COMPARATIVE GEO-ACCUMULATION INDEX OF HEAVY METAL CONCENTRATION IN THE URBAN SOILS OF CHANDIGARH AND BADDI AREAS UNDER INDUSTRIAL ACTIVITIES IN LOWER SHIWALIK REGION, INDIA

Viney Kumar[1], Ram Chand Bhatti[2], Rupinder Kaur[3], Siril Singh[3,4], Chongtham Nirmala[5], Anand Narain Singh[3]*

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Abstract

Aim: Heavy metal pollution in soil resulting from industrialisation continues to pose a significant challenge to humankind. Therefore, the present study was designed to evaluate the distribution and geo–accumulation of heavy metals in the soils from two urban cities (Chandigarh and Baddi) of north-western region of India under the influence of rapid industrialisation phase.

Methodology: The heavy metal concentration of Industrial soils of Chandigarh (site-1 and site-2) and Baddi (site-3), were determined to evaluate the contamination resulting from industrial activities. The soil was analysed for nine heavy metals viz. Cr, Co, Ni, Cu, Zn, As, Sr, Ba, and Pb. A total of 36 soil samples were analysed through a wave dispersive X-ray fluorescence spectrophotometer (WD-XRF).

Results: The results indicated that site-1 and site-2 had higher contamination of Cr, Ni, and Cu, while Sr and As was comparatively higher in site-3. Most soil samples had high contamination of Cr, Cu, and Zn, while all soil samples were observed to be contaminated by As. Geo–accumulation index (GAI) reflected extreme contamination of Co in three sites. Simultaneously, Cu, Zn, As, and Pb was found to show high contamination.

Interpretation: Industrial activities affect heavy metal concentrations in soils, which can pose a threat to soil biota and human health. Both the urban areas (Chandigarh and Baddi) were under significant heavy metal contamination due to industrial activities. Therefore, intensive studies are required to understand its proper mechanism to reduce the contamination and effectively remediate "urban soils" to mitigate the toxicity of heavy metals.

Conclusion: Total heavy metal concentration and geo-accumulation index indicated that most of the selected sites sample locations have toxic levels of arsenic, chromium, copper, zinc and lead. Cobalt concentration was mostly under the permissible limit but had too high GAI in all the sites. On the other hand, all the soil samples were observed to have Ba concentration under permissible limits and indicated no contamination on the GAI scale. Therefore, these observations supported that both the urban areas are under significant heavy metal contamination due to industrial activities. Therefore, intensive studies must understand its contamination in urban ecology as urbanisation is an inevitable part of human development that cannot be stopped. Since Chandigarh city is a well-planned and adequately established city of India, present information may be useful while considering an eco-city development in the future.

Keywords: Industrial activities, Geo–accumulation index, Heavy metal contamination, Urban soil, WD-XRF

[1] Govt. Post Graduate College Sector-1, Panchkula, Haryana, India, Email: anjaanvinay1986@gmail.com
[2] Smt. Aruna Asaf Ali Post Graduate College, Kalka, Haryana, India, Email: hnarambhatti@gmail.com
[3*] Soil Ecosystem and Restoration Ecology Lab, Department of Botany, Panjab University, Chandigarh, 160014, India. E-mails: anjaanvinay1986@gmail.com, rupinderkaurrupy@yahoo.com
[4] Department of Environment Studies, Panjab University, Chandigarh 160014, India.
Email: sirilsingh@gmail.com
[5] Department of Botany, Panjab University, Chandigarh, 160014, India. E-mail: cnirmala10@gmail.com
***Corresponding Author:** A. N. Singh
*Soil Ecosystem and Restoration Ecology Lab, Department of Botany, Panjab University, Chandigarh, 160014, India. E-mails: dranand1212@gmail.com

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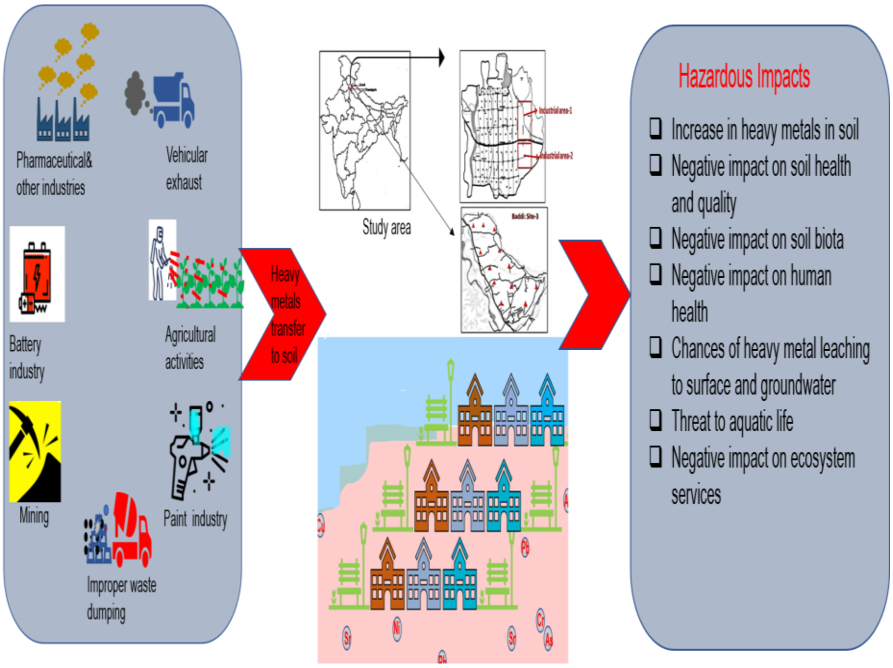
Introduction

The ecological and economic pressure of ever-increasing human population growth has always been endured by the soils (Skordas et al., 2013; Stirbescu et al., 2019). This pressure resulted in disturbance of soil composition, structure, microbial diversity and vegetation, resulted in subsequent degradation and leading to faulty ecosystem processes (Guagliardi et al., 2015; Xu et al., 2016; Ungureanu et al., 2017; Zhang et al., 2021; Hu et al., 2023). Contamination of soil due to anthropogenic activities is known since the beginning of human civilisations (Pan et al., 2017). However, its effects have dramatically increased in more recent times due to increased urban activities (Yang et al., 2016; Zhang et al., 2021: Li et al., 2023). Increased urban activities not only degrade the physical structure of soils but have also significantly altered the geochemical balance by loading large quantities of minerals making them toxic for environmental and soil health. Contamination in the urban soils is presumably increasing with unprecedented rates due to the high rate of anthropogenic activities such as urbanization and industrialization, which is an inevitable part of human development. Heavy metals are one of the most recent and important contaminants, which can cause severe damage to soil health and pose a high risk for human well-being. In general, heavy metals are naturally occurring elements with a density ranging from 3.5-7.5 g cm^{-3}; their contents in soils may vary significantly in different geographical areas (Duffus, 2002). Their abundance in soils beyond their permissible limits may lead to ecological risks and diverse after-effects (Wang et al., 2016; Spahic et al., 2018; Liu et al., 2022; Xie et al., 2023).

GRAPHICAL ABSTRACT



The literature survey has indicated that mining, metal processing, and manufacturing industries are the main contributors of ever-increasing heavy metal load. Across the globe, various studies have investigated and established individual roles of different industries in an increase of specific heavy metal (Krishna and Govil, 2007; Ndungu and Bhardwaj, 2016; Liao et al., 2021; Raji et al., 2023). Different types of activities add a different set of metals into the soils; such as vehicular emissions add lead (Pb) and metal industries add more copper (Cu) and chromium (Cr) into the soils (Yang et al., 2020). Along with industrial, other anthropogenic activities such as agriculture, mining, building constructions, transportation and vehicular emissions are also adding a substantial amount of heavy metals in to the soils (Li et al., 2013; Kumar et al., 2014;Raji et al., 2023). Literature has indicated that excavation/mining industry is the top soil polluter with heavy metals, followed by smelters, metallic goods manufacturing, electroplating, bio-medical industry, textiles, paints, pharmaceutical and agrochemical industries.Heavy metals are highly mobile and persistent as they are non-biodegradable. Biological fertility of soil and nutrient cycles are also severely affected if their concentrations are beyond their critical loads or permissible limits, which may increase ecological health risk. They can translocate into plant species and subsequently to the food chain, ultimately to the living organisms and can potentially disturb their biochemical processes (Chowdhury and Maiti, 2016; Aschale et al., 2017). It has also been reported that the concentrations of these heavy metals have been substantially increased from their base values of parent rock material in many urban areas, and content has also crossed the threshold of permissible limits, given by various governmental agencies across globe. Due to which an increase in risk to environmental balance and human health has been observed. Therefore, increased concentration of the trace elements resulting from human activities is the driving force to analyse their distribution, geo-accumulation and risks associated with them by using standard procedures (Ngole-Jeme 2016; Giri et al.. 2017; Sayooj et al., 2023; Xie et al., 2023). Various studies from China, Europe, Turkey, USA and India etc., have reported increase in heavy metal content of soils due to various urban industrial activities (Skordas et al., 2013; Guagliardiet al., 2015;Xu et al., 2016; Ungureanu et al., 2017;Liu et al., 2022). However, to best of our knowledge, no study has reported the heavy metal status of soils under urban industrial activities from selected study areas.

Therefore, the present study was designed to evaluate the distribution and geo–accumulation of heavy metals in the soils from two urban cities under the influence of rapid industrialisation phase. In this study, three urban sites of North-western India under the influence of industrial activities were selected from Chandigarh and Baddi region. With urban development and rapid industrialisation in Chandigarh and Baddi, managing industrial effluents has become challenging task. Contamination of soils around selected industrial sites is mainly due to following sources: (a) random and mismanaged dumping of industrial waste, (b) organised dumping sites due to leaching and leakage of heavy metals, (c) discharge of untreated industrial effluent into the streams nearby, (d) emission from chimneys and smokestacks, (e) discharge from smelters and metal industries. However, presumably, discharging of the effluents does not to affect the contamination of the soil equally throughout the area. Thus, there is always a possibility of extremely high heavy metal contamination of certain sites which are directly under the effect of these sources.Therefore, dumping of waste in open and closed sites significantly increases the risk of heavy metal contamination in the soils. The areas under investigation have not been explored yet, and not much information is available on heavy metal status of these sites. Determination of distribution and geo–accumulation index (GAI) of heavy metals is important to differentiate contaminated soils from uncontaminated ones to evaluate the level and severity of ecological risk assessment (Ngole-Jeme, 2016; Sharma and Kuniyal, 2016;da Silva et al., 2017; Liu et al., 2022). Furthermore, such investigation is also important to potentially mitigate the heavy metal contamination from already polluted soils and to prevent the contamination of vulnerable soils, so that the future strategies and policies on soil health management can be designed on the basis of determined data.

Therefore, present study is inclined to know, how industrial activities affect the heavy metal concentrations in the urban soils and to what extent industrialisation has enhanced the heavy metal contamination in the urban soils concerning their baseline values in the study area.

Materials and Methods

Study sites: Study sites investigated in the present study are located in the Shiwalik foothills of North-western India. The first and second study sites (i.e., industrial area phase-I and industrial area phase-II) are the urban areas of Chandigarh union territory is under various industrial activities. In contrast, the third site taken from the Baddi area is the mega industrial and pharmaceutical hub rapidly developing in a part of the Solan district of Himachal Pradesh (Fig. 1). Site-1 and site-2 (combined) are approximately 2.35 km^2, and site-3 is about 0.36 km^2. Most of the area is beneath the industrial establishments. Site-1 and 2 are adjacent to each other and lie entirely in Chandigarh. Site-3 is approximately 35 km away (from site-1 and 2) and lies in Baddi.

Site-1 and Site-2 are located in a region of Shiwalik foothills of the great Himalayas and lies in India's north-western plains. Soil horizons in the area are composed of rock beds followed by boulders and pebbles. The soil's upper surface layers are a mixture of sand, silt and clay, providing a sandy loam texture. Chandigarh is situated at an elevation of about 360 m above mean sea level. Summer is usually dry and comparatively more prolonged than other seasons, starting from mid-March and lasts till June. Mean daily temperature ranges between 38ºC and 24ºC. Maximum temperature may rise beyond 47ºC sometimes, especially in June. Average annual rainfall ranges between 720 to 1250 mm and maximum rainfall generally occurs in July and August.

Various kind of industries exist in the Chandigarh (site-1 and site-2) such as automobile industry, sanitary fittings, paper and paper products, industrial fasteners (nuts, bolts and screws), auto and tractor parts, steel fabrication, wooden and steel furniture, job tools and dyes, repairing and servicing of cars and buses were major industries of site-1 industrial area. However, in site-2 industrial area of Chandigarh, electrical appliances, printing and stationery, telephone workshop, battery manufacturing, glass industry and electric cables industry were more common. Therefore, urban areas of site-1 and site-2 are at higher risk of soil contamination with heavy metals such as Cr, Ni, Pb, Cu and Zn due to industrial activities.

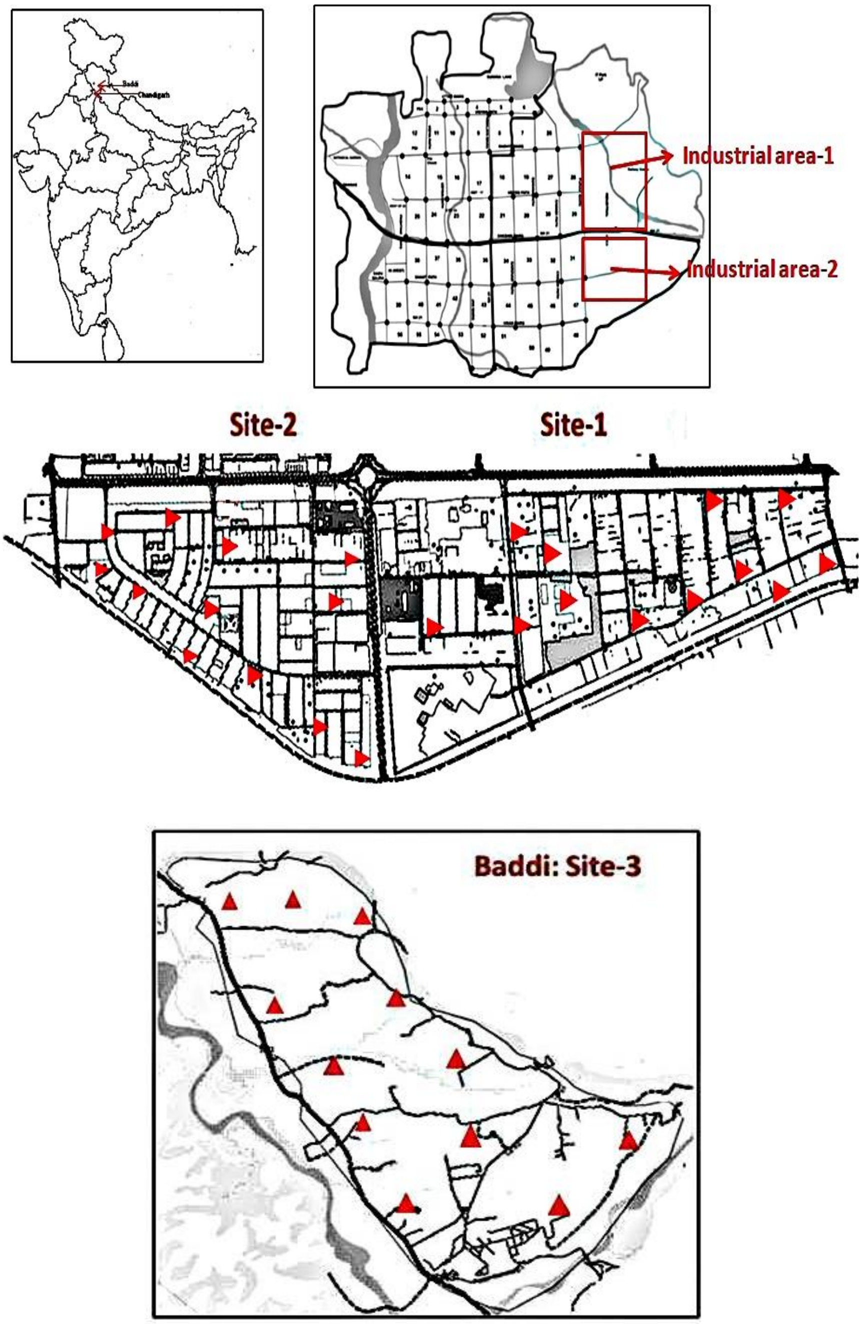


Fig. 1: Map showing study area and sampling sites

Site-3 selected for the present study is a renowned industrial hub and economic town Baddi of district Solan, Himachal Pradesh, India. This industrial town is also a part of the Shiwalik foothills and is situated at 426 m above mean sea level. Baddi lies in the subtropical belt and exhibits the climate accordingly. The winter is experienced from the start of November to February end. The chilling may extend up-to March, followed by summer from April to June, monsoon or rainy period of three months (July-September). The average annual rainfall in the region is about 1200 mm and the annual temperature ranges from 0-45ºC. Baddi is now developing many micro-, small and medium enterprises and has become India's largest pharmaceutical hub. Many small- and large-scale industries are being set up such as pharmaceutical, pesticides, paint, chocolate and confectionary industry, food processing, paper and card printing industry, soap manufacturing, nets making and tyre industry, that can lead to higher heavy metal loading in the soil and environment (da Silva et al., 2017).

Soil sampling: Sampling was done in a random sampling method from three study sites to study heavy metal distribution patterns. Twelve samples were collected from each location; each sample was a composite mixture of three subsamples. Therefore, total of36 samples were collected, out of which 24 were from Chandigarh industrial areas and 12 from Baddi; each sample is a mixture of 3 subsamples to attain homogeneity. The soil was sampled from 36 points in replicate (n = 3) from each study site, from soil depth of 0-10 cm with a spade (stainless steel); thus, 36 locations were marked for collecting soil samples in total. Stainless steel spade was used for the collection of samples to prevent the contamination from heavy metals. It was cleaned and washed with distilled water in between each sampling to wash away the previously attached soil. The replicates of collected soil samples were mixed thoroughly on a plastic sheet. Then12 samples from each site were packed into airtight polyethene bags and transported to the laboratory for further analyses.

Heavy-metal analyses: Collected soil samples were air-dried at room temperature for two days and oven-dried at 105°C for 24 hrs and moisture content of soils was maintained below 20%. Dried samples were manually crushed and sieved (<2mm mesh size) and packed in air tight polythene bags for further analysis with Wave Dispersive- X-Ray Fluorescence spectrophotometer (WD-XRF: Model-S8 TIGER Bruker). To reduce matrix effect, a thorough homogenisation of each sample was done by XRF aluminium test-sieves with vibratory electronic sieve shaker into a fine soil of about 75 µm particle size. As WD-XRF can analyse better only at a depth of 100 µm or less, particle size of 75 µm was ideal.

Since WD-XRF spectrometers only use surface layer of sample, each sample was carefully prepared into pellets under homogenous hydraulic pressure to obtain smooth surfaces of almost equal density, by further pulverizing them to a particle size of 60 µm and below. Pellets were made manually by mixing 4 gm of pulverised soil with 0.9 gm of binder (cellulose, starch, polyvinyl alcohol, or other organic material) and subsequent 4.9 gm sample was pressed under hydraulic pressure limit of about 15 tons in screw-top grinding aluminium cups. Pellets obtained were of 3 mm thickness and 32 mm diameter. These soil pellets were loaded in WD-XRF slots to obtain content of different heavy metals.

Background data and permissible limits: Geochemical baseline values for Indian soils are not available yet but work for the same has already been started under Global Baselines Programme. Therefore, background data has been determined based on the parent rock material of Chandigarh and Baddi's soils (Kabata-Pendias, 2010). Permissible limits for heavy metals in soil were obtained from Canadian Environmental Soil Quality Guidelines, as standardization of permissible limits for heavy metals in Indian soils is still under process (Sharma and Kuniyal, 2016). The standard reference soil used to certify the results by WD-XRF was GBW07406.

Geo-accumulation index (GAI): Indices of geo-accumulation (GAI) of heavy metals were calculated to evaluate the intensity of heavy metal contamination of soil by industrial activities. GAI was calculated according to the formula given by Müller (1981). He has distinguished six classes of the geo–accumulation index (Chandel, 2011), as shown in Table 1.

$$\mathrm{GAI} = \log_2[\mathrm{C_n}/1.5\ \mathrm{B_n}]$$

Where, Cn is the measured concentration of heavy metal in each soil sample, Bn is the geochemical background value in the parent soil material as described by Alloway (2013). Therefore, the soil's background values in the Shiwalik region were taken the same as described earlier (Alloway

2013). The constant value (1.5) allows us to analyse the fluctuations. Based on obtained GAI values, a class was adopted by Müller (1981). Calculated data of GAI in the present study is, however, explained with the accepted given level.

Table 1: Classes of geo–accumulation index as described by Müller (1981)

Class	Value	Soil Quality
0	≤ 0	practically uncontaminated
1	0-0.9	uncontaminated to moderately contaminated
2	1-1.9	moderately contaminated
3	2-2.9	moderately to heavily contaminated
4	3-3.9	heavily contaminated
5	4-4.9	heavily to extremely contaminated
6	≥ 5	extremely contaminated

Statistical analyses: Data of heavy metal concentrations and GAI were subjected to the General Linear Model (GLM) for multivariate analysis of variance with SPSS-PC statistical software (IBM, SPSS, version 20.0).

Results and Discussion

Concentration of selected heavy metals: Selected urban soils in the present study have shown high contamination of heavy metals due to industrial activities. All the sub-sites had arsenic contamination, whereas barium content was found under the permissible limit in all samples. Site-1 was found to have the highest total concentrations of Cr, Ni, Sr and Ba, while site-2 had higher Cu, Zn and Pb. Higher concentrations of Co and As were observed in site-3.

In the present study, Cr ranged from 82- 4758 mg kg^{-1}; the highest concentration was recorded in site-1 and lowest in the site-3. Mean values of three study sites have also shown the same trend. However, ANOVA indicated insignificant variation due to site (Table 2). Various studies revealed a high concentration of Cr in the topsoil due to contamination from industrial activities such as steel industries, alloys, tanneries, textile industries, electroplating, and leather manufacturing wastes (Machender et al., 2011; Wang and Lu, 2011). High contamination of Cr in the soils and water bodies generally reaches the human diet due to stoichiometric changes and biogeological cycles of the nutrients. Several studies across the globe reported that how heavy metal concentrations cause liver and kidney damage. Some studies have also reported carcinogenic effects of Cr on human health (Yaylali-Abanuz, 2011; Govil et al., 2001). In the present study, higher contamination of Cr was found in Chandigarh's industrial areas compared to the industrial area of Baddi, which is due to the presence of more steel and metal industries in these areas. Furthermore, three samples of site-1 have shown very high contamination of Cr (2475-4758 mg kg^{-1}) which might be due to direct influence of metal processing industries on these samples. However, chromium was mainly higher beyond permissible limits (87 mg kg^{-1}) in nearly all the sub-sites (Fig. 2a). In agreement with this, high Cr concentrations were reported in urban soils (10-1161 mg kg^{-1}) of Turkey with similar industry types (Yaylali-Abanuz, 2011). A much lower concentration (6.21- 16.11 mg kg^{-1}) was observed in the industrial area of Dhaka (Bangladesh) under the vegetable plantations in the same industrial area (Ahmad and Goni, 2010). In one study from India, Patancheru industrial area (pharmaceuticals, paints and steel industries) of Andhra Pradesh, a comparable range of Cr contamination in the topsoil layer was reported (Govil et al., 2001). A similar range of Cr contamination was also reported from (177- 1039 mg kg^{-1}) another Indian region (Thane- Belapur industrial area of Mumbai, India) which is a very fast-growing industrial area with steel, paint, pharmaceutical, and textile industries (Krishna and Govil, 2005). In the Manali industrial area of Chennai, India, with petrochemical and fertiliser industrial activities, showed a comparatively lower range (149- 418 mg kg^{-1}) of chromium contamination in the soil (Krishna and Govil, 2008).

Higher Co levels in polluted soils can seriously affect plant growth and metabolic functions. In the present study, Co was found to be under the permissible limit (300 mg kg^{-1}) in nearly all the samples (except one), values of Co concentration ranged from 109- 362 mg kg^{-1}, being highest in site-3 and lowest in site-2 (Fig. 2b). Cobalt was reported to be higher in the soils around medical equipment and agro-chemical industries (Kabata-

Pendias, 2010). Therefore, high content of Co found in site-3 can be attributed to pharmaceutical and agro-chemical industries present in the area. However, the comparatively low range was reported in the Manali industrial area of Chennai city, India. This area is mainly affected by the petrochemical industry, refineries and fertilisers industries (Krishna and Govil, 2008).

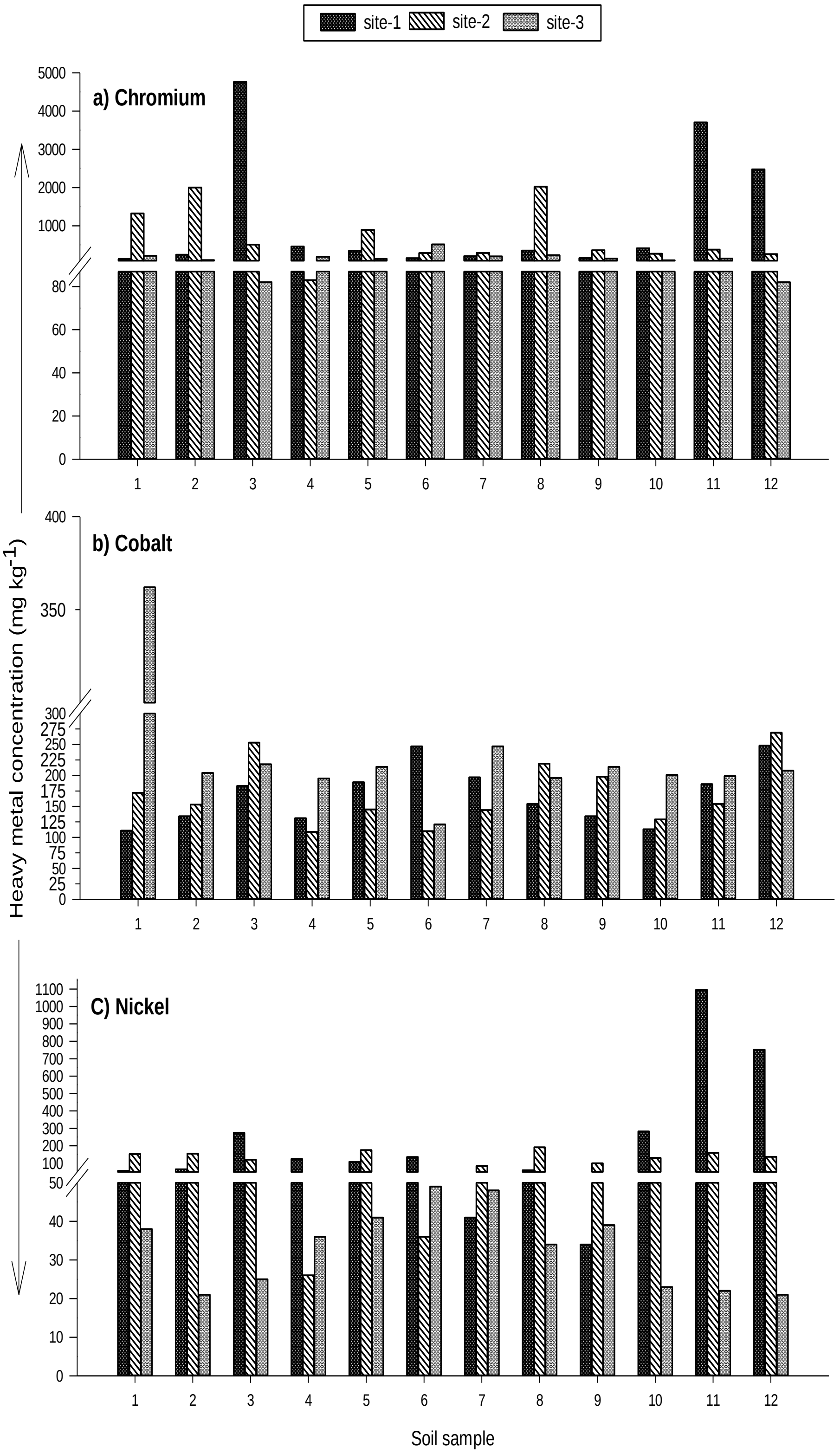


Fig. 2: Total concentration of selected heavy metals (a) Chromium, (b) Cobalt and (c) Nickel (mg kg^{-1}) in the urban soils of selected industrial areas of Chandigarh and Baddi region. Breaks in the bars show the permissible limit value of each heavy metal

Ni in soils is mainly dependent on the Ni content of parent material; however, increasing concentration of this metal in various soils reflects man-induced pollution and may pose a health risk. Out of the selected urban areas, site-1 was observed to have the highest Ni (1096 mg kg^{-1}) content, while site-3 had the lowest concentration of this metal (21 mg kg^{-1}). However, the mean values were 252.17, 121.92 and 33.08 mg kg^{-1} in site-1, 2 and 3, respectively (Table 2). Nickel is found to be higher in soils around steel and smelting industries. In agreement with this, Ni contamination beyond permissible limit was recorded in ten out of twelve samples in the site-1 (34-1096 mg kg^{-1}) and site-2 (26-191 mg kg^{-1}), whereas site-3 (21- 49 mg kg^{-1}) had a comparatively lower concentration of nickel (Fig. 2c), perhaps due to very little use of this metal in the pharmaceutical industries. Generally, Ni metal is used in the electroplating and steel industries. These industries are lesser in number at site-3 in comparison to site-1 and site-2. In agreement with this, high Ni concentration (64-538 mg kg^{-1}) was reported from Thane-Belapur industrial area, Mumbai, India, due to scrap materials of metal processing industries, mainly steel (Krishna and Govil 2005). The Manali industrial area of Chennai, India, dominated by the petrochemical and fertilisers industry, had a lower range of Ni concentration 11-79 mg kg^{-1}(Krishna and Govil 2008).

Table 2: Mean, median and range of heavy metal concentrations (mg kg^{-1}) in selected study sites along with permissible limits and base values. Values suffixed with the same letter in a row are not significantly different from each other at probability level $p < 0.05$

Heavy metal	PL	BV	Site-1 Mean ± 1SD	Median	Range	Site-2 Mean ± 1SD	Median	Range	Site-3 Mean ± 1SD	Median	Range
Cr	87	120	1115.10 ± 1604.80^{a}	347.5	133-4758	721.83 ± 689.22^{b}	367.0	83-2025	177.08 ± 117.23^{c}	142.5	82-511
Co	300	4	168.92 ± 47.30^{a}	168.5	111-248	171.25 ± 52.84^{a}	153.5	109-269	214.92 ± 54.66^{b}	206.0	121-362
Ni	50	90	252.17 ± 332.69^{a}	115.5	34-1096	121.92 ± 52.12^{b}	133.5	26-191	33.08 ± 10.40^{c}	35.0	21- 49
Cu	91	20	642.42 ± 1089.10^{a}	269.0	102-4008	1230.40 ± 1411.30^{b}	741.0	18-4887	255.50 ± 261.18^{c}	189.0	22-890
Zn	360	41	626.83 ± 453.23^{a}	425.0	197-1394	1170.80 ± 867.58^{b}	1023.5	48-3034	581.17 ± 386.59^{c}	561.5	84-1553
As	12	2	32.17 ± 3.64^{a}	31.0	26- 38	33.08 ± 6.69^{a}	31.5	25- 50	48.00 ± 12.76^{a}	45.5	31- 84
Sr	95	20	74.42 ± 22.80^{a}	67.5	52-131	76.42 ± 14.95^{a}	76.0	37- 93	75.17 ± 27.92^{a}	65.0	44-119
Ba	2000	425	620.58 ± 359.09^{a}	535.5	295-1641	626.92 ± 231.95^{a}	603.0	358-1129	409.75 ± 135.93^{b}	375.0	234-639
Pb	600	10	223.42 ± 216.80^{a}	132.0	39-756	487.25 ± 686.03^{b}	260.5	17-2535	394.75 ± 496.87^{c}	150.5	37-1482

PL= Permissible limit, BV= Base value.

Bioaccumulation of Cu in surface soils reflects the anthropogenic loading of the element substantially enhanced by various industrial activities. Cu has shown the highest concentration in the present investigation compared to other metals, and Cu concentration values ranged from 18-4887 mg kg^{-1} (Table 2). The highest and more frequent contamination was observed in the site-2 (18-4887 mg kg^{-1}) followed by site-1 (102- 4008 mg kg-1), while site-3 exhibited corresponding values of this metal (22-890 mg kg^{-1}) above the permissible limit in seven

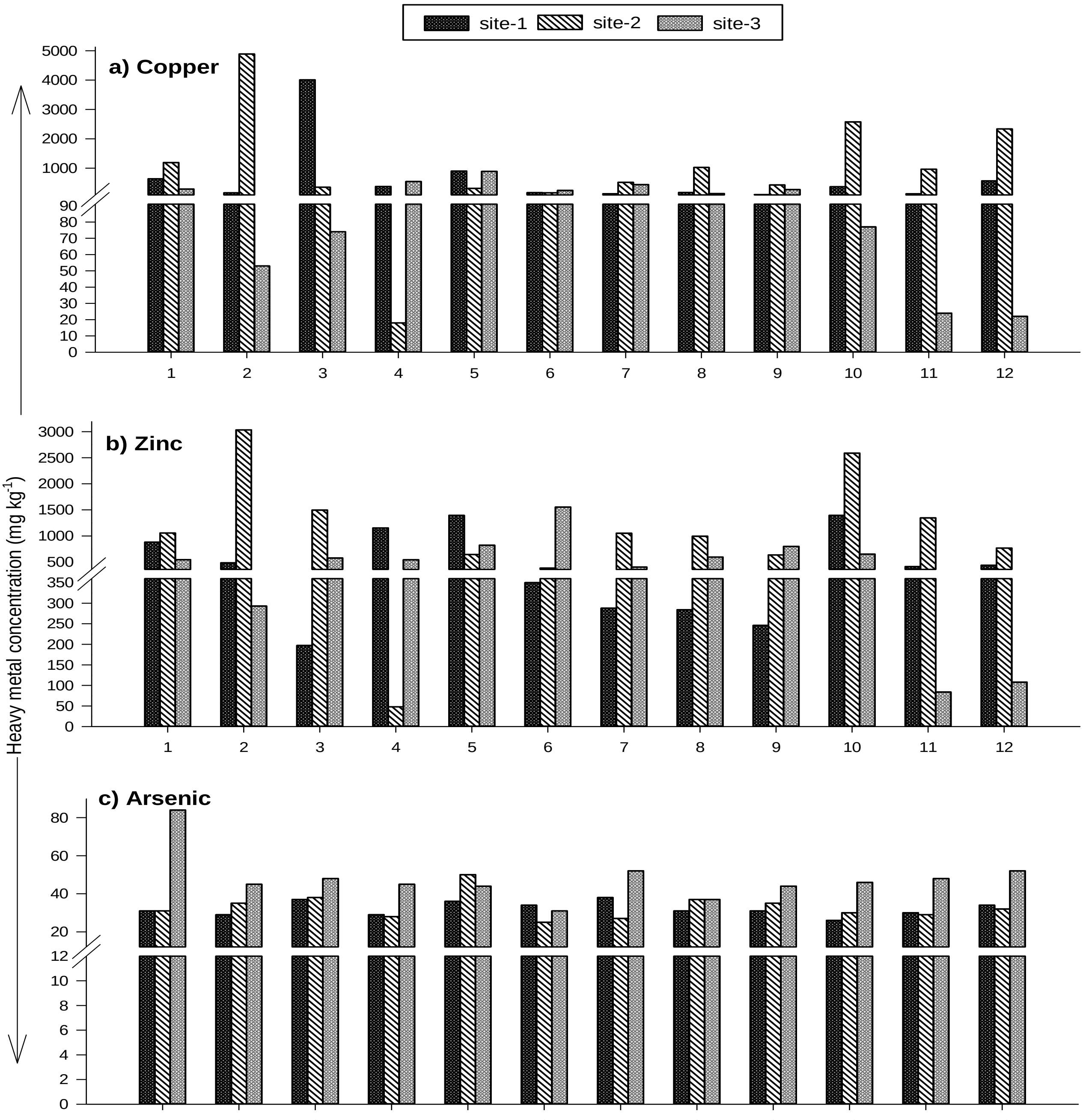


Fig. 3: Total concentration of selected heavy metals (a) Copper, (b) Zinc and (c) Arsenic (mg kg^{-1}) in the urban soils of selected industrial areas of Chandigarh and Baddi areas. Breaks in the bars show the permissible limit value of each heavy metal

out of twelve samples (Fig. 3a). Some samples have shown high content of heavy metal due to pressure of electrical and electronics industrial activities, and therefore in those soil samples, a high standard deviation was observed. Although Cu is an essential micro-element used as micro-nutrient for life processes of all the living organisms, its high range in the soil caused toxicity to the plants and soil biota; excessive concentration of Cu may cause root and shoot damage of the plants and may reduce the yield and production of crop plants (Kabata-Pendias 2010). Also, it has adverse effects on the health of invertebrates and vertebrates when it exceeds the permissible range. The comparatively lower range of Cu (7-102 mg kg^{-1}) was reported from industrial areas from Wuhan, China, whereas a similar range (3-372 mg kg^{-1}) was reported from various industrial areas of India (Krishna and Govil 2005; Krishna and Govil 2008). A similar range (7-725 mg kg^{-1}) was also reported from

Gebze industrial area, Turkey (Yaylali-Abanuz 2011).

Zn is reported to be involved in several biological and chemical interactions; however, the higher concentration of this metal in soils can lead to Zn toxicity in plants and animals. In the present study, a higher concentration of this metal was found in site-2 followed by site-3 and site-1; this may be due to more paint and battery manufacturing industry in site-2 and fertiliser and pesticide industries in site-3. In site-2, 11 out of 12 subsamples exhibited Zn concentration beyond the permissible limit (360 mg kg^{-1}), and values ranged from 48-3034 mg kg^{-1} (Table 2). Two samples of site-2 have shown very high values of Zn which might be due to the effect of industrial discharge on these samples. Site-1 has shown comparatively lower but still high contamination of Zn (197-1394 mg kg^{-1}), whereas, third site (84-1553 mg kg^{-1}) also had Zn contamination in comparison to its permissible limit (Fig. 3b), analysis of variance (one-way ANOVA) significantly varied due to sites (Table 3). However, lower range of corresponding metal was reported from Surat, Patancheru, Andhra Pradesh and Thane-Belapur industrial areas (Krishna and Govil 2007; Govil and Krishna 2001). The literature revealed a close range (110- 1950 mg kg^{-1}) from Tiexi old industrial zone of Shenyang, China (Ren et al. 2017) and a higher range (67- 5820 mg kg^{-1}) from Balanagar industrial area, Hyderabad, India, due to battery manufacturing, petrochemical and pharmaceutical industry (Machender et al., 2011).Although Zn is vital for numerous plant's metabolic activities and acts as an essential co-factor in various biochemical processes, its toxicity in the food chain is also reported to have carcinogenic effects. It can cause neurological, kidney and liver disorders in humans (Yaylali-Abanuz, 2011).

Arsenic is a beneficial metal for both animals and plants in small concentrations; however, soil contaminated with high concentrations can cause toxicity to the plants and soil biota (Alloway 2013). High As concentrations in the food chain can cause skin and lung cancers and cardiovascular diseases (Ravenscroft et al., 2009). Arsenic contamination in the urban soils is mainly contributed by the agro-chemical and pharmaceutical industry. The concentration of As significantly varied due to site and was recorded highest in site-3 (31-84 mg kg^{-1}), followed by site-1 (26-38 mg kg^{-1}) and site-2 (25-38 mg kg^{-1}) (Table 2 and Table 3). All the collected samples from three study sites had shown their concentration above the permissible limit (Fig. 3c). A close range was reported from (1.5- 66 mg kg^{-1}) Gebze industrial area, Turkey (Yaylali-Abanuz, 2011) and urban soils under the impact of industrialisation (0.9- 36.5 mg kg^{-1}) of Lishui, China (Wang and Lu, 2011) while, Manali industrial area of Chennai, India exhibited much lower As concentration (0.2- 2.5 mg kg^{-1}) (Krishna and Govil, 2008).

Sr is considered to be one of the most damaging and biologically hazardous elements for ecological processes. Strontium concentrations observed in present studies were found to be comparatively lower than that reported from other industrial areas (8- 468 mg kg^{-1}) of India (Krishna and Govil, 2007; Govil et al., 2001). Only two samples from site-1 and three samples from site-3 have shown strontium contamination, although no sample from site-2 has shown this metal values beyond the permissible limit (Fig. 4a). Corresponding metal among three sites insignificantly varied due to site, viz. from 52-131 mg kg^{-1}, 37- 93 mg kg^{-1} and 44-119 mg kg^{-1} in sites-1, 2 and 3, respectively (Table 2).

Barium contamination of soils can be caused by unmanaged disposal systems of automotive paints, plastics, steel, tiles, lubricating oils, and pesticides industry (WHO, 2017) Barium concentration analysed in the present study was found to be in a variable range from 234- 1641 mg kg^{-1}, being highest concentration in the site-1 and lowest in site-3 (Table 2); however, variation was statistically insignificant due to sites (Table 3) therefore, no sample from the study sites have gone above the permissible limit (2000 mg kg^{-1}) of industrial soil (Fig. 4b). Similar observations with close-range were also reported from India's various urban industrial soils (Govil et al., 2001; Krishna and Govil, 2008).

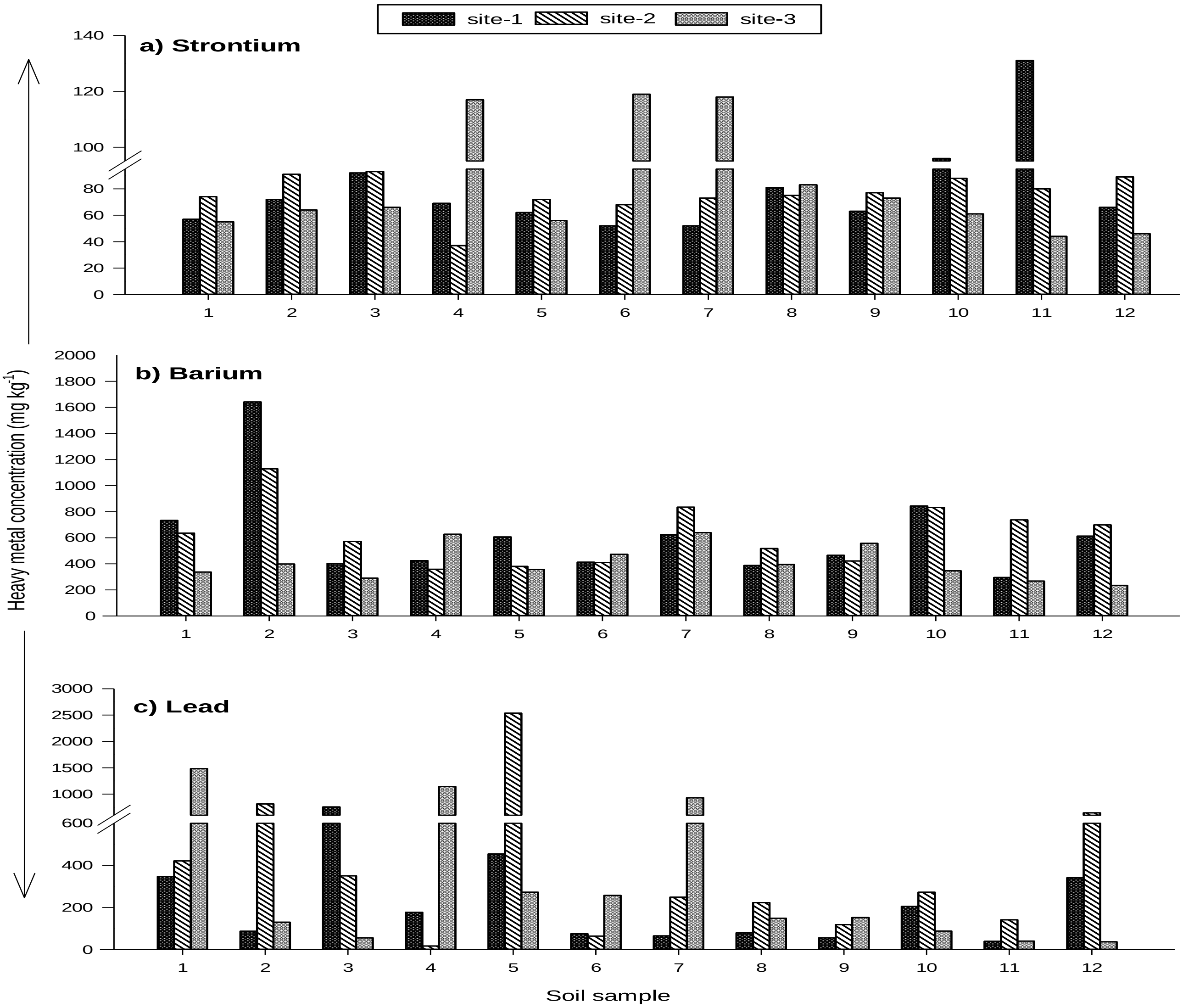


Fig. 4: Total concentration of selected heavy metals (a) Strontium, (b) Barium and (c) Lead (mg kg^{-1}) in the urban soils of selected industrial areas of Chandigarh and Baddi areas. Breaks in the bars show the permissible limit value of each heavy metal

Table 3: Effect of sites on heavy metal concentration in the urban soils

Source	Variables	Sum of squares	*df*	Mean square	*F*	*P*
Sites	Chromium	5324968.5	2	2662484.250	2.607	0.089
	Cobalt	16112.889	2	8056.444	3.015	0.063
	Nickel	291415.722	2	145707.861	3.851	0.031
	Copper	5783644.056	2	2891822.028	2.673	0.084
	Zinc	2582912.889	2	1291456.444	3.498	0.042
	Arsenic	1896.167	2	948.083	12.872	0.000
	Strontium	24.500	2	12.250	0.024	0.976
	Barium	366608.667	2	183304.333	2.733	0.080
	Lead	430077.556	2	215038.778	0.844	0.439
Error	Chromium	33707311.50	33	1021433.682		
	Cobalt	88184.083	33	2672.245		
	Nickel	1248609.500	33	37836.652		
	Copper	35708010.83	33	1082060.934		
	Zinc	12183175.00	33	369187.121		
	Arsenic	2430.583	33	73.654		
	Strontium	16753.500	33	507.682		
	Barium	2213418.083	33	67073.275		
	Lead	8409687.417		254839.013		

Lead is considered very toxic to human health and is reported to affect children's nervous system and cause mental impairment. High exposure to lead can also cause cardiovascular and kidney damages in human adults (Davies, 2015). The primary sources of Pb contamination in urban soils are leaded petrol in automobiles as more vehicles and traffic systems are found in urban areas (Gulson et al., 1995). Also, mining, smelting, tyre industry, pesticides and ammunition industry are primary sources of the Pb. In the present study, Pb concentration above the permissible limit (600 mg kg^{-1}) (Connelly, 2011) was found only in one sample from site-1, three from site-2 and three from site-3 (Fig. 4c). Overall, Pb concentration in selected industrial sites ranged from 17- 2535 mg kg^{-1}, wherein the highest and lowest values were detected in the samples of site-2 (Table 2). Very high Pb content found in one sample of industrial site-2 might be due to the effect of battery manufacturing and paint industry. Although a variation in Pb concentration values was observed, it did not reflect significant differences due to sites (Table 3). A comparable range of Pb concentration in soils due to industrial activities was reported by various studies worldwide (Machender et al., 2011; Velea et al., 2009; Lu and Bai, 2010).

Geo-accumulation index: The mean index of geo–accumulation index indicated that site-1 (1.4157 ± 1.83) and site-2 (1.4179 ± 1.31) is moderately contaminated with chromium (Fig. 5) heavily. The industrial area of Baddi (-0.231 ± 0.75) is practically uncontaminated, although the values ranged from 82-511 mg kg^{-1} (Fig. 5). Summary of ANOVA also indicated significant variation in GAI of this metal due to site. Furthermore, in conformity with this, GAI reported for Cr varied in the range of moderate to heavy contamination in soils of the industrial area in various soils under the influence of industrial activities (Machender et al., 2011; Krishna and Govil, 2008).

In this study, Co was found to have a high concentration; therefore, GAI reflected heavy contamination of cobalt in all three sites compared to their base values. The concentration of cobalt ranged within 109- 362 mg kg^{-1} but insignificantly varied due to site (Table 2 and Table 4), while GAI recorded lay in the range of 4.0-5.5, i.e., significantly contaminated for all study sites (Fig. 5), which means that cobalt concentration has highly increased due to industrial activities. However, a comparatively low Co range was reported in the Manali industrial area of Chennai, India and less than zero (0) GAI was found (Krishna and Govil, 2008).

Table 4: Effect of sites on geo–accumulation index of heavy metals in urban soils

Source	Variables	Sum of squares	*df*	Mean square	*F*	*P*
Sites	Chromium	21.717	2	10.858	5.572	0.008
	Cobalt	1.003	2	0.501	3.217	0.053
	Nickel	30.170	2	15.085	12.404	0.000
	Copper	25.563	2	12.782	3.830	0.032
	Zinc	5.238	2	2.619	1.629	0.211
	Arsenic	2.291	2	1.145	16.099	0.000
	Strontium	0.037	2	0.019	0.104	0.902
	Barium	2.502	2	1.251	4.046	0.027
	Lead	3.340	2	1.670	0.580	0.566
Error	Chromium	64.311	33	1.949		
	Cobalt	5.143	33	0.156		
	Nickel	40.132	33	1.216		
	Copper	110.127	33	3.337		
	Zinc	53.047	33	1.607		
	Arsenic	2.348	33	0.071		
	Strontium	5.958	33	0.181		
	Barium	10.202	33	0.309		
	Lead	95.063	33	2.881		

According to the geo-accumulation index mean values, all three sites were practically uncontaminated with Ni about its base value. However, few samples of site-1 exhibited moderate contamination of nickel and values for GAI was varied from 1.9 to 3.02 (Fig. 5). In agreement with this, ANOVA showed an insignificant variation of Ni due to sites. A similar range of this metal was also reported in the Thane-Belapur industrial area, which was also a result of enhanced industrial activity (Krishna and Govil, 2005).

On the other hand, copper has shown apparent heavy contamination in all the sites concerning their base values and permissible limits. Although the site-1 (102-4008 mg kg^{-1}) and site-2 (18-4887 mg kg^{-1}) had a higher range of Cu concentration, most of the sample locations from site-3 (22-890 mg kg^{-1}) also indicated higher values in comparison to the permissible limit (Fig. 3a). The analysis of variance also showed a significant variation in GAI of this metal. In conformity with this, mean values of GAI revealed heavy contamination of Cu in site-1 (3.4356 ± 1.543) and heavy to too contaminated site-2 (4.3344 ± 2.050), while site-3 (2.2758 ± 1.744) was observed moderate to heavily contaminated (Fig. 5).

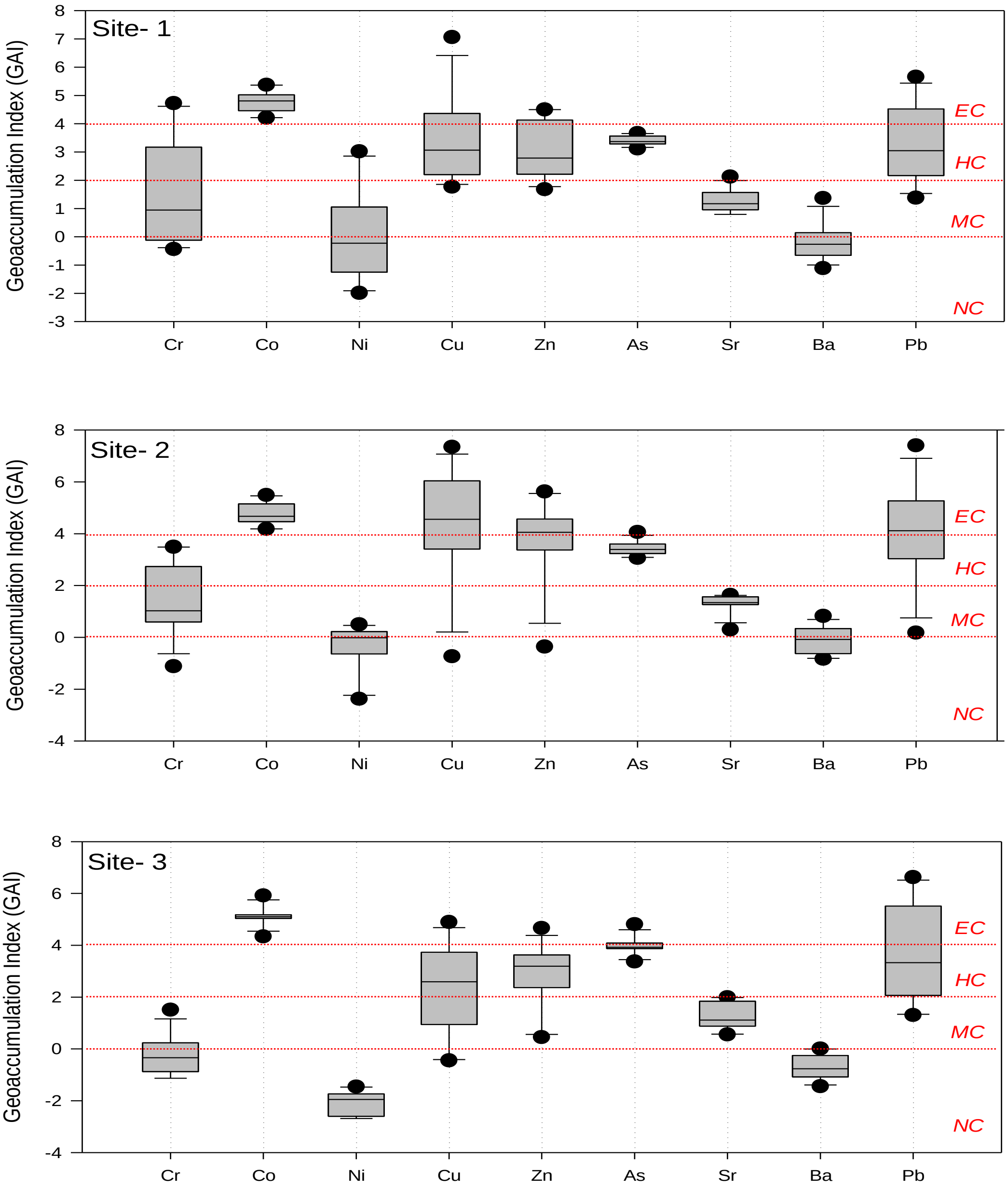


Fig. 5: Geo accumulation index of selected heavy metals in the industrial areas of Chandigarh and Baddi areas. NC= no contamination, MC= moderately contaminated, HC= heavily contaminated and EC= extremely contaminated

Geo–accumulation index has also indicated heavy to extreme contamination of zinc in site-1 (3.020± 1.00) and site-2 (3.748 ± 1.475). Simultaneously, site-3 (2.877 ± 1.201) came under moderately to heavily contaminated soils (Fig. 5). However, a summary of ANOVA indicated insignificant variation due to site. Extreme contamination of Zn and high GAI (up to 6.64) was reported in Turkey's Gebze industrial area (Yaylali-Abanuz, 2011). Heavy contamination of Zn was also reported in an old industrial city, Shenyang, China, due to very high industrial activities in the area (Li et al., 2013).

Arsenic was higher than its permissible limit in all the 36 samples and was heavily contaminated according to mean GAI values of three industrial sites. Similarly, the highest GAI was recorded in site-3 (3.9611 ± 0.337). However, all three sites were found to have heavy contamination of As (Fig. 3c), a significant difference in GAI values was shown by analysis of variance. Similarly, As contamination was in the substantial range reported in the Gebze industrial area of Turkey and Shenyang industrial area of China, GAI of these areas indicated heavy to extreme contamination of corresponding metal (Yaylali-Abanuz, 2011; Li et al., 2013). Index of geo–accumulation showed all three soils to be moderately contaminated (Fig. 5). However, the highest value for the index of geo–accumulation was observed in site-2 (1.315 ± 0.336) followed by site-1 (1.257 ± 0.396) and site-3 (1.239 ± 0.510).

Barium was found to be the only metal that showed no contamination in any subsample, and the overall values ranged within 234-1641 mg kg^{-1} (Table 2). The Geo–accumulation index of this metal was also observed to be less than zero in three industrial sites, while a few samples showed moderate contamination (Fig. 5). However, a summary of ANOVA reflected a significant variation in GAI of Ba due to different sites.

Geo–accumulation index of lead in three industrial sites varied insignificantly due to site except a few samples showing extreme contamination. The GAI values of site-1, site-2 and site-3 ranged within 1.3-5.7, 0.18- 7.4 and 1.3-6.6, respectively (Fig. 5). High contamination of Pb was also reported from the Gebze industrial area of Turkey and Shenyang industrial area of China due to various vehicular and industrial activities (Yaylali-Abanuz, 2011; Li et al., 2013).

Strontium is reported to be a highly hazardous metal that can severely damage plants and animals' life processes. In the present study, strontium exceeded the permissible limit in three sites three and two samples of site-1. However, GAI revealed moderate to high contamination in all the three selected sites (Fig. 5). Simultaneously, according to the ANOVA summary, no significant variation was observed in site values (Table 3). In conformity with this, moderate contamination of this metal was reported in sub-urban soils near Khanpur Lake, Pakistan (Iqbal and Shah, 2015). In another study on sediments from the Kortalaiyar river basin in Tamilnadu, India, moderate Sr contamination was observed (Bhuvna and Prakash, 2015). A similar finding was also reported in soils collected from different Aricha highway locations, Dhaka (Ahmed et al., 2016).

Conclusions

Total heavy metal concentration and geo-accumulation index indicated that most of the selected sites sample locations have toxic levels of arsenic, chromium, copper, zinc and lead. Cobalt concentration was mostly under the permissible limit but had too high GAI in all the sites. On the other hand, all the soil samples were observed to have Ba concentration under permissible limits and indicated no contamination on the GAI scale. Therefore, these observations supported that both the urban areas are under significant heavy metal contamination due to industrial activities. Therefore, intensive studies must understand its contamination in urban ecology as urbanisation is an inevitable part of human development that cannot be stopped. Since Chandigarh city is a well-planned and adequately established city of India, present information may be useful while considering an eco-city development in the future. Thus, heavy metal accumulation in the urban soils via different industrial activities may raise the scale of contamination, but managing industrial effluents and effective remediation to mitigate heavy metal toxicity is essential to maintain a healthy living system in the urban ecosystem.

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Conflict of Interest

The authors declare no conflict of interest.

Consent for Publication

All the authors have approved the final version of the manuscript and agree with its submission.

Authors contribution

V. Kumar: Investigation and Conceptualization, Soil sampling, Laboratory and Data analysis, Manuscript writing; **R.C. Bhatti and R. Kaur and**: Soil sampling and Data analysis; **S. Singh**: Editing and Reviewing manuscript; **A. N. Singh**: Conceptualization, Supervision and Final review; **C. Nirmala:** Supervision and Final review.

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