Research Article

Assessment of pollution in roadside soils by using multivariate statistical techniques and contamination indices

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Abstract

Pollution of roadside soils by heavy metals (HMs) presents serious concern throughout the world and, specifically, in India, due to the increasing traffic and anthropogenic activities. Understanding this problematic, policymakers and land managers will be able to design correct and sustainable land plans to avoid human health problems. The current study was conducted in order to determine the sources and levels of contamination by physiochemical parameters and HMs (Cu, Co, Cr and Pb) in roadside soils of Jalandhar, Punjab. A total of 90 samples were collected in triplicates from different sites and analysed for physiochemical and heavy metals. The average values of Cu, Co, Cr and Pb were found less than the permissible limits of Indian soils. Pearson's correlation analysis indicated that HMs are positively correlated with each other, indicating a similar source of their origin. Further results of correlation analysis were supported by cluster analysis and Principal component analysis also indicated that HMs have the same source of origin mainly anthropogenic (agricultural and transportation activities), while soil properties have the same source of origin. The results of contamination factor, geo-accumulation index, potential contamination index, pollution index and ecological risk index showed that soils are moderately contaminated by HMs. In the future, further research would be needed to understand which specific factor (agriculture, industry and urban residues) could be considered as the main driving factor. We conclude that this study can provide the baseline data for policymakers and stakeholders to help the protection of soil ecosystem.

Keywords Heavy metals · Cluster analysis · Principal component analysis · Ecological risk assessment

1 Introduction

The soil is the major natural resource for the survival and functions of the ecological ecosystems [1]. However due to the rapid urbanization, industrialization and extensive application of fertilizers and pesticides leads to contamination of soil health [2–4]. Transportation service is a significant pollution source of heavy metals in surroundings soils near the highways, which are produced by vehicles and dust, entering the soil through natural sedimentation [5, 6]. HMs may be harmful to humans and other living organisms due to their toxicity, perseverance, non-biodegradable and non-thermodegradable properties [7]. In addition to the geogenic origin of HMs in some regions,

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their discharge from anthropogenic activities may be considered as the main sources of pollution [8–10]. According to some studies carried out in India, China, England and Iran, the traffic activities, industrial activities, agricultural activities, atmospheric precipitations, wastewater sludge, erosion of buildings and pavement surface are the main sources of HMs in the soil [11, 12].

Zhao et al. [13] while working on roadside soils in Sydney reported that rainfall, distance to the road and soil types are the major factors responsible for HMs pollution. Alexakis and Gamvroula [14] in their study on potentially toxic elements of Oropos-Kalamos Basin, Attica, Greece, reported that natural sources like lithogenic factors were responsible for contamination of the studied area. This situation was also confirmed by Alexakis [15] applying previously pollution indices. Alexakis [16] determined the possible health risks associated with HMs in agricultural soils from Greece and concluded that less risk are associated with HMs. Therefore, authors further inferred that HM pollution was produced from human activities such as construction of roads and traffic activities [16]. Hou et al. [17] gives an overview of multivariate techniques in the determination of pollution sources by HMs and concluded that natural and human origins of HMs were mainly from geogenic, roadways and transportation. Esmaeilzadeh et al. [18] in their studies on Neyshabur Plain, northeast of Iran also used multivariate techniques and different soil pollution assessment indices to find out the degree and sources of contamination. In India, where rapid development of roads and associated services such as industries and urban development, there is a lack of information about soil contamination indices and multivariate statistical techniques. The application of multivariate statistical techniques in combination with contamination indices has been employed to find out the source apportionment and pollution level of HMs in the roadside soils [19].

Therefore, the main aim of this study is to evaluate the pH, SOM, P, Ca, Mg, Cu, Cr, Co and Pb in roadside soils of Jalandhar, Punjab in India using multivariate statistical analysis (cluster analysis and principal component analysis) and contamination indices like contamination factor (CF), enrichment factor (%), potential contamination index (Cp), geo-accumulation index (Igeo), pollution index (PI) and potential ecological risk (RI).

2 Materials and methods

2.1 Study area

Ninety soil samples in triplicates were collected close to the National roadsides from 30 different sites from Jalandhar District, during February 2018 which is located in the region of Punjab, India. The location of sampling sites can be observed in Fig. 1. The mean temperature and humidity are 15 °C and 77%, respectively. The Jalandhar District is characterized by a humid subtropical climate with cold winters and hot summers. Mean rainfall amount is 600 mm yr^{-1}. It lies in the middle of the State and is located between the Beas and Sutlej Rivers. The main soils are characterized by a loamy texture. The soils are deep and fine-grained, which are formed under submoist and cool to warm temperate conditions [20]. The land of the Jalandhar District is characterized by alluvial deposits of the Indus-Ganga. The geological origins of the Jalandhar took place during the quaternary age and are comprised of the latest alluvial deposits that belong to the vast Indus alluvial plains [21]. The Jalandhar district is underlain by sub-recent to quaternary alluvium consisting of clay, sand, pebbles, and gravel. Older alluvium inhabited the uplands except for Sutlej River, and young alluvium inhabited the floodplains of Sutlej River [21]. It occupies about 5.3% of the total geographic area of the state and regarded as larger and densely populated District of Punjab State. It is considered the most important District of Punjab from an agricultural point of view. The total area of this District is 266,224 hectares and out of this area, 90% is under cultivation and 2.1% and 7.4% are under forest cover and non-agricultural use. The total population of Jalandhar was 2,193,590 according to 2011 census and it was projected to be 2,383,415 by 1st of October 2018. The District is interconnected by roads and is known for agriculture, textile industry, wood products, and spare parts of automobiles [22]. The samples were collected close to the National Highways roads connecting Jalandhar with Jammu and Amritsar, and Amritsar.

2.2 Soil sampling and determination of physicochemical soil properties and heavy metals

Soil samples were air dried, grounded and passed through a sieve to eradicate any effect of particle size before analysis and stored in clean polyethene bags. For the determination of pH, 10 g of soil was added in 20 ml of distilled water in a ratio of 1:2. It was done by following the method of [23]. It was measured by using micro pH Analytica pH-meter. Total phosphorus was estimated by following Olsen et al. [24]. Ca and Mg were estimated by the Ethylenediamine tetra-acetic acid (EDTA) titration method. Soil organic carbon was estimated by the Walkley–Black wet oxidation method [25]. HMs were determined in the soil samples by using AAS (Model Agilent Technologies 200-Series AA). Soil samples were digested in the aqua-regia (HNO_3 and HCl; 1:3). In 1 g of oven dried soil, 12 ml HNO_3 and HCl were used and the solution was heated on

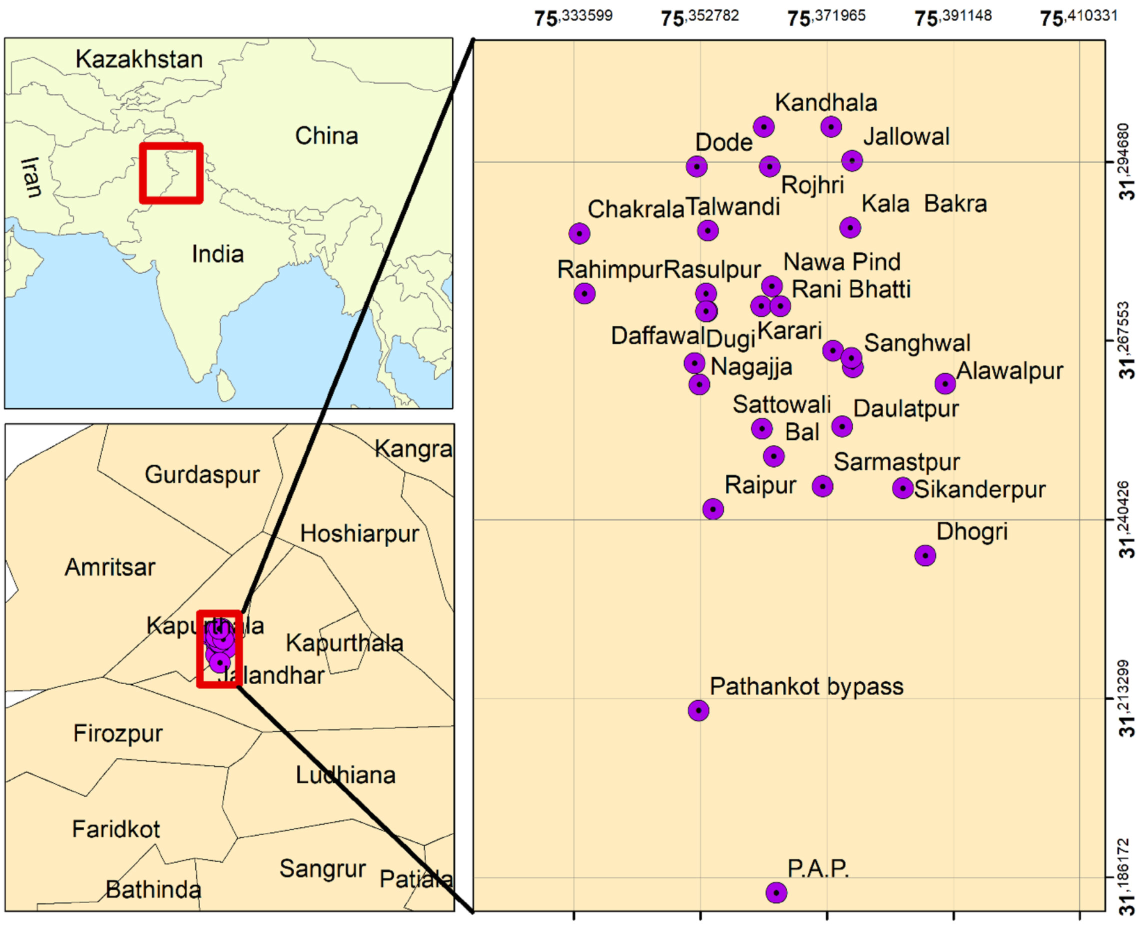

Fig. 1 Location of the study area and soil samples

the hot plate for 1–2 h. After that, the samples were filtered and diluted with 50 mL of steam distillation water and used for the estimation of HMs such as Co, Cu, Cr, and Pb. 1000 mL standard solution of each metal was acquired from Agilent which is used to make diverse concentrations of each metal. The limit of detection of the instrument is Cr 5.0 µg/L, Co 5 µg/L, Cu 1.2 µg/L and Pb 14 µg/L. Analytical grade chemicals and reagents were used during the whole analysis. Double distilled water was used for the preparation and dilutions of samples and chemicals. Calibration curves were made using standard made by diluting stock of standards; 10, 000 mg/L in 5% HNO3 for heavy metals obtained from Agilent Technologies, USA. For quality assurance and quality control (QA-AC), the standards and blanks were run after every ten samples in order to check the working of the machine with 95% reliability [26]. The 95–105% recovery rates for samples spiked with standards confirmed that results are satisfactory [27].

2.3 Assessment methods for the heavy metals

The degree of HM contamination in the soils was computed by the contamination factor, geo-accumulation factor (CF), enrichment factor (EF %), potential contamination index (Cp) and the pollution index (PI). These indices are dependent on the evaluation of HM contamination in the study area in comparison with the reference/background environment [28]. However insignificant sources were accessible concerning the reference HM content in the studied area, the content of metals in the earth's crust was taken from the Taylor and Mclennan [29]. The reference/background value varies from region to region, but global average values are of universal use [30]. The CF reflects the anthropogenic inputs of metals [31]. It was determined by the method of Hakanson [32]:

$$C_f = \frac{C_s}{C_b} \tag{1}$$

where C_s and C_b are the contents of HM in the samples and background environment taken from Taylor and

McLennan [29]. The CF is classified into the following categories such as < 1 less pollution, 1–3 average pollution, 3–6 considerable pollution and ≥ 6 for high pollution.

The geo-accumulation index (Igeo) was computed to find the content of HM in the soils in order to evaluate the degree of metal contamination. The following equation is proposed by Muller [33]:

$$I_{geo} = \log_2\left[\frac{C_s}{1.5 \times C_b}\right] \tag{2}$$

where Cs and Cb are the contents of HMs in the samples and background environment, and the constant 1.5 represents the feasible alterations in the reference values of heavy metals because of lithogenic effects in the soil. The grades for classifying the level of contamination are Igeo ≤ no contamination, unpolluted to average contamination (0–1), average to contamination (1–2), average to strong contamination (2–3), maximum contamination (3–4), high to very contamination (4–5) and very high contamination (5). The Enrichment factor (EF %) was calculated by applying the equation suggested by Zonta et al. [34]:

$$EF\,(\%) = \frac{C - C_{\min}}{C_{\max} - C_{\min}} \times 100 \tag{3}$$

where C, C_{min}, and C_{max} are the averages, minimum and maximum concentrations of the individual metals in the samples.

The potential contamination index (Cp) was estimated using the formula suggested by Davaulter and Rognerud [35]:

$$Cp = \frac{C_{\max}}{C_b} \tag{4}$$

where C_{max} is the maximum content of analyzed samples and C_b background values of heavy metals in the environment. Davaulter and Rognerud [35] proposed categories of Cp: $p \leq 1$ which represents less contamination, 1 < Cp ≤ 3 indicates average contamination and Cp > 3 represents high contamination.

The CF, Igeo, EF (%) and Cp allow us reporting the impact of human activities on the enrichment of single heavy metal and did not take into consideration the combined impact of different HMs [36]. Therefore, we applied the pollution index (PI) and ecological risk index to further determination of the comprehensive pollution and ecological risk (RI) by different HMs in the roadside soils.

PI considers the influence of contamination of one element by using the maximum CF to form a weighted average. By applying the weighted average, the PI enables the adjustment of soil quality which was considerably higher significant of the impact of individual metal [37]. It was calculated by applying the equation proposed by Nemerow [38]:

$$PI = \sqrt{\frac{(cf_{\text{mean}})^2 + (cf_{\max})^2}{2}} \tag{5}$$

where Cf_{mean} and Cf_{max} are the mean and maximum values of contamination factors.

Finally, the Er was applied considering the CF, Er and toxicological response factors (Tr) such as 2 for Cr; 5 for Co and Cu, and Pb [39]. It was calculated by the equation:

$$RI = \sum_{i=1}^{n} E_r^i = \sum_{i=1}^{n} T_r^i \times CF^i \tag{6}$$

where *Er* and *Tr* are the potential ecological risk factors and toxicological response factors.

2.4 Statistical analysis

All the samples were collected in triplicates and the data were summarized as mean, standard deviation, skewness, kurtosis and coefficient of variance. The software's used for this analysis was Microsoft Excel (Microsoft, USA), PAST 3.15, Minitab-14 and SPSS v.16 (IBM, USA). Multivariate techniques such as hierarchical cluster analysis (HCA) and principal component analysis (PCA) are efficient techniques in differentiating the origin of sources that cause variations in the soil properties and HM contents [40]. HCA was employed to find the associations between soil properties and HMs, and their mode of origin by using the PAST 3.15 software. It was done according to Ward's method and Euclidean distance as a measure of similarity. The results are presented in the form of dendrograms which gives the overview of clusters for different physiochemical properties and HMs [41]. PCA is mainly applied to reduce the soil properties and HMs to a smaller set of variables. Varimax rotation with Kaiser Normalization was selected to conduct the PCA using SPSS v.16 software (IBM, USA).

3 Results and discussion

3.1 Soil physiochemical properties and heavy metals

The descriptive statistics of pH, SOM, calcium, magnesium and phosphorus, and HMs (Cr, Cu, Co, and Pb) for all the sampling sites are given in Table 1. Out of the studied sampling sites, the Dode village recorded the highest value of pH (8.7), whereas the lowest values were recorded for Durgi site of Jalandhar. The pH of

Table 1 Descriptive statistics of different soil properties and heavy metal from Jalandhar, Punjab

Sites	pH Mean ± SD	SOM (%) Mean ± SD	Ca (meq/100 g) Mean ± SD	Mg (meq/100 g) Mean ± SD	P (mg/g) Mean ± SD	Cu (µg/g) Mean ± SD	Co (µg/g) Mean ± SD	Cr (µg/g) Mean ± SD	Pb (µg/g) Mean ± SD
Karari	7.1 ± 0.1	4.0 ± 0.7	0.3 ± 0.18	0.11 ± 0.08	0.04 ± 0.01	0.006 ± 0.0003	0.011 ± 0.0005	0.02 ± 0.001	0.017 ± 0.01
Dugri	7.0 ± 0.1	2.8 ± 1.1	0.15 ± 0.07	0.07 ± 0.04	0.044 ± 0.014	0.003 ± 0.0002	0.007 ± 0.0003	0.019 ± 0.0003	0.005 ± 0.001
Rahimpur	7.1 ± 0.1	3.4 ± 1.1	0.17 ± 0.15	0.19 ± 0.08	0.039 ± 0.011	0.002 ± 0.0001	0.008 ± 0.0001	0.019 ± 0.001	0.007 ± 0.001
Chakrala	7.2 ± 0.1	3.9 ± 0.3	0.2 ± 0.12	0.12 ± 0.05	0.019 ± 0.002	0.005 ± 0.002	0.008 ± 0.0001	0.025 ± 0.0005	0.019 ± 0.004
Sanghwal	7.1 ± 0.1	3.5 ± 1.9	0.15 ± 0.05	0.14 ± 0.09	0.031 ± 0.015	0.001 ± 0.001	0.006 ± 0.0001	0.017 ± 0.001	0.003 ± 0.001
Raipur	7.2 ± 0.2	3.8 ± 1.8	0.16 ± 0.02	0.05 ± 0.04	0.078 ± 0.0001	0.01 ± 0.004	0.017 ± 0.001	0.03 ± 0.0007	0.02 ± 0.015
Kisangarh	7.2 ± 0.2	4.9 ± 0.9	0.15 ± 0.005	0.06 ± 0.01	0.055 ± 0.0001	0.008 ± 0.005	0.014 ± 0.0003	0.022 ± 0.001	0.023 ± 0.001
Rasulpur	7.2 ± 0.10	3.7 ± 0.9	0.11 ± 0.01	0.09 ± 0.04	0.062 ± 0.02	0.009 ± 0.0002	0.014 ± 0.0004	0.032 ± 0.001	0.021 ± 0.012
Reru	7.1 ± 0.2	3.7 ± 1.7	0.17 ± 0.03	0.11 ± 0.06	0.08 ± 0.0004	0.007 ± 0.005	0.009 ± 0.0002	0.024 ± 0.002	0.013 ± 0.016
Talwandi-Abdar	7.0 ± 0.1	3.5 ± 1.0	0.18 ± 0.04	0.07 ± 0.06	0.09 ± 0.0002	0.01 ± 0.0006	0.008 ± 0.0001	0.024 ± 0.003	0.029 ± 0.004
Jallowal	7.7 ± 0.2	3.5 ± 0.9	0.30 ± 0.34	0.14 ± 0.095	0.08 ± 0.0001	0.014 ± 0.001	0.01 ± 0.0001	0.11 ± 0.83	0.023 ± 0.002
Daffarwal	7.7 ± 0.2	2.9 ± 1.2	0.91 ± 1.18	0.05 ± 0.045	0.06 ± 0.01	0.002 ± 0.002	0.004 ± 0.0002	0.02 ± 0.0006	0.008 ± 0.005
Bal	7.8 ± 0.1	3.5 ± 0.5	0.41 ± 0.04	0.09 ± 0.025	0.06 ± 0.01	0.094 ± 0.021	0.022 ± 0.0008	0.047 ± 0.001	0.20 ± 0.060
Rani Bhatti	8.1 ± 0.1	4.5 ± 0.4	0.11 ± 0.01	0.90 ± 0.07	0.02 ± 0.0002	0.011 ± 0.0005	0.01 ± 0.0005	0.036 ± 0.001	0.035 ± 0.002
Naugajja	7.9 ± 0.2	4.8 ± 0.5	0.13 ± 0.05	0.63 ± 0.005	0.08 ± 0.0007	0.001 ± 0.0003	0.014. ± 0.0003	0.022 ± 0.001	0.008 ± 0.002
GarhiBakhsha	7.6 ± 0.1	3.8 ± 1.1	0.11 ± 0.02	0.02 ± 0.01	0.013 ± 0.002	0.008 ± 0.002	0.012 ± 0.0001	0.018 ± 0.0008	0.022 ± 0.009
Daulatpur	7.9 ± 0.2	1.9 ± 0.4	0.36 ± 0.03	0.13 ± 0.08	0.07 ± 0.0001	0.009 ± 0.0001	0.011 ± 0.0002	0.025 ± 0.0004	0.006 ± 0.0005
Sarmastpur	7.9 ± 0.1	5.7 ± 0.5	0.30 ± 0.05	0.12 ± 0.03	0.007 ± 0.0001	0.016 ± 0.005	0.018 ± 0.0002	0.028 ± 0.001	0.006 ± 0.001
Dode	8.7 ± 0.1	3.4 ± 0.5	0.09 ± 0.03	0.03 ± 0.02	0.03 ± 0.0003	0.005 ± 0.0004	0.026 ± 0.0002	0.064 ± 0.001	0.006 ± 0.001
Alawalpur	8.1 ± 0.1	3.1 ± 0.7	0.09 ± 0.051	0.14 ± 0.02	0.05 ± 0.0002	0.007 ± 0.001	0.005 ± 0.0001	0.027 ± 0.001	0.03 ± 0.001
Rojhri	7.4 ± 0.3	6.7 ± 0.7	0.29 ± 0.005	0.10 ± 0.03	0.10 ± 0.0002	0.007 ± 0.001	0.014 ± 0.0003	0.033 ± 0.001	0.023 ± 0.001
Sikanderpur	7.3 ± 0.1	2.2 ± 0.6	0.32 ± 0.02	0.15 ± 0.05	0.07 ± 0.0003	0.001 ± 0.0001	0.010 ± 0.0006	0.031 ± 0.0003	0.017 ± 0.014
NawanPind	7.4 ± 0.1	2.4 ± 0.9	0.29 ± 0.03	0.13 ± 0.02	0.05 ± 0.031	0.002 ± 0.001	0.016 ± 0.0001	0.026 ± 0.0002	0.008 ± 0.001
Kala Bakra	7.6 ± 0.2	2.7 ± 1.3	0.12 ± 0.005	0.05 ± 0.04	0.07 ± 0.0001	0.001 ± 0.0002	0.010 ± 0.0002	0.026 ± 0.0002	0.048 ± 0.026
Dhogri	7.5 ± 0.1	3.1 ± 1.7	0.16 ± 0.02	0.14 ± 0.089	0.08 ± 0.0001	0.009 ± 0.0001	0.007 ± 0.001	0.026 ± 0.0001	0.019 ± 0.005
Sattowali	7.5 ± 0.1	3.6 ± 1.1	0.33 ± 0.03	0.13 ± 0.02	0.136 ± 0.034	0.007 ± 0.0003	0.015 ± 0.0001	0.036 ± 0.0002	0.024 ± 0.011
Mustfapur	7.6 ± 0.2	4.3 ± 1.2	0.09 ± 0.03	0.07 ± 0.035	0.06 ± 0.0002	0.006 ± 0.001	0.010 ± 0.0002	0.029 ± 0.0001	0.017 ± 0.002
Beas Pind	7.2 ± 0.1	4.6 ± 0.4	0.13 ± 0.043	0.11 ± 0.045	0.037 ± 0.0001	0.005 ± 0.0006	0.012 ± 0.0005	0.032 ± 0.0004	0.016 ± 0.006
Kandhala	7.4 ± 0.1	5.0 ± 0.7	0.12 ± 0.03	0.033 ± 0.015	0.07 ± 0.0001	0.008 ± 0.003	0.013 ± 0.0002	0.028 ± 0.0002	0.011 ± 0.001
P.A.P.	7.4 ± 0.2	3.1 ± 0.6	0.19 ± 0.005	0.12 ± 0.04	0.09 ± 0.0001	0.003 ± 0.0005	0.012 ± 0.0004	0.033 ± 0.0001	0.025 ± 0.019
Min	7.0	1.9	0.09	0.023	0.007	0.001	0.004	0.017	0.003
Max	8.7	6.7	0.91	0.63	0.13	0.12	0.026	0.118	0.2
Mean	7.5	3.0	0.22	0.119	0.065	0.013	0.012	0.031	0.024
S.D.	0.4	1.0	0.16	0.11	0.03	0.03	0.00	0.02	0.03
Skewness	1.1	0.8	2.96	4.19	0.30	3.64	1.02	3.73	4.77
Kurtosis	1.4	1.3	11.66	20.75	0.15	12.71	1.62	16.14	24.63
CV	5.2	26.9	71.41	89.32	45.48	197.53	41.01	60.38	147.08
Awashthi [51]	–	–	–	–	–	135–270	–	–	250–500
Bhagure and Mirgane [52]	–	–	–	–	–	100	30	120	80

the studied samples was found to be alkaline in nature which is similar to other studies done in Punjab [42, 43]. The alkaline nature of the soil is responsible for reducing the mobility of metals and has greater retention in the soil [44]. The SOM was found in the range of 1.9–6.7%. SOM has a great impact on the retention of metals in the soil [45]. The lowest content of phosphorus was found in Sarmastpur (0.007 mg/g), whereas the highest content was found in Sattowali (0.136). The phosphorus fertilizers contributes to the pollution of HMs in the soils and act as a sink for the immobility of metals [46]. The minimum Ca content was recorded in Alawalpur (0.093 meq/100 g), whereas Daffarwal showed the highest level of Ca (0.91 meq/100 g). The Ca content is responsible for inhibiting the absorption and translocation of metals in the soils [47]. The lowest Mg content was registered in Garhi

Bakhsha (0.023 meq/100 g), whereas the highest one in Naugajja (0.63 meq/100 g). The Mg content is responsible for enhancing the toxicity of metals in the soils [48]. The skewness and kurtosis of pH, Ca and Mg were higher than one, indicating right-handed skewness and leptokurtic kurtosis [49]. The coefficient of variation of Ca, Mg and P was high, indicating greater alterations in the soil samples due to human activities [50].

The average values of HMs followed a trend, i.e., Cr > Pb > Cu > Co. The average values of HMs in the present study were lower than the Indian standard limits [51] and Swedish ones [52]. Among the analyzed HMs in the studied sampling sites, the CV of Cu was found maximum, followed by Pb, Cr, and Co. All the HMs showed skewness and kurtosis values higher than one, indicating right-handed skewness and leptokurtic kurtosis [49]. The high kurtosis of these metals may be due to the fact that the majority of the samples are assembled at relatively low values [53]. The anthropogenic activities such as increasing urbanization and agricultural activities could also have a great impact on the alterations of these HMs in the sites [54].

Finally, Pearson's correlation analysis was conducted to soil properties and HMs (Fig. 2). The pH showed a positive correlation with Cr and Pb. The SOM showed a negative correlation with Ca and Mg, and positive correlation existed with Pb. The negative correlation of Mg was found with Pb. All the analyzed HMs such as Cu, Cr, Co and Pb are positively correlated with each other. HMs indicating high correlations may attribute to a similar type of sources [55].

3.2 Multivariate statistical approach

Hierarchical cluster analysis (HCA) was applied to the contents of different soil parameters by using Ward's method and Euclidean distance as a measure of similarity (Fig. 3). Mainly two groups were formed by cluster analysis. Cluster 1 includes (pH and SOM) and cluster 2 contains (Ca, Mg, P, Cu, Cr, Co, and Pb) which is further grouped into (Ca, Mg, and P), and (Cu, Cr, Co, and Pb). All the HMs such as Cu, Co, Cr, and Pb were included in the same cluster indicating similar origin. The metals like Cu, Cr, Co, Mn, and Pb included in the same cluster likely to be originated from the same source [56]. Ca, Mg and P are also included in the same cluster and had close proximities with each other. pH and SOM also formed the same group. Esmaeilzadeh

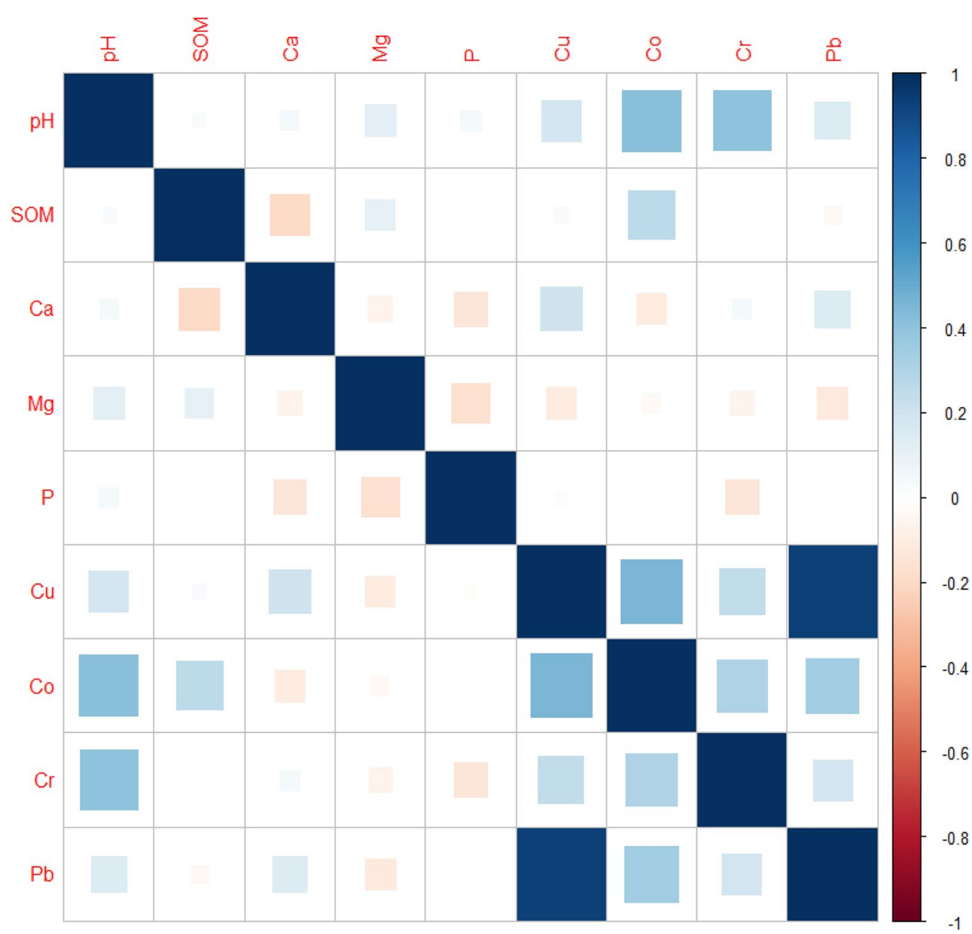

Fig. 2 Pearson's correlation analysis

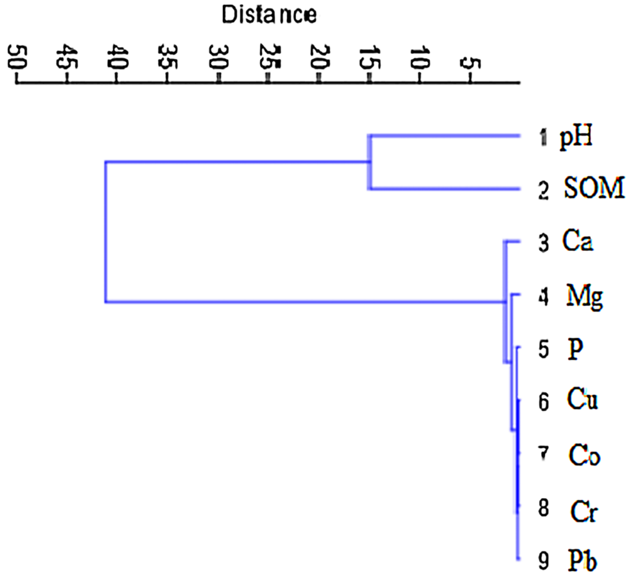

Fig. 3 Cluster analysis of soil properties and potentially toxic trace elements from the soils of Jalandhar, Punjab

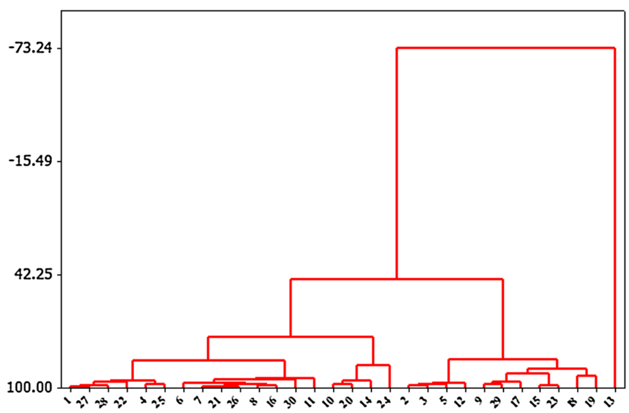

Fig. 4 Cluster analysis of sampling sites on the basis of physiochemical properties and heavy metal contents

et al. [18] in their studies on Eshghabad region, Iran also reported that Pb and Cu are included in the same cluster.

HCA was also applied to different sampling sites on the basis of physiochemical parameters and HMs content (Fig. 4). From the HCA results, it was found that mainly two clusters are formed: cluster 1 (Bal site) and cluster 2 includes all the sites which are further sub-grouped into various clusters. Dode, Sarmastpur, Naugajja, Nawan Pind, Daulatpur, Kandhala and Reru are included in the same sub-group. On the other hand, Kala Bakra, Rani Bhatti, Alawalpur and Talwandi Abdar are included in the same cluster which can be attributed to the less variations of physiochemical and HMs in these sites. Finally, Karari, Mustfapur, Beas Pind, Sikanderpur, Chakrala and Dhogri are also registered in the same cluster which may also due to the less alteration in HM content of these sites.

Table 2 Factor loadings of physiochemical properties and potentially toxic trace elements from soils of Jalandhar, Punjab

Variables	PC-1	PC-2	PC-3	Communality
pH	0.019	**0.813**	0.035	0.663
SOM	−0.132	0.156	**0.696**	0.526
Ca	0.230	0.020	−**0.656**	0.484
Mg	−**0.344**	0.224	0.094	0.177
P	−0.122	0.148	−**0.473**	0.261
Cu	**0.856**	0.085	−0.050	0.742
Co	0.495	**0.577**	0.402	0.740
Cr	0.059	**0.765**	−0.178	0.621
Pb	**0.767**	0.206	−0.079	0.637
% Var	24	18.5	15.5	58

Bold letters indicate high loadings on principal components

PC Principal components

Based on the results of the principal component analysis (PCA) (Table 2), the eigenvalues of the first four extracted components were higher than 1.0 (Supplementary Table S1). The first four principal components explained 71.0% of the total variance for soil properties and HMs. PC-1 had maximum loadings on Cu and Pb and explained 24% of the total variance. Soil parent materials like sedimentary and sulphide-bearing shales contains naturally high content of Cu and Pb. Soil formed on such materials generally can register a high content of these heavy metals. Also, anthropogenic activities (application of fertilizers and pesticides, and traffic activities) also contribute to the content of these metals [57]. pH and Cr had high loadings on PC-2 and accounted for 18.5% of the total variance. PC-2 also had moderate loading on Co. Co and Cr formed the cobalt-chromium (CoCr) alloy which is used in engine components and many other industrial or mechanical components where high wear-resistance is required [58]. PC-3 explained 15.5% of the total variance and dominated by SOM, Ca and P. This dipolar factor presents moderate positive loading of SOM and moderate negative loadings of Ca and P. Suryawanshi et al. [59] working on road dust of Delhi confirmed loadings of Cu and Pb on PC-1. They suggested that particles released due to traffic activities are responsible for their contents. Bhatti et al. [60] while working on agricultural roadside soils reported loading of Cu on PC1 and indicated that geogenic factors and parent rock materials contributed to this metal. Anju and Banerjee [61] in their studies on soils of India reported loadings of Mg, Co, Pb and Cu on PC1 and Ca on PC3. They concluded that anthropogenic and lithogenic factors are responsible for the contamination of HMs in the soils. Chabukdhara and Nema [62] while

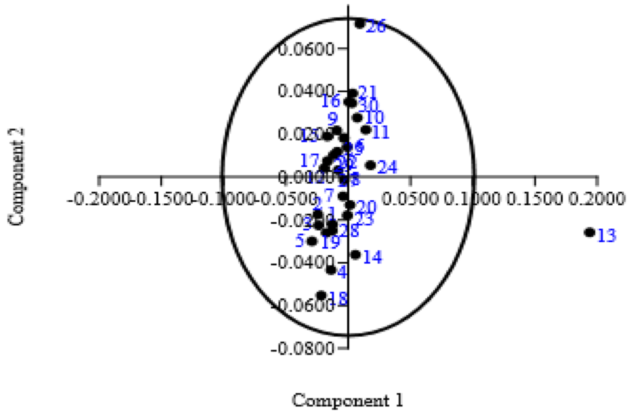

Fig. 5 PCA loading plot for different sampling sites

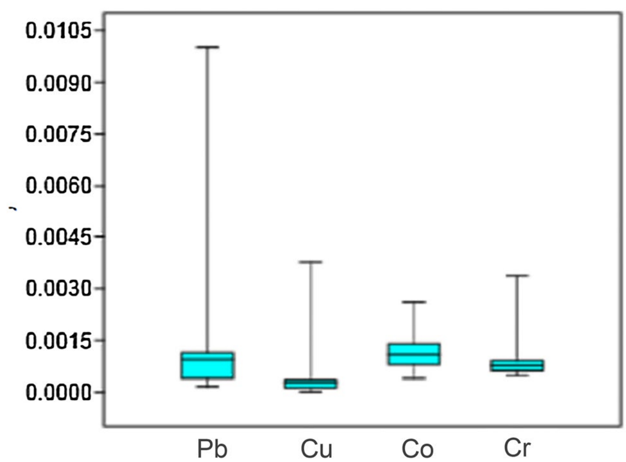

Fig. 6 Box plot of contamination factor for different metals

working on urban soils of Ghaziabad, reported loadings of Cu and Pb on PC1, and inferred that traffic and human activities are responsible for the pollution of these metals in the studied region.

PCA was also conducted to different sampling sites on the basis of physiochemical parameters and HM contents (Fig. 5). The first three components were able to explain 96.3% (54.6, 29.3 and 12.4%) of the total variance. All the sampling sites were retained in the 2 D space except site 13 (Bal). In HCA, Bal site also formed the different cluster which is attributed to comparatively less variations of physiochemical parameters and HM contents.

3.3 Evaluation of heavy metals in soils by using indexing approach

The content of studied metals was found below the Indian and Swedish permissible limits, which indicates low pollution of metals in the soils of Jalandhar but their

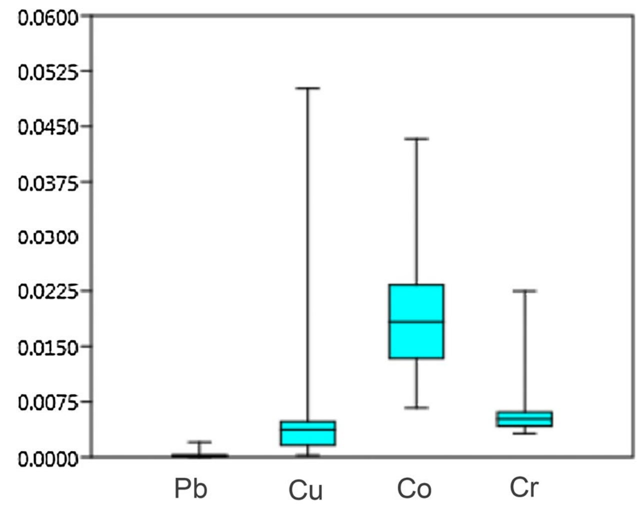

Fig. 7 Box plot of the geo-accumulation index for different metals

Table 3 Cp, PI and EF (%) values of different heavy metals for studied area

	Pb	Cu	Co	Cr
Potential contamination index (Cp)	0.01	0.0038	0.0026	0.0034
Pollution index (PI)	0.0071	0.0027	0.0020	0.0025
Enrichment factor (EF (%)	10.49	9.38	35.30	14.09

assessment is not only determined through their concentrations [44]. In order to find their contamination, these were compared with uncontaminated soil environments by computing contamination factor (Fig. 6). The CF of all the sampling sites for studied metals was found to be less than one, indicating low contamination in the soils of the Jalandhar. Geo-accumulation index gives us an indication of the impact of anthropogenic activities based on environmental geochemistry background [63]. Figure 7 showed the Igeo of the studied metals for different samples. From the results of Igeo, it was found that HM values for this index were found less than one indicating a low accumulation of metals in the studied soil samples. Liu et al. [64] in their studies on suburban vegetable soils of Northeast China reported average values of Igeo for Pb (0.02), Cr (– 0.12) and Cu (0.17), all of them less than one, indicating low pollution as our results demonstrated. Table 3 showed the results of potential contamination index (Cp), pollution index (PI) and enrichment factor (%). The results of Cp indicated that Pb showed maximum value followed by Cu, Cr, and Co. The results of Cp for the analysed metals were found less than one, representing low pollution in the studied soil samples. The PI values obtained maximum for

Pb followed by Cu, Cr, and Co. Their results also showed less pollution of metals in the present study. The enrichment factor (%) was also computed for different metals. The maximum EF (%) was found for Co followed by Cr, Pb, and Cu. The potential ecological risk indices of each metal (Er^i) are presented in supplementary table S2. The results of RI for the analysed sites and metals showed a low ecological risk of roadside soils in the present study. Consequently, potential ecological risk, which represents the comparative sensitivity of biological communities to harmful substances and explains the potential ecological risk posed by the toxic metals, was done in the current study to determine the ecological assessment of metals in the soils of Jalandhar. The methods employed in this study may be helpful to other researchers.

We can state that more attention should be paid for the areas where the pollution indices and the high concentration of HMs were found. In the last century, numerous investigations have claimed that local and regional impacts on soils are key factors to understand environmental problems at global scales [65, 66]. Possibly, as other authors mentioned, there is a strong necessity to connect the issues related to soils with the public; however, to date, it is not well-divulgated through the society [67]. Therefore, more work would be necessary to correlate the local and regional scales with global studies. Due to the connectivity processes, we can be sure that roadside soils will not be an isolated problem [68]. As recently several authors demonstrated in highly populated urban areas, agricultural fields or mining areas, the second most affected source affected by roadside soils is the water [69–72]. So, it would be interesting to assess for this studied territory, the possible impacts of roadside soils on the nearly water bodies. This kind of studies will allow us understanding that the transport of the polluted sediments can reach higher rates far from the original source and possibly, to prevent future negative and irreparable environmental and human consequences.

4 Conclusions

The present study showed that the mean values of Cu, Co, Cr, and Pb were below the permissible limits of Indian soils. Pearson's correlation analysis indicated that HMs are highly correlated with each other and have the same source of origin. Furthermore, their results are confirmed by results of CA and PCA also showed that HMs have a source of origin, while physiochemical properties have a different source. The results of CF, EF %, Cp, Igeo, PI and RI showed that roadside soils are moderately contaminated by HMs. This study provides the baseline data of HMs and physiochemical properties for policymakers and stakeholders in roadside soils of Jalandhar. Further research is needed to identify and evaluate the sources responsible for the contamination of roadside soils.

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Compliance with ethical standards

Conflict of interest The authors declare that they have no conflict of interest.

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