

A Health Risk Assessment of Heavy Metals in Contaminated Vegetables and Soil Irrigated with Wastewater in the Dera Ghazi Khan, Pakistan, Area

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Abstract

Anthropogenic factors like industrialization, urbanization, and agrochemical products causes metal pollution in the food chain. Vegetables produced on polluted soil expose individuals to carcinogenic heavy metals once they ingest them. The study examined the risks of contaminants in vegetables cultivated on soils irrigated through wastewater, their origins, and the consequences to individuals. Through analytical techniques of atomic absorption spectrophotometer, total 164 water samples, topsoil, and vegetables for the concentration level of eight toxic metals (Pb, Cd, Cu, Mn, Fe, Zn, Ni, and Cr) were examined. Heavy metals (Cd, Zn, Fe, Cu, Mn, Cr, Pb, and Ni) in untreated wastewater ranged from 0.405 to 0.501, 0.207 to 0.288, 0.185 to 0.273, 0.565 to 0.883, 0.077 to 0.210, 0.206 to 0.293, 7.750 to 10.080, and 0.189 to 0.293 mg L⁻¹ respectively. The results showed that heavy metals had accumulated significantly in the soil and transferred to vegetables. Vegetables grown on soil irrigated with untreated wastewater had metal concentrations substantially higher than those grown on freshwater-irrigated soil and were above US-EPA and World Health Organization (WHO) guidelines. ANOVA analysis showed no significant differences between the levels of heavy metals in soil. Pearson's correlation coefficient showed a significant positive association between (Pb-Cr) and (Zn-Cu) for soil data. Eight heavy metals categorized into three cluster for soil and seven cluster for vegetables. Three latent components with eigenvalues greater than 1.0 displayed a positive load of anthropogenic trace metals (Ni and Cu) generated for soil data. Pb and Cd have HRIs of > 1 in all vegetables, and Ni has HRIs > 1 for *Raphanus sativus*, *Brassica oleracea*, and *Spinacia oleracea*. Children and adults exposed to a substantial amount of harmful metals using such vegetables.

Introduction

Freshwater is necessary for the existence of life on earth. On average, there are 1.4 trillion cubic meters of water on the earth [1]. Agricultural activities depend on two natural resources such as water and soil. These two natural resources are directly related with the agricultural production rate and also threaten for production rate, if soil is poor and water is insufficient. Pakistan has total 20.63 million hectares of land, and 12.49 million hectares are under cultivation [2]. For vegetables production only 2.54 hectares of land is dedicated. According to estimates, in more than 50 countries, 20 million acres of land are irrigated with wastewater for agriculture, and this number will likely increase very soon due to the non-availability of adequate sources of good water for irrigation [3]. There are numerous types of contaminants, affecting our ecosystem, but heavy metal pollution is particularly significant [4]. Heavy metals are the primary contributors of all toxins as they change the physicochemical form of the environment [5]. Despite the existence of about 38 heavy metals, only 10 are crucial for human health. Heavy metals play very crucial role in biological systems for proper functioning [6]. Heavy metals are primary sources of water pollution and reservoirs degradation because heavy metals are not biodegradable [7]. When their concentration exceeded in water and other surrounding atmosphere become a risk for human beings and plant kingdom. The heavy metals come in environment through different routes. The very serious and highly researched route is through wastewater irrigation of soil. Wastewater from different effluent system are utilized for irrigation. The heavy metals from wastewater enter into soil and accumulate there and subsequently transfer to vegetables [8]. The heavy metals in soil also leached into ground water. Cadmium and lead are two severe trace metals that causes serious health problems and certain complicated diseases [9]. Toxic concentrations of all trace metals damage cell membranes, disrupt cellular processes and affect the three-dimensional structure of an enzymes [10]. Due to its neurotoxic and cancer-causing effects, trace metals toxicity is a major issue for peoples in all over the world [11]. Human heavy metal consumption is linked to cancer, kidney problems, blood acidity, development retardation, and finally mortality. Six commonly consumed vegetables in Pakistan, particularly Tomato and Carrot are two usually consumed vegetables in Dera Ghazi Khan, District. The people of this region utilize ginger for preserving and eat tomato and pickle with their meals as a salad. Consequently, we examined heavy metals in this research. The goal of the study was to find out conclude the accumulation levels of trace metals in wastewater, soil, and samples of different vegetables irrigated with mixed wastewater of industrial and residential area in Dera Ghazi Khan, Punjab, Pakistan. we also computed the health risk index to investigate the possible health risk connected to the use of these potentially harmful metals.

Materials And Methods

The Dera Ghazi Khan District served as the site for this study (Figure 1), where farmers grow vegetables in urban farming sectors. Water from city runoff and domestic sewage are used to irrigate approximately 300 acres of farmland for vegetable. Dera Ghazi Khan has a warm, and moderate climate, in comparison to winter, July had less precipitation. Dera Ghazi Khan's annual average temperature (32°C) and rainfall 104 mm, respectively. Three sites of vegetable farming sectors in Dera Ghazi Khan, Pakistan were selected.

Sample Collection and Preparation

From June 2021 to January 2022, water samples of (500 mL) from various locations were collected in plastic container from pre-selected sites. The plastic bottles were first cleaned with acid 5% HNO₃ before being washed twice with deionized water. A total of 50 samples of wastewater used for irrigating the dietary vegetables were carefully collected. The samples were brought straight to the lab, where they were treated with 1 mL of pure HNO₃ to prevent any microbial growth. A pure solution was created by digesting 50 mL of water samples, including fresh and sewage water, using 10 mL of concentrated HNO₃ at 90 °C on a hot plate for around 50 minutes. The samples were decomposed, filtered via Whatman No. 42 filter paper, and then diluted to a volume of around 50 mL with purified water. A graphite tube, furnace, and an auto sampler are components of the atomic absorption spectrometer model 7000 (AA) used to detect the presence of heavy metals. Agricultural fields that were irrigated with both wastewater and clean water and were in the main and control sectors were collected for soil composite samples (1 kg). Several kilometers distant from cities with low traffic densities, few people and businesses, and low industrial activity levels, control sectors were chosen. Using a spiral auger, samples of soil were reserved in triplicate at random locations from the top layers (0–30 cm) of several soil types.

At a temperature of 100°C, 1g of soil was mixed with 5:1:1 tri-acid solution of HNO₃, HClO₄, and H₂SO₄ to digest soil samples in beakers. It was heated until the mixture became a transparent solution. After cooling, the processed sample was finally filtered using filter paper (Whatman No. 42). and double deionized water was added to the filtrate to make it 50 mL in volume. The similar area from which wastewater and soil and were extracted also dietary vegetables, which were chosen at random. These vegetables were grown for both domestic uses and sold to Dera Ghazi Khan residents. Each vegetable sample was collected in plastic bags. Every vegetable had an approximate 1 kg sample obtained, transported to the lab, and kept there for testing under environmental temperature. The eatable portions of the veggies were cleaned from the soil by rinsing with clean water. Samples were cut into pieces, the excess water was dried out, and air dried before being baked at 80°C to achieve continuous mass. The oven-dried ingredient was ground into a precipitate, put through a 2 mm sieve, and let to cool before being kept for digesting. In a beaker, 0.5 g of dried vegetable sample was obtained. The beaker was filled with approximately 15 mL of the mixture (5:1:1) of three acids. The temperature was then steadily raised to 110–120°C till a solution was achieved after the digesting tubes had been in place at 80°C for 60 minutes. A furnace, graphite tube, and an auto sampler are components of atomic absorption spectrometer model 7000 (AA), which was used to determine the existence of trace metals. It employed a hollow cathode lamp as a source of radiation. By using a digital Cole INOLAB 7110 pH meter and EC meter (HANNA) at room temperature, the obtained samples of water were evaluated for pH and electrical conductivity (EC). An electrochemical analyzer was used to quantify total dissolved solids (TDS) in mg/L.

Data Analysis

Heavy metals transfer factor (HMTF)

Transferring trace metals from the soil to plants required a complicated procedure. The proportion of trace metals taken by vegetables to those accumulated in soil was used to estimate the transfer factor from soil to veggies. The HMTF was measured using the below equation [12].

$$TF = C_{\text{vegetables}} / C_{\text{soil}} \quad (1)$$

C vegetables, C soil are for the metals in vegetables and soil. HMTF represents for heavy metals transfer factor.

Health Risk Assessment (HRA)

The health risk proportion was used to calculate the health hazard of metal-contaminated vegetables that usually causes harm to human health [13]. This is a connection between calculated and reference amounts. If the ratio is below one, the population is considered safe, while if exceeds or equals one, the population will threat.

$$HQ = [W \text{ plants}] \times [M \text{ plants}] / Rf D \times B \quad (2)$$

[W plant] = extreme (mg L⁻¹) dried influence of contaminated plant portion,

[M plant] = vegetables (mg kg⁻¹) metals absorption,

RfD = metals (mg/L) indication amount in foodstuff, B = normal body weight [14].

Daily Dietary Index (DDI)

Because heavy metals harm vegetables, the US-EPA suggested analyzing their daily nutrition requirements. For the Daily Dietary Index, the following equation is used [15].

$$DDI = L \times M \times N / B \quad (3)$$

Daily Intake of Metals (DIM)

The number of concentrated heavy metals taken by humans daily is calculated in DIM. For the determination of DIM, using the equation [16].

$$DIM = C_{\text{metal}} \times C_{\text{feature}} \times D_{\text{food ingestion}} / B_{\text{average mass}} \quad (4)$$

Health risk index (HRI)

The formula that was used to calculate the HRI.

$$HRI = DIM / R_f D \quad (5)$$

If the health risk index ratio is less than one, then treated people are declared secure.

Results And Discussion

Physico-chemical parameters and heavy metals concentration in Water

The physicochemical factor of the water sample collected from both sewage and freshwater sources are described in Table 1. The pH of the sewage water ranged from 7.39 to 7.69, while the pH of freshwater varied from 7.02 to 7.17. Both wastewater and freshwater pH were within WHO reasonable limit (6.5 to 8.5). pH of sewage water was substantially higher than those of fresh water, because sewage water contamination has more carbonates and sulfates than fresh water. The electrical conductivity of wastewater ranged from 1662 to 1843, whereas the EC of clean water ranges between 1260 to 1398 SCM⁻¹. The EC of sewage water was higher than permissible limit (1400 SCM⁻¹). Total dissolved solid of wastewater irrigation ranged 1063 to 1179 and clean irrigation has 604 to 703 mg L⁻¹. Total dissolved solids (TDS) contents in wastewater exceed permissible requirements (1000 mg L⁻¹). As a result, both EC and TDS of effluent water are inappropriate for agriculture, while clean water examined the urban and pre-urban regions of Dera Ghazi Khan and indicate the similar results for EC and pH of the water and soil.

Trace metals include Pb, Zn, Fe, Cu, Cd, Cr, Ni, and Mn and in untreated wastewater ranged 0.71 to 0.93, 0.08 to 0.25, 7.75 to 10.08, 0.26 to 0.29, 0.40 to 0.54, 0.56 to 0.88, 0.206 to 0.293 and 0.16 to 0.29 (mg L⁻¹) while in fresh water contents of (Mn, Cr, Ni and Pb and) ranged from 0.03 to 0.16, 0.04 to 0.12, 0.09 to 0.18 mg L⁻¹, and 0.10 to 0.15, respectively in Dera Ghazi Khan, Pakistan (Table 2) [17]. While comparing the absorption of these heavy metals (Cr, Pb) remained high in recent research also

reported that the wastewater of Dera Ghazi Khan was not well for agriculture purposes due to more contents of heavy metals [18]. Earlier investigators reported that except Zn, all other elements in wastewater were above the permissible limits [19].

Concentration of Heavy Metals and Physico-chemical Analysis of Soil

The pH of wastewater and fresh water irrigated soil was calculated from 8.10-8.69, and 7.66 to 8.52. The pH of soil in sewage water was more than of clean water and above the permissible limit. Because wastewater contains a significant quantity of calcium, magnesium, and bicarbonates. The electrical conductivity averages from 423 to 577 SCM^{-1} for wastewater irrigated soil, which was above permissible standards, and 296 to 432 SCM^{-1} for freshwater irrigation, within WHO limits. The electrical conductivity of wastewater irrigated areas was not appropriate for agriculture [4]. In the district of Dera Ghazi Khan, previous researchers analyzed the fertility of the soil, and their findings are related to the current findings [20].

Heavy metals concentration level Cd, Ni, Mn, Fe, Zn, Cu, Pb, and Cr in wastewater irrigated soil average 1.70 to 3.10, 54.10 to 87.12, 276.30 to 376.70, 420.00 to 476.00, 25.50 to 34.12, 27.10 to 39.20, 66.00 to 88.00, and 65.0 to 120.0 mg kg^{-1} , and above mentioned heavy metal concentration ranged 15.80 to 20.76, 12.02 to 15.21, 1.30 to 1.80, 37.10 to 43.55, 46.3 to 47.4, 153.2 to 241.3, 10.2 to 13.6 and 16.66 to 21.34 in the fresh water-irrigated soil. All toxic metals in sewer water irrigated soil, with exception of lead and manganese were below permitted levels as shown in (Table 3). ANOVA study showed that Mn and Cr were notably different at $P > 0.001$, Cu and Pb are considerably diverse at $P > 0.01$ and Cr, Mn, Pb, and Cu were radically diverse at $P > 0.05$ level in wastewater and underground clean water moistened soil (Table 4). The contamination of soil in this study is due to heavy metal-contaminated wastewater irrigation.

Heavy Metals Content of Vegetables

Trace metals (Cr, Zn, Cu, Fe, Cd, Mn, Ni, Pb,) levels in sewage water irrigated vegetables varied from 6 to 40, 13.0 to 29.10, 8.70 to 20.2, 2.7 to 10.0, and 0.2 to 0.5, 16.8 to 64.0, 9 to 43, 8.0 to 40.0, and concentration of (Nickel, Chromium, Iron, Zinc, Manganese, Copper, lead, Cadmium) ranged from 4.0 to 58.5, 4.0 to 55.0, 4.6 to 17.6, 4.1 to 20, 2.3 to 17.1, 1.3 to 12.3, 1.1 to 3.5, and 0.9 to 1.8, mg kg^{-1} . When wastewater irrigation was compared to clean water irrigation then heavy metals show descending order $\text{Ni} > \text{Cr} > \text{Pb} > \text{Fe} > \text{Cu} > \text{Zn} > \text{Cd}$ and Ni and Cr are observed to be over the WHO permitted limit. Brassica oleracea var. capitates, Spinacia oleracea, Raphanus sativus, Brassica, Brassica oleracea var. botrytis, Rapa subsp. Rapa, Colocasia esculenta, Lactuca sativa, and Daucus carota subsp. Sativus all had higher Cr, and Pb contents in Benincasa fistulosa and Spinacia oleracea but on the other hand, have high Ni concentrations (Figure 2). Cd values were also elevated in crops irrigated with fresh water. In the most recent study, it was discovered that all examined metals were higher in vegetables that irrigated with sewage water than irrigate with fresh water. Heavy metals, including such Pb, Ni, and Cr were detected over the WHO's permitted limit in all vegetables irrigate with wastewater, showing that untreated irrigation and following accretion in the vegetables had taken. Research work showed that vegetables developed on wastewater irrigation acquired trace metals over WHO acceptable standards, posing a major health risk to consumers.

Heavy Metals Transfer Factor (HTMF)

The (HTMF) is assessed to evaluate the health risk assessment related to vegetable cultivated on the ground irrigated with the sewage water. Sector L mean HMTF values for heavy metals in sewage water include Cd, Mn, Ni, Fe, Pb, Cr, Zn, and Cu ranged from 0.070 to 0.46, 0.414 to 0.916, 0.417 to 0.917, 0.042 to 0.183, 0.11 to 0.55, 1.176 to 3.918, 1.17 to 3.91, and 0.018 to 0.091. The mean HMTF results for trace metals in wastewater of sector M, which include Cd, Zn, Mn, Pb, Cr, Cu, and Ni ranged from 0.32 to 0.75, 0.260 to 0.99, 0.04 to 0.20, .096 to .476, .13 to .54, 1.52 to 4.76, .42 to .88, and 0.019 to 0.091 while the mean HMTF results for heavy metals in clean water in sector N, including (Cu, Mn, Zn, Ni, Cr, Pb, Cd, and Fe) ranged in between 0.126 to 0.71, .017 to 0.27, 0.020 to 0.28, 0.63 to 1.26, 0.17 to 0.96, 0.23 to 0.27, 0.10 to 0.23, and 0.24 to 0.93 in that order as shown in (Table 5). The higher adsorption proportion of toxic substances in sewage water vegetables are due to direct ingestion of it, according to the ANOVA study. Except for copper, the results of this study show that all metals had higher HMTF values. Zn and Cr from those 0.11 to 0.55 (Pb), 1.17 to 3.91 (Cd), 0.41 to 0.91 (Cu), 0.33 to 0.72 (Zn), and 0.070 to 0.46 [4], mg kg^{-1} as reported by [21] and that due to variance in soil parameters and irrigation water quality. With higher total metal

concentrations in the soil, HMTF values reduced, representing a contrary correlation between TF and total metal concentrations. That opposite association has also been observed by others for plants.

DIM and HRI for Vegetables

The ingestion of trace metals was determined depend on the number of vegetables ingested. The utilization of dietary crops produced on sewage water irrigated soil results in significantly high DIM values for Trace metals [22]. Tables 8, 9, and 10 indicate the vegetable intake for adults and children. DIM in sewage water irrigated vegetables (sector L) of Ni, Cu, Zn, Fe, Pb, Cr, Cd, and Mn ranged in between $4.40\text{E-}01$ to $1.71\text{E-}01$, $1.03\text{E-}02$ to $1.02\text{E-}02$, $3.03\text{E-}02$ to $1.03\text{E-}02$, $3.01\text{E-}02$ to $1.02\text{E-}02$, $1.03\text{E-}02$ to $1.00\text{E+}01$, $2.01\text{E-}02$ to $0.02\text{E+}01$, $2.02\text{E-}02$ to $1.02\text{E-}02$, and $2.02\text{E-}02$ to $0.02\text{E+}03$. For adults, that was in between while for children, it was between and $3.03\text{E-}02$ to $1.01\text{E-}02$, $2.03\text{E-}02$ to $1.11\text{E-}02$, $1.1\text{E-}02$ to $0.01\text{E+}02$, $1.02\text{E-}03$ to $2.01\text{E-}02$, $1.04\text{E-}03$ to $1.04\text{E-}02$, $4.03\text{E-}03$ to $1.02\text{E-}02$, $2.03\text{E-}05$ to $1.02\text{E-}04$, $4.02\text{E-}02$ to $1.01\text{E-}03$ respectively (Table 6). Zn, Cu, Fe, Mn, Cr, Cd, Pb, and Ni daily intake from vegetables (sector M) were ranged from $0.01\text{E-}02$ to $1.02\text{E-}02$, $2.00\text{E-}04$ to $1.00\text{E-}03$, $1.00\text{E-}03$ to $1.01\text{E+}01$, $3.00\text{E-}01$ to $1.02\text{E-}02$, $2.10\text{E-}02$ to $1.00\text{E+}01$, $2.01\text{E-}03$ to $1.00\text{E+}02$, and $2.00\text{E-}01$ to $2.00\text{E-}01$ correspondingly for mature, while for offspring is in the range of $6.18\text{E+}00$, $1.51\text{E+}00$, $1.00\text{E-}02$ to $0.00\text{E+}00$, $6.03\text{E+}00$ to $1.93\text{E+}00$, $4.10\text{E-}01$ to $3.01\text{E-}01$, $2.03\text{E-}02$ to $2.00\text{E-}0$, $1.91\text{E+}00$ to $5.10\text{E-}01$, $3.00\text{E-}02$ to $2.40\text{E-}0$, respectively (Table 7). The DIM of Zn, Cd, Cu, Fe, Cr, Pb, Mn and Ni in fresh water irrigated vegetables (sector N) is ranged from $1.15\text{E-}03$ to $1.20\text{E+}04$, $2.10\text{E-}02$ to $1.01\text{E+}02$, $2.32\text{E-}03$ to $2.31\text{E+}01$, $1.30\text{E-}02$ to $0.20\text{E+}01$, $3.23\text{E-}02$ to $1.70\text{E+}01$, $3.02\text{E-}02$ to $2.20\text{E+}03$, $1.03\text{E-}00$ to $1.11\text{E+}03$ for adults and for offspring it is ranged from $2.11\text{E-}02$ to $1.20\text{E+}01$, $2.23\text{E-}02$ to $1.33\text{E+}01$ to $1.23\text{E-}02$, $1.20\text{E-}01$ to $1.12\text{E+}02$, $2.24\text{E-}03$ to $1.09\text{E+}01$, $4.11\text{E-}04$ to $1.00\text{E+}03$, $2.04\text{E-}02$ to $2.02\text{E+}02$, respectively. In wastewater irrigated vegetables [23]. DIMS for Ni, Pb, and Cd were above the adequate intake rates in adults and children, while it was below the tolerable daily ingestion rates in clean water irrigated plants for all heavy metals [16] showed no harm from eating common crops produced in sewage water irrigated locations since daily intake metals levels were under the acceptable limits. The results of the current investigation for Pb, Ni, and Cd which are mostly dependable for producing HRI were reliable with those of a former study [24]. For both adults and children, a health risk assessment based on vegetable intake is provided. HRI in sewage water irrigated vegetables (sector N) for Cr, Cd, Pb, Cu, Fe, Zn, Ni and Mn ranges in between $1.18\text{E+}01$ to $5.88\text{E+}00$, $1.70\text{E-}01$ to $4.40\text{E-}01$, $0.01\text{E+}00$ to $1.02\text{E-}02$, $1.41\text{E+}02$ to $4.71\text{E+}00$, $2.02\text{E-}02$ to $3.01\text{E-}02$, $4.60\text{E-}03$ to $1.68\text{E+}00$, $1.00\text{E-}02$ to $3.02\text{E-}02$, $2.20\text{E-}01$ to $9.91\text{E-}01$ for adults while for offspring it ranges in between $1.36\text{E+}01$ to $5.48\text{E+}01$, $0.0\text{E+}02$ to $2.02\text{E-}01$, $1.63\text{E+}04$ to $5.43\text{E+}02$, $1.01\text{E-}02$ to $3.30\text{E-}02$, $2.01\text{E-}02$ to $4.01\text{E-}02$, $5.20\text{E-}04$ to $1.93\text{E+}02$, $1.00\text{E-}04$ to $3.01\text{E-}01$, $2.50\text{E-}03$ to $1.13\text{E+}02$, respectively. The HRI in wastewater irrigated vegetable (sector M) vegetables. For both children and adults, a health risk assessment based on vegetable intake is provided. Cu, Cr, Zn, Pb, Cd, Fe, Ni and Manganese ranges $1.15\text{E+}01$ to $9.31\text{E-}04$, $1.00\text{E-}02$ to $6.00\text{E-}03$, $9.40\text{E-}01$ to $7.39\text{E-}01$, $1.47\text{E-}01$ to $2.00\text{E-}01$, $3.00\text{E-}02$ to $5.63\text{E-}01$ to $7.90\text{E-}01$, $1.94\text{E-}02$ to $4.00\text{E-}02$, $1.93\text{E-}02$ to $3.82\text{E-}04$ for adults whereas for offspring it ranges from $1.52\text{E+}01$ to $6.15\text{E+}02$, $2.01\text{E+}01$ to $2.01\text{E-}02$, $1.93\text{E+}02$ to $6.03\text{E+}01$, $2.00\text{E-}01$ to $3.11\text{E-}02$, $0.01\text{E+}02$ to $3.02\text{E-}01$, $4.12\text{E-}01$ to $1.91\text{E+}00$, $1.00\text{E-}02$ to $3.00\text{E-}04$, $2.40\text{E-}02$ to $1.10\text{E+}02$, respectively. The Health risk index in clean water irrigated vegetables in (sector-N) plants for Ni, Pb, Zn, Cd, Mn, Cu, Cr, and Fe ranges in between $1.01\text{E-}02$ to $1.00\text{E+}04$, $5.20\text{E-}02$ to $1.18\text{E+}03$, $4.70\text{E-}02$ to $1.50\text{E-}03$, $5.01\text{E-}03$ to $1.0\text{E-}03$, $1.00\text{E-}02$ to $5.40\text{E-}03$, $1.40\text{E-}01$ to $3.00\text{E-}02$, and $0.00\text{E+}02$ to $3.40\text{E-}03$ for mature while for offspring having averages from $7.01\text{E-}02$ to $2.33\text{E+}01$, $1.11\text{E+}01$ to $3.02\text{E-}03$, $2.26\text{E-}02$ to $1.29\text{E+}03$, $2.30\text{E-}01$ to $2.20\text{E-}02$, $1.00\text{E-}03$ to $3.41\text{E-}03$, $2.25\text{E+}01$ to $3.22\text{E-}01$, $4.30\text{E-}02$ to $4.40\text{E-}02$, respectively (Table 8). In sewage irrigated plants, the health risk index for Pb and Cd was >1 in *Spinacia oleracea*, *Lactuca sativa*, and *Benincasa fistulosa*. This can harm the health of both children and adults. HRI for all heavy metals was 1 in freshwater irrigated vegetables, indicating no health hazards to adults and children [25]. In Pakistan, where agriculture consumption of water is unmanaged, analyzing health risks via the food chain is essential. They observed that these metals have higher HRI values than 1, indicating that they were harmful to humans even at extremely low levels. The latest study's findings for Cd, Pb, and Ni, which are mainly responsible for causing a health risk to humans, were consistent with prior results of a study. Earlier investigators have find out that vegetables grown on wastewater can causes serous health risks [26].

Cluster Analysis (CA)

Figure 3 displays the categorization of the water, soil and vegetable samples by CA of the physicochemical features and the content of Trace metals coupled with the resulting dendrogram. Cluster analysis revealed eight major heavy metal clusters of wastewater irrigated vegetables in the studied region. Each of the four major heavy metals clusters in which each contained 50% of the investigated samples was identified. The first cluster consists of water samples (5, 6, 7, and 8) of low quality and has the following characteristics: Their categories for the water quality index ranged from "excellent water" to "unsuitable for drinking." These samples (water sources) are those that are most contaminated by anthropogenic activity. On the other hand, it has been demonstrated that changes in depth, geology, and land use (anthropogenic activities) are some of the factors affecting the polluting of water systems in the studied region. Due to their high levels of severe pollution, these borehole samples are just like contaminated springs and rivers in that they are exposed to the surface pollution process. The geology of the study area has been described as having alternated friable sands and shales, which is a setting in which aquifer differentiation is expected; nevertheless, it is inferred that these shallow water sources lack limiting layers. The second cluster consists of (1, 2, 3, and 4).

Principal Component Analysis (PCA)

Tables 9 and 10 shows the complete study of PCA for wastewater and wastewater irrigated soil samples. The PCA and CA are integrated to develop a source of trace metals in the samples of wastewater and soil that were analyzed. The factor loadings have a significance level of 0.05. In the current study, four separate factors of wastewater and three distinct factors of soil in heavy metals were found. Heavy metals had an explanation of 92.74%. (PC) 1, in wastewater which has a variability of 31.19%, there is a considerable loading of Cr, Cu, Pb, Zn, Cd, Fe, Ni, and Mn. This factor class includes the variables in the correlation matrix that have very high correlations. According to PC 1, the main causes of pollutants in the study sites such as industrial, mechanical, and waste disposal activities are human activities. Pb, Cr, and Cu are the primary variables influencing water quality and health risks, according to PCA results (Figure 4). Heavy metals like Cd (0.927) and Mn (0.644) have significant loading in PC 1, of soil which accounts for 40.33% of the variability. The combination of these factors suggests a geogenic origin. The geology of the studied area indicates that there are no remnants of waste disposal, mechanical, or industries in the water.

Source Assessment of Heavy Metals in Soil and Water

The physicochemical parameters and heavy metals in the water samples were linked using the Pearson's correlation, as shown in Table 11. The sources and routes of trace metals and physicochemical parameters in samples of water are shown by the intermetallic interface. According to the results, there is a major positive correlation between TDS (0.907), EC (0.971) and Cd (0.846), Pb (0.966), Cr (0.826), and Fe (0.873), a moderately strong correlation between Mn (0.650) and Cd (0.656), and a significant negative correlation between Ni (0.710) and Zn (0.571). Correlations between Pb, Fe, Cd, Cr, Cu, and Zn are very strong. The strong association between metals indicates a shared origin, mutual dependency, and similar or almost identical metal accumulation in vegetable samples [27]. The Pearson's correlation technique was used to link the heavy metals and physicochemical parameters in the wastewater irrigated soil samples, as shown in Table 12. There are significant correlations between Pb, Ni, Zn, and Mn.

Conclusion

Heavy metals substantially accumulated due to continuing wastewater irrigation practices but the accumulation and heavy metals transfer rate from soil to eatable parts of vegetables were significantly different for different metals. The heavy metals except for Pb, and Ni concentration levels in all of the calculated vegetables were below the national and international acceptable limit. The proportion of heavy metals indicates that Pb, Cd, and Ni can exert a significant impact on vegetables and can cause a potential risk to the health of humans when such types of contaminated vegetables are used. Heavy metals like Ni, Cu, Cr, and Pb consumption levels were higher in leafy vegetables, but Cd and Co consumption rate was in excess amount in other vegetables. Significant variations were observed between wastewater, soil and vegetables when compared with fresh water, soil and vegetables grown on fresh water. The heavy metal transfer factor (HMTF) was generally greater for Pb and Ni in leafy vegetables and was in ascending order Pb > Cr > Ni > Mn > Cd > Fe > C. The HTMF showed variation both for vegetables

and heavy metals mobility rate of trace metals. Factors like DIM [28], and HRI [11] are very useful techniques used for estimating daily ingestion of metals by consumption of vegetables and the related health risk. The result obtained here will be appropriate for legislation, prompt installation of safety measures, and regular observing of heavy metal releases into soil and water. Municipal and industrial wastewater effluents must be treated before being transferred into wastewater to prevent contamination of soil and vegetables. The ingesting of vegetables grown in the district of Dera Ghazi Khan poses a significant risk to consumers.

Declarations

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Authors contribution Hidayat Ullah proposed project idea and provided research facilities for conduction of experimental work in his laboratory and carried out the statistical analysis. Muhammad Abdullah, Tanser Abbass, Irshad Ullah equally contributed in performing the experimental work and statistical analysis. They have completed manuscript writing. Iffat Naz, Aiyeshah Alhodaib, Jalal Uddin contributed in calculation of health risk assessment and interpretation of data.

Data availability The data generated, analyzed and interpreted during the study are all included in the manuscript with no supplementary file.

The manuscript is in compliance with all ethical standards.

Conflict of interest

The authors declare that they have no conflict of interest.

Ethics approval and consent to participate

Not applicable

Consent for publication

Not applicable

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Tables

Table 1. Physico-chemical properties concentration of heavy metals (mgL^{-1}) in the water of pre-urban Dera Ghazi Khan.

Sector L

	Range	Minimum	Maximum	Mean	Standard Deviation	Skewness	Kurtosis
pH value (H ⁺)	0.12	7.41	7.53	7.4725	0.05315	-0.198	-2.215
EC(μSm ⁻¹)	108	1602	1710	1656.75	53.687	-0.029	-5.078
TDS	34	1067	1101	1085.25	13.961	-0.531	1.632
Pb	0.064	0.203	0.267	0.243	0.02814	-1.418	2.071
Cr	0.201	0.565	0.766	0.6555	0.08953	0.467	-1.867
Cd	0.074	0.47	0.544	0.50025	0.03152	1.154	1.774
Cu	0.032	0.266	0.298	0.28175	0.0141	0.076	-2.138
Zn	0.158	0.099	0.257	0.1775	0.06991	0.03	-2.293
Ni	0.057	0.242	0.299	0.27425	0.02367	-0.919	1.977
Fe	3	7.98	10.98	9.35	1.24937	0.585	1.003
Mn	0.066	0.21	0.276	0.25475	0.03115	-1.553	2.144

Sector M

pH value (H ⁺)	0.4	7.22	7.62	7.4175	0.16338	0.092	1.486
EC	131	1652	1783	1714.75	54.322	0.286	0.756
TDS	103	1053	1156	1097	46.08	0.684	-1.295
Pb	0.074	0.185	0.259	0.2235	0.03893	-0.048	-5.622
Cr	0.195	0.688	0.883	0.77125	0.0817	0.983	1.787
Cd	0.093	0.405	0.498	0.46825	0.04299	-1.782	3.201
Cu	0.025	0.273	0.298	0.2825	0.01085	1.448	2.457
Zn	0.2	0.08	0.209	0.14575	0.09222	-1.864	3.564
Ni	0.082	0.206	0.288	0.267	0.04067	-1.999	3.997
Fe	2.18	7.66	9.84	8.56	0.97036	0.862	-0.51
Mn	0.132	0.167	0.299	0.241	0.05808	-0.617	-1.075

Sector N

pH	0.11	7.03	7.14	7.08	0.05831	0.101	-5.42
Ec	30	1310	1340	1327.5	15	-0.37	-3.901
TDS	96	616	712	658.5	44.64	0.415	-3.039
Pb	0.032	0.10	0.15	0.067	0.014	-1.773	3.163
Cr	0.074	0.046	0.12	0.08	0.030	-0.666	1.567
Cd	0.044	0.002	0.046	0.016	0.020	1.757	3.154
Cu	0.027	0.143	0.17	0.15	0.012	0.266	-3.85
Zn	0.078	0.011	0.089	0.054	0.038	-0.265	-4.438
Ni	0.087	0.094	0.181	0.13	0.042	-0.014	-4.889

Fe	16	0.642	4.981	5.62	5.24	0.282	0.936
Mn	16	0.031	0.167	0.19	0.18	0.014	-1.345

Table 2. ANOVA study of heavy metals in peri-urban water from three distinct areas Dera Ghazi Khan is a city in Pakistan.

Sectors	Pb	Cr	Cd	Cu	Zn	Ni	Fe	Mn
Sector L	0.2430 a	0.7712 a	.5003 a	0.2825 a	0.1775 a	0.2742 a	9.3500 a	0.2548 a
Sector M	0.2235 a	0.6555 a	0.468 ab	0.2818 a	0.1457a	0.2670 a	8.5600a	0.2410a
Sector N	0.0678 b	0.865 b	0.0165 b	0.1554 b	0.0548b	0.1378 b	5.2455 b	0.1875 b
Significant	**	***	***	***	ns	*	***	ns

Letters a, and b show significant differences, *stands for significant at 0.05, **for significant at 0.01, *** for significant at 0.001, ns for not significant.

Table 3. Physico-chemical properties concentration of heavy metals (mg/Kg) in soil of pre-urban Dera Ghazi Khan.

	Range	Minimum	Maximum	Mean	Std. Deviation	Skewness	Kurtosis
pH	0.46	8.23	8.69	8.44	0.23	0.17	-4.725
EC	154	423	577	480.25	66.94	1.56	2.890
OM	2	2	3	2.01	0.78	1.98	3.928
Pb	13.00	75.00	88.00	80.75	6.31	0.32	-3.976
Cr	55.00	65.00	120.00	92.25	23.17	0.057	-0.212
Cd	1.20	1.90	3.10	2.55	0.50	-0.560	0.928
Cu	12.60	26.60	39.20	31.95	6.15	0.400	-3.678
Zn	8.20	25.90	34.10	29.10	3.71	1.024	-0.116
Ni	32.60	55.30	87.90	66.62	14.56	1.735	3.299
Fe	33.00	443.00	476.00	460.50	13.82	-0.394	0.385
Mn	100.60	276.10	376.70	324.42	49.60	0.089	-4.892
Sector M							
pH	0.44	8.10	8.54	8.27	0.2065	0.807	-1.469
EC	101	455	556	493.75	43.600	1.432	2.506
OM	1	1	3	1.81	0.650	1.958	3.849
Pb	20.00	66.00	86.00	77.50	9.68	-0.424	-3.514
Cr	31.00	67.00	98.00	82.00	16.82	0.024	-5.824
Cd	1.10	1.70	2.80	2.175	0.59	0.457	-3.110
Cu	7.10	27.10	34.20	31.45	3.06	-1.379	2.291
Zn	7.10	25.50	32.60	29.425	3.35	-0.342	-3.562
Ni	25.20	54.10	79.30	66.35	10.36	0.204	1.521
Fe	41.00	420.00	461.00	437.50	18.77	0.599	-2.089
Mn	69.50	281.30	350.80	313.95	33.52	0.165	-4.402
Sector N							
pH	1.06	7.66	8.72	8.05	0.46	1.41	1.94
EC	136	296	432	376.5	63.73	-0.67	-2.11
OM	2.21	1.24	3.45	2.09	1.03	0.88	-1.08
Pb	3.72	12.03	15.7	2.47	4.49	-0.23	-0.39
Cr	2.45	10.2	13.43	13.18	1.02	0.02	-1.36
Cd	0.50	1.30	1.80	1.55	0.21	0.01	0.39
Cu	4.96	15.80	20.76	17.96	2.39	0.35	-3.79
Zn	5.27	16.66	21.93	18.49	2.34	1.73	3.28
Ni	6.450	37.10	43.55	41.72	3.10	-1.92	3.72
Fe	88.20	153.20	241.40	198.72	45.22	-0.05	-5.47

Mn	0.28	46.34	47.56	6.83	1.08	0.01	1.01
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Table 4. ANOVA study of heavy metals in peri-urban soil from three distinct areas Dera Ghazi Khan is a city in Pakistan.

Sectors	Pb	Cr	Cd	Cu	Zn	Ni	Fe	Mn
Sector L	80.750 a	92.250 a	2.550 a	31.950 a	29.425 a	66.625 a	460.50 a	324.43 a
Sector M	77.500 a	82.000 a	2.175 ab	31.450 a	29.100 a	66.350 a	437.50 a	313.95 a
Sector N	42.472 b	36.188 b	1.550 b	17.962 b	18.492 b	41.723 b	198.72 b	116.83 b
Significant	**	*	*	***	*	*	***	***

Letters a, and b show significant differences, *stands for significant at 0.05, **for significant at 0.01, *** for significant at 0.001, ns for not significant.

Table 5. Heavy metal transfer factor (HTMF) in vegetables grown in selected sectors of pre-urban Dera Ghazi Khan.

Vegetables	Sector	Cu	Fe	Zn	Mn	Pb	Cd	Ni	Cr
Spinacia oleracea	L	0.9194	0.0446	0.7254	0.1887	0.4984	1.8696	0.7131	0.3499
	M	0.8846	0.0475	0.7534	0.2017	0.5132	3.0476	0.7091	0.4337
	N	0.8182	0.2374	0.9317	0.2090	0.2309	1.2632	0.7116	0.9653
Brassica oleracea var.capitala	L	.7804	.0691	.6701	.0419	.5495	3.0435	0.5920	0.4315
	M	0.7772	0.0702	0.7571	0.0440	0.5395	3.2857	.5865	.4699
	N	0.6602	0.1879	0.2435	0.1188	0.1796	1.1930	0.1229	0.8483
Brassica oleracea var. botrytis	L	.8215	.0401	.3800	.0893	.4856	1.1739	0.2634	0.4665
	M	0.8618	0.0385	0.4873	0.1051	0.4868	1.5238	0.2642	0.4458
	N	0.8577	0.2868	0.5029	0.0234	0.1540	1.0526	0.5366	0.4680
Raphanus sativus	L	0.4265	0.0870	0.5389	0.0471	0.4601	1.5217	0.5344	0.0700
	M	0.4293	0.0905	0.5735	0.0507	0.4211	1.9524	0.5346	0.0964
	N	.7392	.1780	.7094	.0503	0.2053	1.1228	0.6359	0.1755
Brassica Rapa subsp	L	0.4107	0.0245	0.4318	0.1814	0.1406	2.6087	0.4133	0.1749
	M	0.4585	0.0294	0.4873	0.1987	0.1711	4.6190	0.3428	0.1807
	N	0.4909	0.0445	0.5188	0.1500	0.1796	0.6316	0.4184	0.2633
Benincasa fistulosa	L	0.4803	0.0178	0.6736	0.1127	0.2045	1.3043	0.6858	0.1516
	M	0.5301	0.0190	0.7346	0.1165	0.2500	1.9048	0.7186	0.1566
	N	0.5699	0.0396	0.7570	0.1812	0.2309	0.6316	0.7069	0.2633
Daucus carota subsp. Sativus	L	0.6793	0.0713	0.3316	0.1160	0.2428	3.6087	0.4133	0.3032
	M	0.7285	0.0745	0.3261	0.1252	0.5395	3.7619	0.4041	0.3494
	N	0.4853	0.0198	0.3335	0.0555	0.1540	0.9123	0.5248	0.5558
Lactuca sativa	L	0.4613	0.0653	0.5527	0.1224	0.1917	3.4348	0.9690	0.3265
	M	0.4976	0.0650	0.5847	0.1386	0.2105	4.1429	0.9937	0.3253
	N	0.6489	0.1286	0.8523	0.1145	0.2053	0.9825	0.6761	0.6143
Colocasia esculenta	L	0.8215	0.0212	0.3558	0.1106	0.1150	3.9130	0.5738	0.2099
	M	0.8390	0.0229	0.3598	0.1249	0.1316	4.7619	0.5865	0.2289
	N	0.7731	0.0297	0.3176	0.0780	0.1026	1.1228	0.6265	0.3803

Table 6. HRI and DIM for adults and children consuming vegetables grown in freshwater- irrigated soil of sector L.

Vegetables	Cu		Fe	Zn	Mn	Pb	Cd	Ni	Cr	
Spinacia oleracea	Adult									
	DIM	1.50E-01	1.12E-03	1.13E-01		3.31E-03	3.01E-01	1.00E-03	1.53E-01	1.44E-01
	HRI	1.20E+02	1.34E-02	3.67E-02		9.85E-01	5.11E+00	2.25E+00	1.23E+02	1.05E-01
	Child									
	DIM	1.81E-02		2.34E-01	3.20E-03	2.22E-03	1.40E-03	3.13E-01	2.35E-02	2.51E-01
	HRI	1.03E-01		2.00E-02	3.21E-01	3.11E+02	3.88E+01	2.59E+00	1.42E+00	1.45E-02
Brassica oleracea	Adult									
	DIM	1.43E-02		2.62E-01	2.23E-01	4.51E-03	1.35E-03	3.76E-01	3.01E-01	2.92E-03
	HRI	3.23E-01		2.32E-02	3.39E-02	2.19E-03	5.88E+00	3.67E+00	1.02E+00	1.29E-02
	Child									
	DIM	1.50E-02		2.61E-02	3.04E-01	5.06E-03	3.62E-04	3.02E-02	1.40E-01	1.45E-03
	HRI	3.72E-01		2.67E-02	3.90E-02	2.52E-04	6.48E+00	4.22E+00	1.18E+00	1.60E-02
Brassica var.botrytis	Adult									
	DIM	4.00E+00		6.42E-01	7.32E-02	2.60E-03	1.12E-02	2.32E-01	8.49E-01	1.34E-03
	HRI	3.30E-02		1.14E-03	1.72E-01	6.56E-03	3.94E+02	2.41E+03	5.53E-02	2.43E-02
	Child									
	DIM	1.60E-01		2.41E-01	6.11E-00	2.29E-03	1.32E-01	3.00E-02	2.02E-01	3.22E-03
	HRI	3.10E-02		2.11E-01	2.26E-02	5.41E-03	5.73E+01	1.63E+02	5.25E-01	1.50E-02
Raphanus sativus	Adult									
	DIM	6.21E-03		1.83E-02	7.05E-02	5.34E-02	2.92E-03	1.03E-02	2.82E-03	2.02E-02
	HRI	1.77E-01		2.02E-01	2.72E-02	2.16E-03	4.71E+00	1.83E+00	9.24E-01	2.10E-03
	Child									
	DIM	8.20E-02		3.98E-02	6.22E-02	6.12E-03	1.21E-01	2.03E-03	2.14E-02	5.60E-01
	HRI	2.42E-03		3.26E-01	3.14E-02	2.41E-03	5.43E+00	2.11E+00	1.06E+00	3.00E-03
Brassica Rapa subsp	Adult									
	DIM	7.02E-02		6.01E-02	7.11E-02	6.24E-01	5.53E-02	3.72E-01	1.40E-22	6.62E-02

	HRI	1.70E-01	8.23E-03	2.18E-02	9.57E-02	1.44E+00	3.14E+00	7.15E-01	5.24E-03
	Child								
	DIM	7.56E-03	6.32E-01	7.10E-03	2.50E-02	7.27E-01	3.02E-011	2.62E-03	6.06E-02
	HRI	1.96E-01	9.48E-03	2.51E-02	1.39E+02	1.66E+00	3.62E+00	8.23E-01	6.00E-03
Benincasa fistulosa	Adult								
	DIM	5.13E-02	3.78E-03	2.74E-01	2.91E-03	5.66E-02	3.00E-02	3.40E-02	6.02E-01
	HRI	1.99E-01	5.99E-03	3.40E-02	4.89E-02	2.09E+00	1.57E+00	1.19E+00	4.54E-03
	Child								
	DIM	9.02E-02	4.90E-04	2.22E-03	1.53E-01	2.67E-03	3.41E-03	3.50E-03	5.00E-01
	HRI	2.29E-01	6.89E-03	3.92E-02	5.78E-02	2.41E+00	1.81E+00	1.37E+00	6.00E-02
Adult									
Daucus carota. subsp	DIM	2.10E-03	3.12E-02	3.55E-03	1.61E-02	3.17E-03	2.30E-01	1.10E-03	2.421E-02
	HRI	1.11E-02	2.29E-03	2.68E-03	4.01E-02	1.49E+01	3.35E+02	6.15E-02	5.08E-02
	Child								
	DIM	2.62E-03	2.91E-02	5.00E-01	1.30E-03	3.13E-01	4.81E-00	1.91E-01	3.21E-02
	HRI	2.42E-01	3.76E-02	2.93E-01	4.98E-02	1.86E+01	4.01E+02	8.23E-02	2.2E-01
Lactuca sativa	Adult								
	DIM	8.41E-03	2.23E-02	6.35E-03	1.10E-00	6.01E-03	3.00E-01	2.40E-03	1.50E-02
	HRI	1.23E-02	2.15E-00	2.89E-01	6.42E-01	1.96E+00	4.14E+00	1.68E+03	8.78E-02
	Child								
	DIM	9.42E-03	2.80E-01	1.33E-01	1.40E-02	9.05E-01	5.92E-02	3.31E-01	1.39E-02
	HRI	2.22E-01	2.52E-02	3.21E-02	7.36E-01	2.26E+02	4.76E+00	1.93E+00	2.10E-01
Colocasia esculenta	Adult								
	DIM	1.40E-01	4.06E-02	5.17E-01	1.12E-02	5.16E-03	4.83E-02	2.00E-02	7.09E-03
	HRI	3.40E-01	7.11E-03	1.80E-02	5.78E-01	1.18E+02	4.71E+00	9.92E-02	5.28E-01
	Child								

DIM	1.60E-03	4.71E-01	6.25E-01	2.27E-01	4.11E-03	5.12E-02	2.27E-03`	3.10E-01
HRI	3.92E-01	8.18E-03	2.07E-02	6.65E-01	1.36E+00	5.43E+00	2.14E+02	7.00E-02

Table 7. HRI and DIM for adults and children consuming vegetables grown sewage- water- irrigated soil of sector M.

Vegetables		Cu	Fe	Zn	Mn	Pb	Cd	Ni	Cr
Spinacia oleracea	Adult								
	DIM	1.32E-01	1.32E-03	2.12E-03	4.22E-01	3.10E-02	2.01E-03	2.40E-03	1.91E-02
	HRI	2.43E-02	3.00E-02	3.11E-03	8.22E-01	2.31E+01	1.68E+02	1.18E+02	1.22E-01
	Child								
	DIM	1.60E-02	1.30E-03	1.20E-02	3.43E-03	2.31E-02	4.33E-01	1.51E-02	2.10E-03
	HRI	4.24E-03	1.81E-03	4.04E-02	1.10E+00	5.88E+00	3.86E+00	1.36E+00	1.00E-00
Brassica oleracea	Adult								
	DIM	1.24E-01	1.90E-03	1.13E-02	7.22E-02	3.18E-02	1.13E-01	3.12E-02	2.13E-01
	HRI	3.13E-01	2.67E-02	3.53E-02	2.08E-01	6.82E-01	2.15E+00	9.77E-01	1.36E-01
	Child								
	DIM	1.22E-02	2.93E-03	3.31E-01	7.04E-00	2.30E-02	3.03E-01	1.24E-01	2.20E-02
Brassica var. botrytis	HRI	3.60E-01	2.67E-01	4.06E-02	2.39E-01	6.18E+00	4.16E+00	1.12E+00	1.00E-01
	Adult								
	DIM	1.40E-02	1.33E-02	7.00E-03	1.13E-02	2.20E-01	5.01E-02	9.05E-02	1.15E-02
	HRI	3.47E-01	1.46E-03	2.27E-02	4.97E-01	7.55E-01	5.08E+00	4.40E-01	1.09E-03
	Child								
	DIM	1.60E-02	1.00E-01	8.00E-03	1.90E-02	2.20E-02	2.00E-03	1.00E-02	2.20E-03
Raphanus sativus	HRI	4.00E-01	1.46E-01	2.61E-02	5.72E-01	5.58E+00	1.93E+00	5.07E-01	1.00E-02
	Adult								
	DIM	7.23E-03	1.42E-01	8.67E-01	7.02E-02	1.71E-02	4.62E-01	1.41E-01	4.27E-01
	HRI	1.73E-01	3.45E-03	2.67E-02	2.40E-01	6.80E-01	2.09E+00	8.90E-01	2.79E-02
	Child								
	DIM	8.209E-02	6.10E-01	9.04E-03	8.50E-01	1.41E-02	2.61E-03	1.36E-01	3.10E-02
	HRI	1.91E-01	1.12E-01	3.08E-02	2.76E-01	4.82E+00	2.47E+00	1.32E+02	1.00E+02
	Adult								
	DIM	7.02E-02	8.10E-02	7.01E-02	3.52E-02	3.61E-02	4.15E-03	1.92E-02	8.42E-02

Brassica rapa.subsp	HRI	1.85E-01	1.12E-02	2.27E-02	9.39E-01	9.00E-01	4.14E+00	5.71E-01	5.24E-01
	Child								
	DIM	9.01E-02	5.20E-02	8.10E-01	3.61E-03	8.1E-03	6.23E-02	1.31E-03	8.01E-02
	HRI	2.13E-01	7.24E-02	9.20E-03	1.08E+00	1.96E+00	5.85E+00	6.57E-01	1.00E-01
Adult									
Benincasa fistulosa	DIM	9.11E-02	5.02E-01	1.40E-02	1.82E-02	2.12E-01	5.01E-02	2.42E-03	7.01E-02
	HRI	2.13E-01	7.23E-01	3.42E-02	5.51E-01	5.37E+00	4.56E+00	1.20E+00	4.54E-02
	Child								
	DIM	1.03E-02	3.00E-02	8.01E-03	2.12E-01	1.14E-01	6.20E-02	2.52E-02	7.30E-02
	HRI	2.25E-01	3.83E-03	2.11E-02	2.20E-02	2.86E+00	3.99E+00	1.31E+03	0.00E+020
Adult									
Daucus carota. Subsp	DIM	1.11E-03	2.30E-01	5.04E-03	1.03E-03	1.93E-03	5.03E-01	1.40E-01	1.51E-04
	HRI	2.93E-01	2.83E-01	1.52E-02	5.92E-01	4.84E+00	5.24E+00	6.73E-01	1.01E-01
	Child								
	DIM	1.43E-03	1.71E-01	1.24E-01	2.23E-01	2.50E-03	5.30E-01	1.51E-03	1.33E-01
	HRI	3.38	2.47E-01	3.94E-02	6.82E-01	6.18E+00	2.01E+00	7.75E-01	1.00E-02
Adult									
Lactuca sativa	DIM	8.03E-01	2.72E-02	8.23E-02	1.20E-03	1.63E-02	3.59E-03	3.10E-02	1.30E-03
	HRI	2.00E-02	2.47E-01	2.72E-02	6.55E-01	4.19E+00	3.01E+00	1.65E+00	9.43E-01
	Child								
	DIM	9.10E-02	2.70E-02	5.20E-03	2.52E-02	1.51E-02	5.35E-02	3.82E-01	1.42E-03
	HRI	2.31E-02	2.47E-01	1.75E-02	7.55E-01	2.41E+00	5.25E+00	1.91E+00	1.00E-01
Adult									
Colocasia esculenta	DIM	1.42E-03	6.01E-02	5.02E-02	1.91E-03	5.20E-02	4.01E-01	2.02E-03	1.20E-02
	HRI	3.38E-01	8.70E-02	1.68E-02	5.90E-01	1.31E+00	5.68E-01	9.77E-01	6.63E-02
	Child								
	DIM	1.63E-	6.30E-02	9.30E-	2.22E-01	6.01E-03	5.01E-03	2.23E-02	1.20E-03

	03			01					
HRI	3.89E-01	8.70E-03		3.14E-02	6.80E-01	1.51E+00	6.03E+00	1.12E+00	1.00E-01

Table 8. HRI and DIM for adults and children consuming vegetables grown sewage- water- irrigated soil of sector N.

Vegetables		Cu	Fe	Zn	Mn	Pb	Cd	Ni	Cr
Spinacia oleracea	Adult								
	DIM	8.01E-02	1.22E-02	2.02E-02	2.32E-01	4.13E-00	2.02E-02	1.63E-02	1.72E-02
	HRI	1.92E-02	3.39E-01	3.17E-02	3.32E-02	1.38E+03	9.41E-3	7.38E-02	1.35E-02
	Child								
	DIM	9.11E-01	2.23E-02	1.22E-02	1.11E-02	3.54E-01	1.29E-03	2.82E-04	2.03E-02
	HRI	2.24E-01	332E-03	3.34E-01	4.03E-01	0.46E+02	1.49E+03	9.05E-03	1.33E-03
Brassica oleracea	Adult								
	DIM	6.30E-03	2.30E-00	0.03E+01	1.30E-03	2.25E-02	1.23E-02	3.30E-01	1.32E-03
	HRI	1.53E-03	2.84E-01	8.03E-02	3.82E-01	9.54E-00	8.76E-01	1.36E-01	2.21E-01
	Child								
	DIM	7.03E-02	6.03E-03	3.13E-01	8.21E-02	4.32E-03	1.50E-01	3.05E-01	1.73E-01
	HRI	1.76E-01	3.21E-03	9.25E-01	2.20E-03	1.16E+03	1.13E+03	1.27E-03	1.20E-03
Brassica var. botrytis	Adult								
	DIM	8.30E-01	3.00E-03	0.32E+02	1.22E-01	3.60E-01	1.50E-02	1.20E-02	8.03E-03
	HRI	1.99E-00	4.34E-01	1.66E-02	4.276E-02	7.35E-03	7.25E-03	5.94E-03	5.59E-02
	Child								
	DIM	9.10E-01	3.50E-03	6.52E-02	3.42E-02	5.36E-01	1.02E-03	2.40E-03	2.12E-02
	HRI	2.22E-01	5.02E-0	1.91E-02	4.31E-01	8.21E-03	9.35E-02	6.24E-03	6.02E-01
Raphanus sativus	Adult								
	DIM	7.32E-00	3.11E-01	1.42E-01	4.71E-02	4.05E-01	1.20E-02	0.41E-03	4.02E-02
	HRI	1.31E-03	2.43E-02	3.81E-00	7.02E-02	2.21E+01	8.32E-03	7.34E-03	2.20E-03
	Child								
	DIM	8.10E-02	2.20E-01	8.03E-03	3.54E-02	4.54E-02	2.01E-02	1.61E-03	4.30E-02
	HRI	1.38E-02	3.13E-04	2.69E-03	1.03E-02	0.21E+02	9.25E-02	8.21E-02	2.30E-02
	Adult								
	DIM	5.41E-02	0.07E+01	2.12E-02	7.54E-01	3.31E-02	0.12E+02	9.40E-02	5.00E-00

Brassica rapa.subsp	HRI	1.14E-02	6.43E-02	1.42E-03	2.21E-03	5.13E-01	4.71E-03	4.63E-01	3.14E-01
	Child								
	DIM	5.11E-03	6.42E-02	6.30E-03	2.09E-02	3.80E-03	1.46E-01	1.10E-03	5.00E-01
	HRI	1.31E-01	7.75E-03	1.34E-03	5.45E-01	2.03E+02	5.43E-02	5.34E-02	4.98E-02
Benincasa fistulosa	Adult								
	DIM	6.29E-03	0.23E+03	1.01E-01	1.11E-02	5.02E-03	0.30E+01	1.63E-01	5.36E-03
	HRI	1.23E-02	3.99E-00	3.50E-02	3.32E-01	1.73E+02	4.82E-01	3.53E-02	2.13E-01
	Child								
	DIM	6.00E-02	5.02E-02	9.43E-02	1.20E-01	5.02E-02	1.22E-02	2.43E-02	5.54E-01
	HRI	1.52E-02	6.89E-01	1.87E-02	3.35E-02	2.33E+01	6.32E-01	6.71E-03	5.32E-02
Daucus carota. Subsp	Adult								
	DIM	5.10E-02	1.04E-01	2.21E+02	3.09E-03	4.02E-01	1.16E-01	1.29E-04	1.10E-01
	HRI	1.31E-03	1.25E-01	1.10E-03	1.32E-01	7.83E-04	6.31E-02	5.11E-03	6.33E-01
	Child								
	DIM	5.32E-02	7.63E-02	4.43E-02	3.40E-01	4.95E-02	1.97E-02	1.30E-02	1.12E-01
	HRI	1.77E-02	3.43E-03	2.33E-03	1.17E-02	9.05E-03	8.24E-02	6.42E-04	8.32E-02
Lactuca sativa	Adult								
	DIM	5.64E-02	2.81E-01	1.30E-03	5.10E-02	4.24E-00	1.18E-03	1.32E-03	1.14E-01
	HRI	1.51E-01	4.29E-03	2.31E-03	2.19E-02	1.39E+02	7.03E-02	7.21E-00	7.42E-03
	Child								
	DIM	7.67E-02	4.76E-03	1.03E-02	8.02E-01	5.28E-02	2.03E-02	1.32E-03	1.14E-01
	HRI	1.23E-03	2.35E-01	3.34E-03	9.83E-04	1.23E+01	6.54E-02	8.42E-03	5.97E-02
Colocasia esculenta	Adult								
	DIM	7.30E-01	1.52E-01	0.34E+02	5.02E-01	2.02E-03	1.20E-01	1.31E-01	4.32E-01
	HRI	1.01E-03	3.92E-03	2.06E-02	1.23E-02	5.34E-03	8.38E-02	6.94E-01	4.54E-02
	Child								
	DIM	8.10E-	2.30E-03	4.02E-02	5.61E-02	4.07E-03	2.17E-02	1.32E-	5.11E-

	02							02	01
HRI	2.23E-01	4.31E-02	1.27E-03	1.18E-00	2.03E+02	9.65E-00	7.99E-03	4.70E-03	

Table 9. Principal component analysis for wastewater of two sectors (L, M) in pre-urban area of D.G.Khan.

Elements	Communality	Eigen	Total variance	Cumulative TV	Factor 1	Factor 1	Factor 3	Factor 4
Pb	0.963	2.554	31.919	31.919	0.908	0.507	- 0.224	0.024
Cr	0.967	2.118	26.475	58.394	- 0.765	0.138	0.227	- 0.558
Cd	0.973	1.622	20.270	78.685	0.706	0.284	0.316	0.541
Cu	0.767	1.126	14.070	92.741	0.273	- 0.744	0.316	0.195
Zn	0.960	0.501			0.670	0.308	- 0.513	0.391
Ni	0.986	0.058			- 0.093	- 0.672	0.604	- 0.284
Fe	0.993	0.022			0.198	0.649	0.691	0.235
Mn	0.882	0.143			0.494	0.489	0.463	0.441

Table 10. Principal component analysis for wastewater irrigated soil of factors of two sectors (L, M) in pre-urban area of D.G.Khan.

Elements	Communality	Eigen	Total variance	Cumulative TV	Factor 1	Factor 1	Factor 3
Pb	0.787	3.235	40.433	40.433	- 0.265	- 0.106	0.840
Cr	0.837	2.130	26.624	67.052	- 0.833	- 0.008	0.379
Cd	0.891	1.278	15.980	83.037	- 0.177	0.927	0.001
Cu	0.860	0.759			0.903	- 0.115	0.174
Zn	0.821	0.449			0.395	0.813	- 0.066
Ni	0.855	0.038			0.803	0.350	- 0.297
Fe	0.716	0.023			0.584	0.114	0.601
Mn	0.875	0.103			0.025	- 0.678	0.644

Table 11. Correlation between heavy metals and physiochemical properties in waste and fresh water used for irrigation of soil of peri-urban area of D G khan

	pH	EC	TDS	Pb	Cr	Cd	Cu	Zn	Ni	Fe	Mn
pH	1										
EC	0.879**	1									
TDS	0.907**	0.971**	1								
Pb	0.784**	0.849**	0.911**	1							
Cr	0.828**	0.971**	0.972**	0.865**	1						
Cd	0.846**	0.926**	0.963**	0.966**	0.943**	1					
Cu	0.864**	0.942**	0.971**	0.948**	0.951**	0.971**	1				
Zn	0.798**	0.657*	0.641*	0.512	0.621*	0.587*	0.671*	1			
Ni	-0.71*	0.861**	0.867**	0.878**	0.852**	0.876**	0.872*	-0.57	1		
Fe	0.873**	0.858**	0.890**	0.848**	0.826**	0.889**	0.869*	0.97*	0.67*	1	
Mn	0.650*	0.621*	0.638*	0.584*	0.692*	0.656*	0.657*	0.75*	0.59*	0.54	1

Table 12. Correlation between physiochemical properties and heavy metals in waste and fresh water irrigated soil of peri-urban area of D G khan

	pH	EC	OM	Pb	Cr	Cd	Cu	Zn	Ni	Fe	Mn
pH	1										
EC	0.724*	1									
OM	-0.376	-0.357	1								
Pb	0.565	0.87**	-0.30	1							
Cr	0.367	0.669	0.13	0.85**	1						
Cd	0.363	0.429	-0.23	0.58	0.619	1					
Cu	0.463	0.495	0.18	0.89**	0.584	0.475	1				
Zn	0.397	0.556	-0.24	0.81**	0.652	0.74**	0.82**	1			
Ni	0.522	0.527	-0.18	0.633	0.419	0.635	0.84**	0.84**	1		
Fe	0.349	0.614	-0.01	0.84**	0.82**	0.704	0.86**	0.83**	0.78**	1	
Mn	0.470	0.77**	-0.12	0.95**	0.83**	0.541	0.89**	0.75**	0.689	0.94**	1

Figures

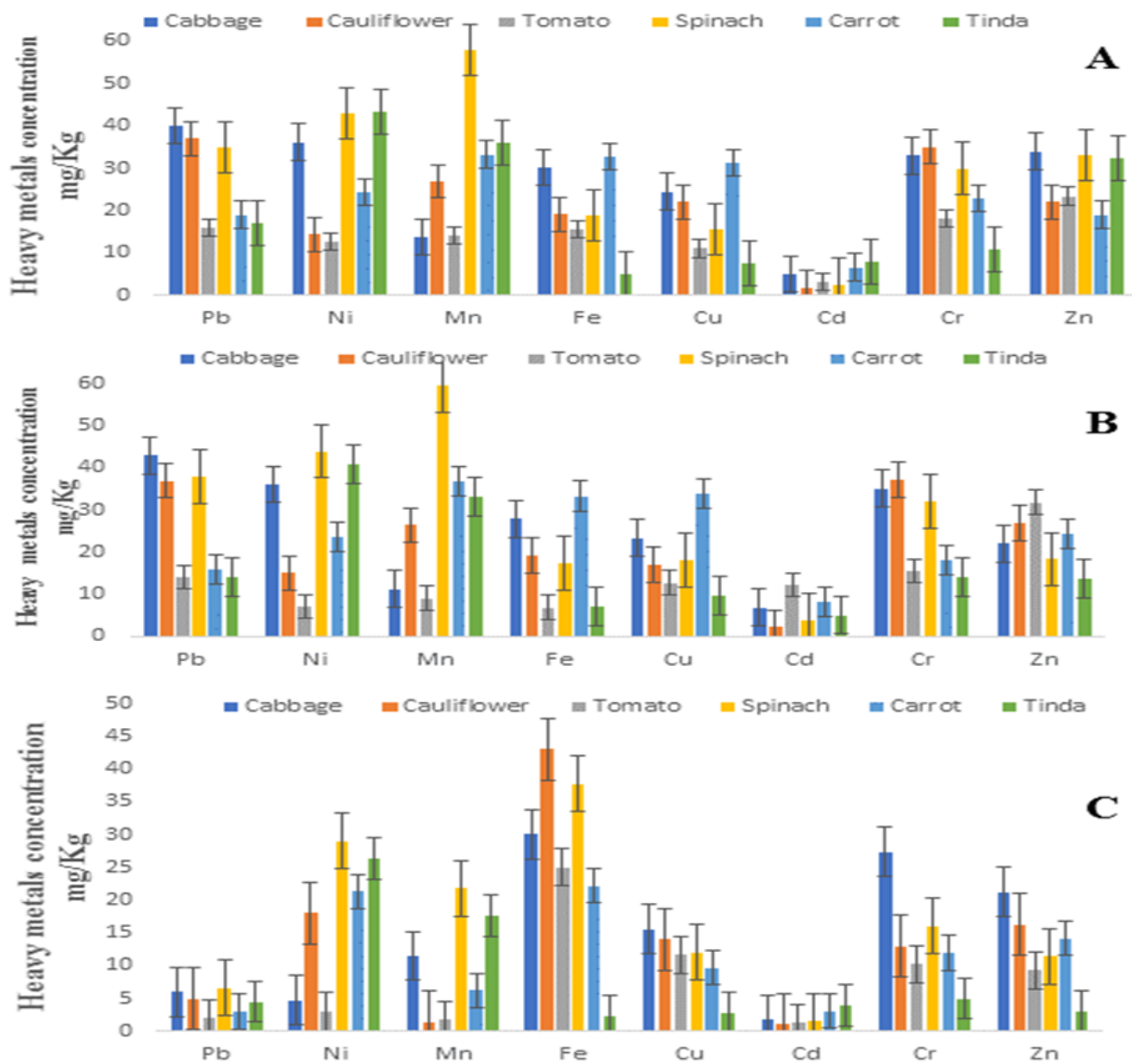


Figure 2

(A) Levels of heavy metals in wastewater irrigated vegetables in sector L. (B) Contents of heavy metals in wastewater irrigated vegetables in sector M. (C) Contents of heavy metals in wastewater irrigated vegetables in sector N.

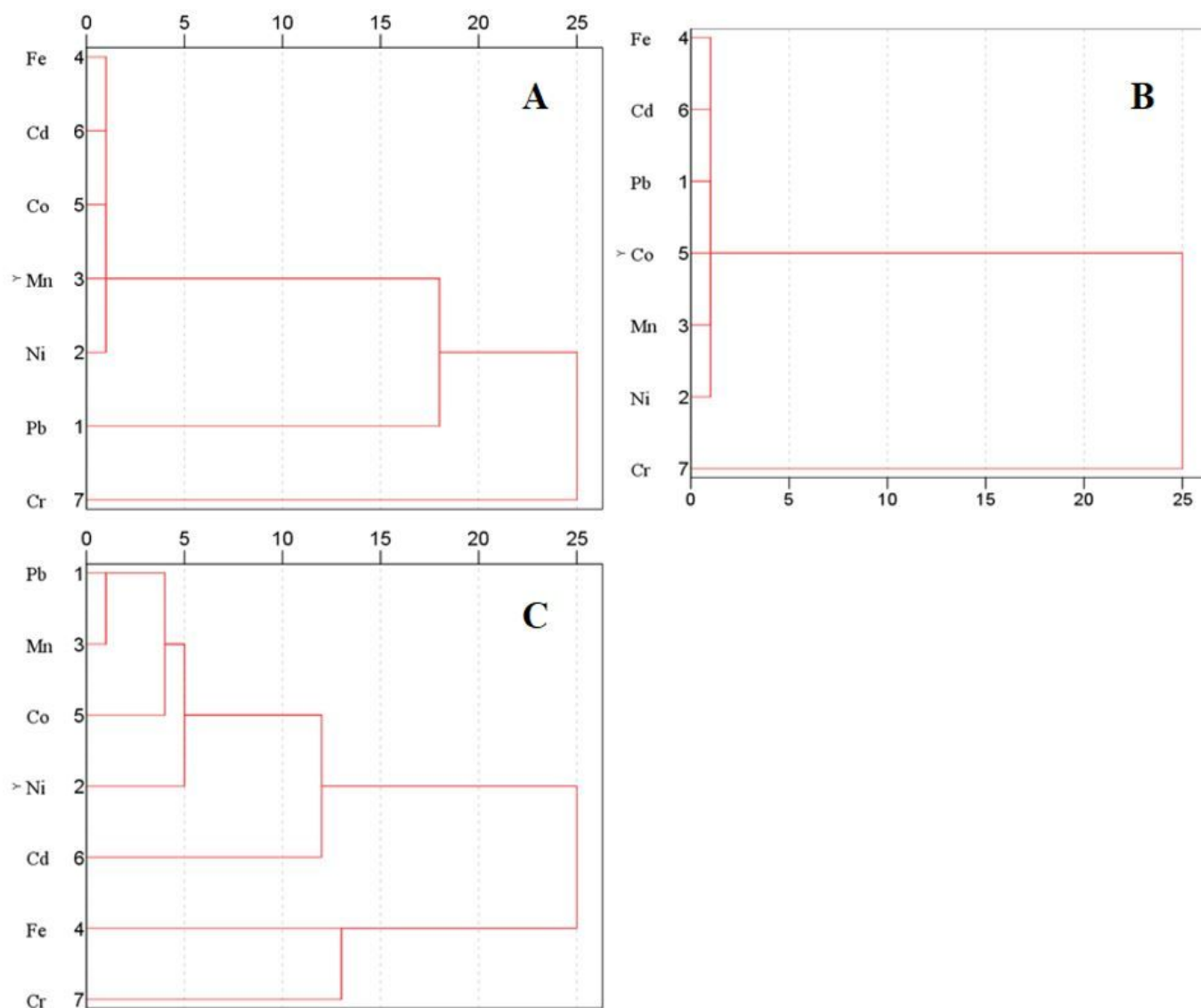


Figure 3

(A) Cluster analysis of sewage water (B) sewage water irrigated soil (C) sewage water irrigated vegetables.

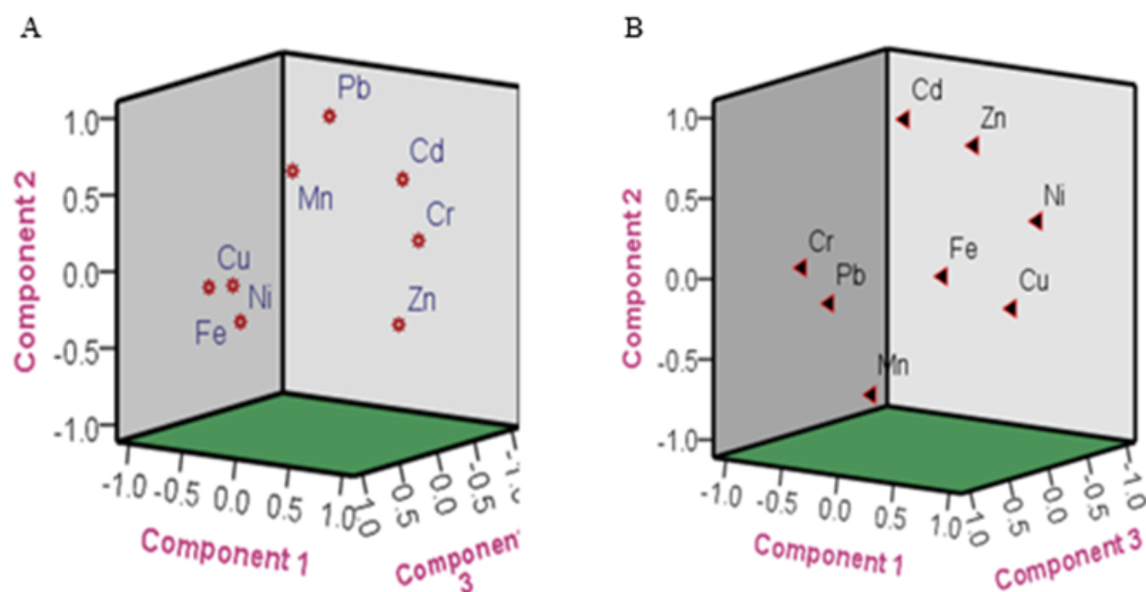


Figure 4

(A) PCA of sewage water (B) PCA of sewage water irrigated soil.

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