09- 0.39 (0.23)	0.07- 0.40 (0.25)	0.08 – 0.29 (0.21)	0.09- 0.31 (0.19)
OC (%)	0.46 – 0.79 (0.69)	0.21 – 0.52 (0.37)	0.17 – 0.58 (0.40)	0.12 – 0.48 (0.26)
$CaCO_3$ (%)	Nil – 1.44 (1.02)	Nil – 2.00 (1.13)	Nil – 2.26 (1.27)	Nil – 2.25 (1.52)
CEC (Cmol kg^{-1})	8.09 – 10.90 (9.42)	6.61 – 10.13 (8.80)	5.95 – 6.63 (6.85)	5.88 – 6.35 (6.15)
Sand (%)	52.9 – 76.6 (66.6)	59.0 – 79.9 (68.1)	51.7- 68.0 (59.3)	50.8 – 71.1 (62.6)
Silt (%)	1.9 – 34.4 (17.5)	6.0 – 32.0 (21.5)	20.2 – 32.6 (26.7)	22.4 – 33.3 (27.3)
Clay (%)	9.4 – 19 (14.9)	2.9 – 18.6 (10.4)	7.0 – 24.0 (15.5)	3.4 – 20.2 (10.2)
DTPA –Cr (mg kg^{-1})	0.015 – 0.045 (0.03)	0.013- 0.045 (0.03)	0.023 – 0.042 (0.03)	0.022 – 0.032 (0.03)
Total – Cr (mg kg^{-1})	38.5 – 71.7 (51)	23.0 – 45.8 (36.2)	25.79- 38.8 (34.82)	18.08 – 30.55 (26.35)

Values in parentheses are means of 10 locations

Soil organic carbon (SOC) content ranged from 0.17 to 0.58 percent in the surface layer and 0.12 to 0.48 percent in the sub-surface layer, with mean values of 0.40 and 0.26 percent, respectively, indicating a 35% decrease in the mean value in the sub-surface layer. Calcium carbonate content ranged from nil to 2.26 percent in the surface layer and nil to 2.25 percent in the sub-surface layer, with mean values of 1.27 and 1.52 percent, respectively, indicating an increase in the sub-surface layer. Cation exchange capacity (CEC) ranged from 5.95 to 6.63 Cmol kg^{-1} in the surface layer and 5.88 to 6.35 Cmol kg^{-1} in the sub-surface layer, with mean values of 6.85 and 6.15 Cmol kg^{-1}, respectively (Table 1), indicating a slight decrease in the sub-surface layer.

The DTPA-Cr content varied from 0.023 to 0.042 mg kg^{-1} in the surface layer and 0.022 to 0.032 mg kg^{-1} in the sub-surface layer, with mean values of 0.03 mg kg^{-1} in both layers. The total Cr content varied from 25.79 to 38.80 mg kg^{-1} in the surface layer and 18.08 to 30.55 mg kg^{-1} in the sub-surface layer, with mean values of 34.82 and 26.35 mg kg^{-1}, respectively, indicating a decrease in the sub-surface layer.

Comparison of soil properties between sewage vs. tube well irrigated fields

Comparison of both soils has shown that the pH of sewage water-irrigated soil was lower compared to tube well water-irrigated soil. This is attributed to the acidic nature of the effluents used for irrigation on sewage water-irrigated sites. Khurana and Aulakh (2010) also noted that irrigation with sewage water decreased soil pH, potentially leading to heavy metal accumulation in agricultural soils.The electrical conductivity (EC) of sewage water-irrigated soils was relatively higher than that of tube well-irrigated soils. The increase in electrical conductivity depended on the rate of effluent addition and its chemical composition. Rattan *et al.* (2005) observed EC values exceeding 1.0 dS m^{-1} in sewage water, indicating its saline nature.

The soil organic carbon (SOC) content in sewage water-irrigated soils was relatively higher than in tube well-irrigated soils, suggesting a higher concentration of organic matter in sewage water. Conversely, the calcium carbonate content was higher in tube well water-irrigated soil, likely due to the higher pH values of these soils. Ariffkhan and Kamalakar (2012) suggested that the increase in calcium carbonate with depth might be attributed to calcification and inheritance from parent material. Dheri *et al.* (2007) found that the calcium carbonate content in soil irrigated with tube well water was 1.3 to 2.3 times higher than that in soils irrigated with sewage, primarily due to the higher calcium carbonate content present in tube well-irrigated soil. Higher cation exchange capacity (CEC) was found in sewage water-irrigated soils compared to tube well water-irrigated soils, with variations among different sites. Similar findings were reported by Rattan *et al.* (2005) and Akan *et al.* (2010).

The DTPA-extractable chromium (Cr) content of sewage water-irrigated soils was relatively higher than that of tube well water-irrigated soils. Bansal *et al.* (2013) indicated that concentrations of DTPA-extractable heavy metals remained similar in partially sewage-irrigated and sewage-irrigated soils, possibly due to heavy metal deposition in crops grown on these soils.

Total chromium content was found to be higher in sewage water-irrigated soils compared to tube well water-irrigated soils. Xu *et al.* (2022) studied heavy metal bioavailability in mining soils and found concentrations of heavy metals (Cu, Zn, Pb, Cd, and Mn) exceeding local geochemical background values (43.0, 81.0, 28.5, 0.196, and 616 mg/kg, respectively), with a particularly high over-standard rate (98%) for cadmium (Cd). In more than 86% of the samples, the total soil cadmium concentrations (ranging from 0.1 to 24.8 mg/kg) exceeded the soil pollution risk screening value.Kebir and Bouhadjera (2011) observed very high concentrations of chromium in different agricultural soil samples. Similarly, Koul *et al.* (2016) noted statistically higher concentrations of chromium in soils of polluted sites near Buddah Nullah compared to soils at reference normal site (PAU, Ludhiana).

Mandi Gobindgarh

Sewage water irrigated soil

In Mandi Gobindgarh, the pH ranged from 7.67 to 8.25 in the surface layer and 7.74 to 8.45 in the sub-surface layer, with respective mean values of 7.99 and 8.08 (Table 2). Mandi Gobindgarh is home to iron and steel industries, and the effluents from these industries are acidic in nature. The decrease in soil pH may be attributed to the acidic components in wastewater, which convert to acidic compounds, leading to a reduction in pH value. The electrical conductivity (EC) values ranged from 0.23 to 0.89 dSm^{-1} in the surface layer and 0.20 to 0.80 dSm^{-1} in the sub-surface layer, with respective mean values of 0.40 and 0.36 dSm^{-1}. The EC of sewage water used for irrigation contains a higher salt concentration, contributing to the elevated EC values in the soil.

The soil organic carbon (SOC) content in both the surface and sub-surface layers ranged from 0.84 to 1.69 percent and 0.67 to 1.77 percent, respectively, with mean values of 1.32 and 0.98 percent. The calcium carbonate content in the surface and sub-surface soil ranged from nil to 1.25 percent and nil to 1.85 percent, respectively, with mean values of 0.96 and 1.35 percent.

Table 2. Physico-chemical properties of surface and sub-surface soils irrigated with sewage water and tube well in Mandi Gobindgarh, Punjab

Soil Property	Sewage water irrigated		Tube well water irrigated	
	0-15 cm	15-30 cm	0-15 cm	15- 30 cm
pH	7.67 – 8.25 (7.99)	7.74 – 8.45 (8.08)	7.60 – 8.48 (8.17)	6.70- 7.50 (7.01)
EC(dS m^{-1})	0.23 – 0.89 (0.40)	0.20 – 0.80 (0.36)	0.24 – 0.36 (0.28)	0.10 – 0.34 (0.21)
OC (%)	0.84 – 1.69 (1.32)	0.67- 1.77 (0.98)	0.91 – 1.58 (1.21)	0.16- 0.47 (0.34)
$CaCO_3$ (%)	Nil- 1.25 (0.96)	Nil- 1.85 (1.35)	Nil- 2.00 (1.33)	Nil- 1.25 (0.96)
CEC(Cmol kg^{-1})	10.30 -14.56 (12.36)	10.09 – 14.13 (11.63)	10.84 – 12.87 (11.63)	5.78- 6.95 (6.33)
Sand (%)	55.9 – 70 (62.3)	60.1- 70.4 (63.4)	54.0- 66.6 (58.9)	74.8- 79.6 (77.1)
Silt (%)	17.4- 30.0 (24.7)	18.4- 24.6 (27.7)	21.4- 31.4 (25.3)	10.1- 13.1 (10.8)
Clay (%)	7.2- 20.9 (13.2)	6.6- 19.8 (8.9)	2.6- 20.6 (13.0)	10.0- 15.0 (12.0)
DTPA –Cr (mg kg^{-1})	0.023- 0.041 (0.03)	0.020- 0.035 (0.03)	0.015-0.028 (0.02)	0.005- 0.023 (0.01)
Total – Cr (mg kg^{-1})	36.45- 86.5 (58.6)	34.6- 71.4 (47.9)	12.3- 71.0 (39.2)	11.5- 62.9 (35.9)

Values in parentheses are means of 10 locations

The increase in calcium carbonate with depth may be attributed to calcification and inheritance from parent material. The cation exchange capacity (CEC) ranged from 10.30 to 14.56 Cmol kg^{-1} in the surface layer and 10.09 to 14.13 Cmol kg^{-1} in the sub-surface layer, with respective mean values of 12.36 and 11.63 Cmol kg^{-1} (Table 2), indicating a decrease in the sub-surface layer. The higher values of cation exchange capacity in soils of Mandi Gobindgarh may be due to a higher content of organic matter. The CEC of the investigated soils falls within the range of 5-15 Cmol kg^{-1}. The U.S. Environmental Protection Agency Regulation (1977) takes into account cation exchange capacity when permitting metal loading. This is based on the understanding that soils with high cation exchange capacity would retain metals in relatively unavailable forms, allowing them to accommodate higher rates of metal loading without becoming toxic.

The DTPA-Cr ranged from 0.023 to 0.041 mg kg^{-1} in the surface layer and 0.020 to 0.035 mg kg^{-1} in the sub-surface layer, with respective mean values of 0.03 mg kg^{-1} in both layers. The DTPA-Cr content was higher in sewage water-irrigated soil compared to tube well-irrigated soil. The accumulation would depend on the chromium concentration in sewage water, frequency of irrigation, and soil type.

The total Cr content ranged from 36.5 to 86.5 mg kg^{-1} in the surface layer and 34.6 to 71.4 mg kg^{-1} in the sub-surface layer, with respective mean values of 58.6 and 47.9 mg kg^{-1}, indicating a decrease in the sub-surface layer.

Tube well water irrigated soil

The pH of this soil ranged from 7.75 to 8.52 in the surface layer and 7.87 to 8.67 in the sub-surface layer, with respective mean values of 8.18 and 8.29 (Table 2). The electrical conductivity (EC) ranged from 0.08 to 0.29 dSm^{-1} in the surface layer and 0.09 to 0.31 dSm^{-1} in the sub-surface layer, with mean values of 0.21 and 0.19 dSm^{-1}, respectively.

The soil organic carbon (SOC) in the surface layer ranged from 0.17 to 0.58 percent and in the sub-surface layer from 0.12 to 0.48 percent, with mean values of 0.40 and 0.26 percent, respectively, indicating a decrease in mean soil OC in the sub-surface layer. The calcium carbonate content in the surface and sub-surface soil ranged from nil to 2.26 percent and nil to 2.25 percent, respectively, with mean values of 1.27 and 1.52 percent.

The cation exchange capacity (CEC) ranged from 5.95 to 6.63 Cmol kg^{-1} in the surface layer and 5.88 to 6.35 Cmol kg^{-1} in the sub-surface layer, with mean values of 6.85 and 6.15 Cmol kg^{-1} (Table 2), indicating a decrease with depth. The DTPA-Cr ranged from 0.023 to 0.042 mg kg^{-1} in the surface layer and 0.022 to 0.032 mg kg^{-1} in the sub-surface layer, with mean values of 0.03 mg kg^{-1} in both layers. All these values lie below the permissible limit of chromium (100 mg kg^{-1}).

The total Cr content varied from 25.79 to 38.80 mg kg^{-1} in the surface layer and 18.08 to 30.55 mg kg^{-1} in the sub-surface layer, with respective mean values of 34.82 and 26.35 mg kg^{-1}, indicating a decrease in the sub-surface layer. According to Pendis (2010), the maximum allowable concentration of total Cr in soil is considered to be 50-200 mg kg^{-1}, above which the toxicity of Cr is possible depending on soil texture.

Comparison of soil properties in sewage vs. tube well irrigated fields

The soil pH of sewage water-irrigated fields was lower compared to tube well water-irrigated soil. This

Table 3. Correlation coefficient of DTPA-Cr and total Cr with soil properties of Malerkotla, Punjab

Soil Property	Sewage water irrigated soils				Tube well irrigated soils			
	DTPA-Cr	Total-Cr	DTPA-Cr	Total-Cr	DTPA-Cr	Total-Cr	DTPA-Cr	Total-Cr
	0-15 cm		15-30 cm		0-15 cm		15-30 cm	
pH	-0.072	0.305	-0.147	-0.060	-0.550	0.066	-0.145	0.841**
EC	-0.722*	-0.158	-0.388	-0.475	0.714*	-0.235	-0.114	-0.452
OC	0.648*	0.305	0.872**	0.000	-0.644*	0.240	-0.419	0.084
$CaCO_3$	0.224	0.056	-0.643*	-0.652*	-0.165	0.692*	0.045	-0.170
CEC	0.120	0.258	-0.196	-0.391	-0.837**	0.233	0.433	0.780**
Sand	0.159	-0.274	0.245	0.253	0.457	0.223	-0.721*	-0.443
Silt	-0.003	0.458	0.166	-0.197	-0.177	0.186	0.138	0.351
Clay	-0.455	-0.474	-0.479	-0.086	-0.430	-0.043	0.790**	0.299

*significant at $p \leq 0.05$
**significant at $p \leq 0.01$

indicates that continuous use of sewage-contaminated water with higher acidity over many years has lowered the soil pH. Malerkotla has chilled roll industries, and the effluents from these industries are acidic in nature. Dheri *et al.* (2007) reported that the pH of sewage-irrigated soil was slightly lower compared to soils irrigated with tube well water. The variable decrease in pH may also be due to the release of organic acids during the decomposition of the high load of organic matter. The electrical conductivity (EC) of sewage water-irrigated soils was relatively higher than that of tube well water-irrigated soils. The magnitude of increase in EC depended on the rate of addition and chemical composition of sewage water. Antil (2012) also reported higher EC in sewage water-irrigated soil compared to tube well water-irrigated soil. This indicates that long-term use of sewage water may render the soils unproductive due to high accumulation of salt. The soil organic carbon (SOC) content of sewage water-irrigated soils was comparatively higher than that of tube well water-irrigated soils. Kaur and Najam (2016) also observed that the use of sewage water increased SOC content, further improving crop yield and fertility status of the soil. Higher cation exchange capacity (CEC) was found in sewage water-irrigated soils compared to tube well water-irrigated soils. These differences are due to higher concentration of Cr metal ions and CEC in sewage-contaminated soils. Dheri *et al.* (2007) revealed that CEC of sewage-irrigated and partially sewage-irrigated soils was greater than tube well-irrigated soils. The DTPA-Cr content of sewage water-irrigated soils was relatively higher than that of tube well water-irrigated soils. The accumulation would depend on Cr concentration in sewage water, frequency of irrigation, and soil type. Ariffkhan *et al.* (2012) also observed higher DTPA-Cr content in surface soil, which decreased with depth.

The total Cr content of sewage water-irrigated soils was three times higher in the surface soil and almost four times higher in the sub-surface layer compared to tube well water-irrigated soils. Similarly, Kharche *et al.* (2011) also observed higher total Cr content in

Table 4. Correlation coefficient of DTPA-Cr and total Cr with soil properties of Mandi Gobindgarh, Punjab

Soil Property	Sewage water irrigated soils				Tube well Irrigated Soils			
	DTPA-Cr	Total-Cr	DTPA-Cr	Total-Cr	DTPA-Cr	Total-Cr	DTPA-Cr	Total-Cr
	0-15cm		15-30cm		0-15cm		15-30cm	
pH	-0.873**	-0.128	-0.849**	-0.199	-0.303	-0.885**	-0.746*	-0.471
EC	0.191	0.764*	0.062	0.057	0.327	0.711*	0.700*	0.767**
OC	-0.102	0.007	0.408	-0.094	0.800**	0.185	0.830**	0.695*
CEC	-0.556	-0.276	-0.404	-0.489	0.391	-0.582	0.399	-0.364
Sand	-0.233	0.282	-0.074	0.473	0.078	0.860**	0.800**	0.645*
Silt	0.063	0.180	-0.262	-0.083	0.133	-0.297	-0.271	-0.399
Clay	-0.429	0.609	-0.576	0.173	-0.266	0.211	0.327	0.390

*significant at $p \leq 0.05$
**significant at $p \leq 0.01$

Table 5. **Multiple linear regression equations for describing DTPA-Cr and total chromium in sewage water irrigated soils of Malerkotla district and Mandi Gobindgarh town**

Regression Equation		R^2
	0-15 cm depth	
Total Cr =	82.620 – 1.985 (Clay)	0.335
	15-30 cm depth	
DTPA-Cr =	0.032- 0.006 ($CaCO_3$)	0.217
DTPA-Cr =	0.049 - 0.007 ($CaCO_3$) - 0.002 (CEC)	0.326
Total Cr =	30.256 + 17.445 (OC)	0.351
Total Cr =	36.715 + 16.097 (OC) – 8.846 ($CaCO_3$)	0.573

surface and subsurface layers of sewage-irrigated soils compared to normal soil. This indicates that heavy metals accumulate in the surface soil, which is the effective rooting depth for most vegetable crops.

District-wise comparison revealed that the pH of sewage water-irrigated soils in Malerkotla was lower compared to Mandi Gobindgarh. This difference may be attributed to the more acidic nature of effluents from chilled roll industries in Malerkotla compared to iron and steel industries in Mandi Gobindgarh.The electrical conductivity (EC) of sewage water-irrigated soils in Mandi Gobindgarh was higher compared to Malerkotla, likely due to the higher concentration of salts in Mandi Gobindgarh district. Organic carbon content was higher in Mandi Gobindgarh district compared to Malerkotla. Additionally, surface soils irrigated with tube well water in Malerkotla exhibited higher calcium carbonate content. The higher values of cation exchange capacity (CEC) in soils of Mandi Gobindgarh may be attributed to a higher content of organic matter. Soils with high CEC can retain large amounts of metals in relatively unavailable forms, potentially accommodating higher rates of metal loading without becoming toxic. DTPA Cr levels were higher in Malerkotla town compared to Mandi Gobindgarh, while total Cr was higher in Mandi Gobindgarh soils. In order to demarcate Cr-contaminated sites, the guidelines of Pendis (2010) suggest a maximum allowable concentration of 50-200 mg total Cr kg^{-1} soil, beyond which Cr toxicity is possible depending on soil texture. All samples used in the study exhibited higher chromium content. According to the guidelines proposed by Pendias (2010), most of the investigated soils fell into the highly contaminated category.

Correlation coefficient

In Malerkotla, DTPA-Cr and total Cr showed no correlation with pH (Table 3). However, Dheri *et al.* (2007) observed a negative correlation between DTPA-extractable Cr and pH. In Mandi Gobindgarh, DTPA-Cr exhibited a significant negative correlation with pH in both surface and sub-surface soil layers (Table 4), with respective correlation coefficients of -0.873* and -0.849**. However, no correlation was found between total Cr and pH in either layer. This indicates that as pH increased, there was a decrease in Cr solubility due to the negative correlation with pH. The effect of pH on the extractability of soil Cr may be attributed to its impact on adsorption sites. The increase in soil pH enhances the deprotonation of hydroxyl and carboxyl groups, thereby increasing the negative charge density on soil colloids. Consequently, higher soil pH promotes adsorption and reduces the extractability of chromium in soils. Mani *et al.* (2015) also found a significant negative correlation

Table 6. **Multiple Linear regression equations for describing DTPA-Cr and total chromium in tube well water irrigated soils of Malerkotla and Mandi Gobindgarh town**

Regression Equation	R^2
0-15 cm depth	
Total Cr = 26.499 + 21.142 (OC)	0.425
Total Cr = 226.159 + 20.753 (OC) – 24.398 (pH)	0.691
15-30 cm depth	
DTPA Cr= 0.129- 0.012 (pH)	0.336
DTPA Cr = 0.116- 0.013(pH) + 0.001 (silt)	0.447
DTPA Cr = 0.107- 0.012(pH) + 0.001 (silt) + 0.003 ($CaCO_3$)	0.558
Total Cr = 1.312 + 3.956 (CEC)	0.672

between pH and DTPA-Cr, while Khan *et al.* (2016) reported a strong negative correlation between total soil chromium and pH.

Multiple regression coefficients

To account for data from areas with similar industries, multiple regression coefficients were determined by grouping the data, such as combining data from Malerkotla and Mandi Gobindgarh due to their shared iron and steel industries. Regression analysis of sewage-irrigated surface soil in Malerkotla indicated that clay content explained 33.5% of the variability in total Cr in the surface layer. In the sub-surface layer of sewage-irrigated soil, organic carbon, along with calcium carbonate, explained 57.3% of the variability in total Cr. In Mandi Gobindgarh town, CEC alone explained 67.2% of the variability in total Cr in the sub-surface layer of tube well-irrigated soil (Table 6).

The investigation concluded that all soil properties were higher in sewage-water-irrigated surface soil compared to tube well water-irrigated soil and decreased with depth. The mean DTPA-Cr was higher in Malerkotla town compared to Mandi Gobindgarh town, but the total Cr content was found to be 1.14% higher in Malerkotla town.

Correlation coefficients of DTPA-Cr and total Cr contents with soil properties showed significant correlations (0.648*, -0.643) with organic carbon, pH, calcium carbonate, and clay contents. Partial regression analysis demonstrated that pH, OC, CEC, silt, and calcium carbonate content significantly explained the variability in DTPA-Cr and total Cr contents.

Authors' contribution

Conceptualization and design of the research work (DS, NR); Execution of field/lab experiments and data collection (NR, DS); Analysis of data and interpretation (NR, DS); Manuscript preparation (NR).

Declaration

The authors declare that they have no conflicts of interest to declare.

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