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Heavy metal concentration of Chandigarh urban soils due to urbanization in a changing environment: An ecological assessment

Viney Kumar, Rupinder Kaur and A. N. Singh*

Soil Ecosystem and Restoration Ecology Lab,
Department of Botany, Panjab University, Chandigarh 160 014, India

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ABSTRACT

Incessantly expanding urbanization is severely affecting soil ecosystems across the globe by endlessly loading with contaminants (particularly heavy metal concentrations) which is becoming a major health hazard for human being as well as for vegetation. Many studies, have reported the distribution of heavy metals in the urban soils under different anthropogenic activities world-wide. However, present study was conducted in a well-planned city (Chandigarh) of India that is the only city established with well designed ecological concept and unique architectural planning; therefore, whole urban region of the city is systematically segregated into residential, roadside, industrial and agricultural areas. This urban region can be a reference model for further study in the urban ecology. Therefore, we conducted present study on simple hypothesis that this urban area would be pollution free and no heavy metal concentration will be accumulated in the soils. But in present study, we got surprising results, most of the harmful heavy metals such as Arsenic (As), Chromium (Cr), Nickel (Ni), Copper (Cu), Zinc (Zn) and Lead (Pb) have significantly shown a substantial accumulation of heavy metal concentrations in the soil from permissible limits under selected sites. Although, across sites, industrial areas (1 and 2) exhibited higher range of heavy metal concentrations followed by roadside, residential and agricultural soils, respectively. However, across heavy metals, arsenic has tended a higher concentration of accumulation in the urban soils. Since, arsenic element has been considered as one of the highly toxic metals for humans and plants life, thus, its deposition in more quantity in the urban soil will augment more degree of toxicity with time. Therefore, intensive studies are urgently required to determine the mechanism and its cause of the contamination to curb the problem in urban areas in a changing environment.

Key words: *Urban soil, Urbanization, Climate change, Heavy metal concentration, Urban ecosystem*

Introduction

Heavy metal contamination of soils is a continuously increasing challenge across the globe due to rapidly progressing urbanization. With advancement of technology, various sectors of the urban development are providing a serious pressure on natural resources. Along with soil, water and air biotic components are also being adversely affected by this never-ending procedure of contamination. Heavy metals such as arsenic (As), chromium (Cr), copper (Cu), lead (Pb), zinc (Zn), nickel (Ni) etc., have exceeded their safety limits in various soils across the globe due to various anthropogenic and environmental alterations (Nagajyoti *et al.,* 2010; Adimalla *et al.,* 2020). But when these heavy metals enter the food chain via leaching into water resources, start to affect the health of human beings as well as of vegetation too (Alloway, 2012; Kim *et al.,* 2017).

Various sectors of urbanization which conjoint with inevitable parts such as: industries, agriculture, transportation etc. are reported to be a vital reason of substantial increase in the concentrations of these harmful heavy metals in the soils (Yaylali-Abanuz, 2011; Stirbescu, 2019). Although, proper planning of the urban city into well segregated areas may help in many ways to channelize the discharge of heavy metals; but their contamination cannot be reversed or reduced significantly without proper planning to stop them from entering into the resources at first place. It has been reported by many studies across globe that certain heavy metals when are in excess amount in soil tend to leach into water table causing a serious risk to the vegetation and human health (Gasparatos *et al.*, 2015). However, opposite with this, several studies have also reported low content of these metals in the soils under residential and agriculture sectors, while, few have shown their serious contamination (Imperato *et al.,* 2003; Nezat *et al.,* 2017; Mihaileanu *et al.,* 2019).

Therefore, present study was conducted in a well-planned city Chandigarh of North-western India, which is segregated into several sectors (industrial, roadside, agricultural and residential areas) as per architectural design. Therefore, the main objective of the present study was to analyze the spatial distribution of heavy metal concentrations in the soil having a high degree of toxicity to the health of urban ecosystem and are directly responsible for affecting the human health and vegetation in a changing environment with following questions:

1. What is the status of heavy metal concentrations across the selected sites of urban areas?
2. Across the heavy metals, which has exhibited in higher range and augmented high degree of deposition in the soil across sites?
3. Is there any direction for spatial distribution of the heavy metal concentrations within or across sites or does it closely link with the degree of anthropogenic activities?

Materials and Methods

The study area under investigation is the north-western union territory of India, it is a well-planned urban pocket located in the foothills of the Shiwalik range. It is carefully separated into different sectors to curtail environmental impacts, these are industrial, agriculture, residential and transport areas, respectively. Thus, we selected these sites as study area for the present study.

The city dwells at an elevation of about 360 m above sea level and climate is mostly affected by the Shiwalik Mountains in the north. Four major seasons are experienced throughout the year viz. summer, rainy, autumn and winter season. Summer is usually dry and comparatively longer than other seasons, which starts from mid-March and lasts till June. Mean daily temperature ranges between 38 °C and 24 °C. Maximum temperatures may rise beyond 47 ^{o}C sometimes in June and July. Average annual rainfall ranges between 720 mm to 1250 mm; maximum rainfall is received generally in July and August, June is the hottest and January is the coldest month. Soil horizons are composed of rock beds followed by boulders and pebbles. Upper surface layers are a mixture of sand, silt and clay; therefore, providing a texture of sandy loam.

Chandigarh is a union territory of the country, and its surroundings are completely landlocked with well-connected two adjacent cities (Panchkula and Mohali), therefore, also named as tri-city; it has a very limited area under agriculture. The major area lies in the periphery especially in Jagatpura village which is the outskirts of Chandigarh urban areas. As the urban area is expanding, agricultural land is being gradually acquired for urbanization to build offices and houses. The cultivated area has been shrunk since recent years from 5441 hectares in 1966 to about 1300 hectares in 2005-06 and is still decreasing with significant rates. The main sources of irrigation are deep-bore tube-wells and major cultivated food grains are wheat and maize. Many facilities like pesticides, fertilizers, seeds and garden tools are being provided to the farmers by Chandigarh administration. Various crops like fruit plants, seeds and even seedling of crops and vegetables are being supplied to the farmers at reasonable costs by the administration. Soil samples were taken from an agricultural area near Jagatpura in a completely randomised block design.

Various industries present in Chandigarh are automobile industry, sanitary fittings, paper and paper products, printing, industrial fasteners (nuts, bolts and screws), auto and tractor parts, steel fabrication, wooden and steel furniture, electrical appliances, job tools and dyes, repairing and servicing of cars and buses, poultry, flour mills, broiler farm, dairy farm, printing and stationary, telephone workshop, etc. The industrial area is divided into two industrial phases to properly manage their activities, however, both sites/phases are at higher risk of soil contamination with heavy metals such as Cr, Ni, Pb, Cu, As and Zn, etc. due to industrial activities. Sampling of soil samples was done near or around industries, and near the effluent outlets.

Roads in Chandigarh are made in accordance with their functions. Seven major roads are acting as an integrated system of roads, so as to ensure efficient traffic circulation. These seven roads are vertical projections that run northeast and southwest and are called as the 7Vs, or the Paths. The horizontal roads that run in the direction of northwest/ southwest commonly called as the Margs. The vertical and horizontal system of roads intersects at right angles, forming a regular grid pattern or network for traffic movement to and fro. Soil sampling was done along the major roads, in both north-south and east-west direction to achieve homogeneity.

Residential area is divided into various sectors and each sector or the neighboured unit measures 800 ×1200 m^2, covering a total of 250 acres of area. Each sector is surrounded by either a V-2 or V-3 roads. A peculiar feature is that none of the buildings directly opening on to them. Access is only possible from 4 specific points, which is roughly at the middle of each side of the road. Generally, a residential sector is divided in 4 parts called as A, B, C and D corresponding to North, East, South and West sides such as Sector 1-A, 1-B and so on. A maximum area in residential sectors is beneath the buildings. Each Sector provided with shopping and community facilities at walking distance. As maximum area in residential sectors is beneath the buildings and therefore sampling was done in open spaces available in a completely randomised block design.

Soil Sampling, monitoring and analysis

To study the distribution pattern of heavy metals sampling was done in a randomized block design (RBD) from selected study sites. Sixty samples in total were collected from all the sites together (12 samples each were collected from each site; each sample was a composite mixture of three subsamples). Out of the total samples collected, 24 were from Chandigarh Industrial areas as the site was further sub-divided into Industrial area Phase-I and Phase - II, whereas, 12 samples were collected each from agricultural, residential and roadside areas.

Soil was sampled from 36 points (n=3) from each study site, from 0-10 cm layer with the help of a plastic spade. Plastic spade was used for the collection of samples to prevent the contamination from heavy metals and was washed with distilled water in between each sampling to wash away any previous contamination. The replicates (n=3) were mixed thoroughly on a plastic sheet to form 12 samples from each site. In total, 60 samples (12×5) were collected and were prepared and were packed in airtight polythene bags and were transported to the laboratory for further analyses.

Collected soil samples were air-dried at room temperature for 2 days and were oven-dried at 105°C for 24 hrs. Dried samples were further crushed to achieve more homogeneity and sieved first through 2 mm mesh size sieve to set aside the debris and then sieved through <2 mm sieve, dried soil samples were then compressed, and pellets were formed for analysis by WD-XRF (Wave Dispersive- X Ray Fluorescence spectrophotometer).

Statistical analyses

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

Results and Discussion

Relative concentrations of heavy metals in selected land use areas are given in Table 1 along with their assigned permissible limits in the soil. The highest concentrations of selected six heavy metals were found in industrial areas and lowest was recorded in residential or roadside (Table 1). It has also been observed that copper (4887.00 mg kg^{-1}) and chromium (4758.00 mg kg^{-1}) metals have the highest concentration in soil followed by zinc and lead (3034.00 and 2535.00 mg kg^{-1}, respectively) while lowest concentration recorded for lead (6.00 mg kg^{-1}).

Arsenic content was unexpectedly found in a higher concentration in the Chandigarh urban soils, their values were found in a contrasting range (11.00 to 43.00 mg kg^{-1}) across sites, however, two sites (agriculture and roadside soils) exhibited a very narrow range (i.e. 13.00-18.00 mg kg^{-1} and 11.00

-15.00 mg kg^{-1}, respectively), while, industrial-2site had greater concentration (50.00 mg kg^{-1}) followed by residential (43.00 mg kg^{-1}), which is surprisingly higher than the permissible limit that might be a high health risk (Figure 1). Several reports have suggested that high concentration of arsenic in residential soils can increase the risk of lung cancer (Ravenscroft *et al.,* 2009); also, being in physical contact with arsenic-contaminated resources may be one of the major reason of skin cancer (Kabata-Pendias, 2000; Bhattacharya *et al.,* 2007). In literature, plenty of research findings provided information that pesticide use has also been a major cause of arsenic contamination (Krishna and Mohan, 2016; Wang *et al.,* 2017), but in the present study, agriculture soil have shown comparatively lower As content which was however above the permissible limit in all collected samples indicated that accumulation of this metal in the soil may reach to the toxic level with increasing time. In the second site (roadside soil) which exhibited comparatively less concentration and range with corresponding metal but was significantly comparable with agricultural soil. Therefore in this favour, statistical analysis indicated a significant difference in concentrations of this metal ($F_{4,55}$= 29.468, P=0.000) due to site variation. On the other hand, the highest content of the same metal was recorded in industrial soils and

Table 1. Heavy metal concentration (mg kg^{-1}) of urban soils from selected sites of Chandigarh, values are means of twelve replicates (n=12) with standard deviation. Mean values of each heavy metal concentration within sites suffixed with same letters are not significantly different at p<0.05 probability level.

Heavy Metal	Permissible limit	Site	Maximum	Minimum	Average	Standard deviation
As	12	Residential	43.00	27.00	32.54^{a}	5.52
		Industrial^{1}	38.00	26.00	32.00^{a}	3.77
		Industrial^{2}	50.00	25.00	33.18^{a}	7.01
		Roadside	36.00	11.00	16.58^{b}	8.48
		Agriculture	18.00	13.00	14.70^{b}	1.70
Cr	87	Residential	105.00	52.00	81.15^{a}	16.75
		Industrial^{1}	4758.00	133.00	991.45^{b}	1622.14
		Industrial^{2}	2025.00	83.00	691.36^{c}	732.35
		Roadside	1899.00	105.00	606.75^{d}	579.43
		Agriculture	229.00	97.00	139.70^{e}	44.98
Cu	91	Residential	36.00	14.00	22.92^{a}	7.61
		Industrial^{1}	4008.00	102.00	649.19^{b}	1142.0
		Industrial^{2}	4887.00	18.00	1129.91^{c}	1434.45
		Roadside	35.00	16.00	23.92^{a}	7.03
		Agriculture	27.00	21.00	23.60^{a}	2.01
Ni	50	Residential	34.00	20.00	25.46^{a}	4.96
		Industrial^{1}	1096.00	34.00	206.73^{b}	307.41
		Industrial^{2}	191.00	26.00	120.55^{c}	54.43
		Roadside	55.00	12.00	28.92^{a}	16.08
		Agriculture	59.00	31.00	38.20^{d}	8.97
Pb	600	Residential	47.00	14.00	22.08^{a}	8.38
		Industrial^{1}	756.00	39.00	212.73^{b}	224.04
		Industrial^{2}	2535.00	17.00	473.09^{c}	717.67
		Roadside	32.00	6.00	16.17^{d}	8.60
		Agriculture	28.00	11.00	19.70^{ad}	4.99
Zn	360	Residential	215.00	41.00	76.31^{a}	46.84
		Industrial^{1}	1393.00	246.00	684.18^{b}	447.61
		Industrial^{2}	3034.00	48.00	1207.46^{c}	900.14
		Roadside	144.00	58.00	102.5^{d}	24.78
		Agriculture	81.00	71.00	76.90^{a}	3.57

their respective values were significantly higher than the permissible limits (Figure 1). Similar to this trend, it has been reported by many studies from urban soils across the globe. For example, residential soils of Mieres, Spain was also reported to have a very high content of As by Loredo *et al.* (2003) and urban and roadside soils from one of the metro city which is densely populated urban region (Kolkata) with highest human stock in India were also reported to have high concentrations of As. On the contrary, urban industrial and residential soils of Detroit, USA have been reported to exhibit a much lower range of As (5.00-7.00 mg kg^{-1}) by Murray *et al.* (2004).

Chromium in all selected sites was recorded in the range from 52.00-4758.00 mg kg^{-1}, where, being lowest was recorded in residential and highest in industrial^{-1}. Industrial activities of area^{-1} (133.00-4758.00 mg kg^{-1}) has observed to increase its content higher than other study areas, this might be due to significant numbers of heavy and small-sized industries in their proximity. However, this metal was in higher concentration in the soils of both the soils of both industrial and roadside areas as compared to As, while, residential soil had significantly lower content in comparison to other sites (Figure 1). All the samples of agriculture soils (97.00-229.00 mg kg^{-1}) were found to have Cr content above the permissible limit. But effect of site was statistically insignificant ($F_{4,55}$= 2.349, P=0.065). This may be due to higher concentration reflected by each site and also a little heterogeneity takes place in the respective values of Cr concentration. Literature survey indicated that higher chromium content was reported from various industrial soils across the globe due to industrial activities like textile and electroplating (Wang and Lu, 2011; Yaylal-Abanuz, 2011), however, opposite to this, certain studies have reported comparatively lower Cr content in different urban soils (Chon *et al.* 1998; Linde *et al.,* 2001; Mesilio *et al.*, 2003; Zhai *et al.*, 2003; Shi *et al.*, 2008; Adimalla, 2020). The lower content of Cr is perhaps not so hazardous but high chromium content has been reported to have carcinogenic effects on human beings (Yaylali-Abanuz, 2011).

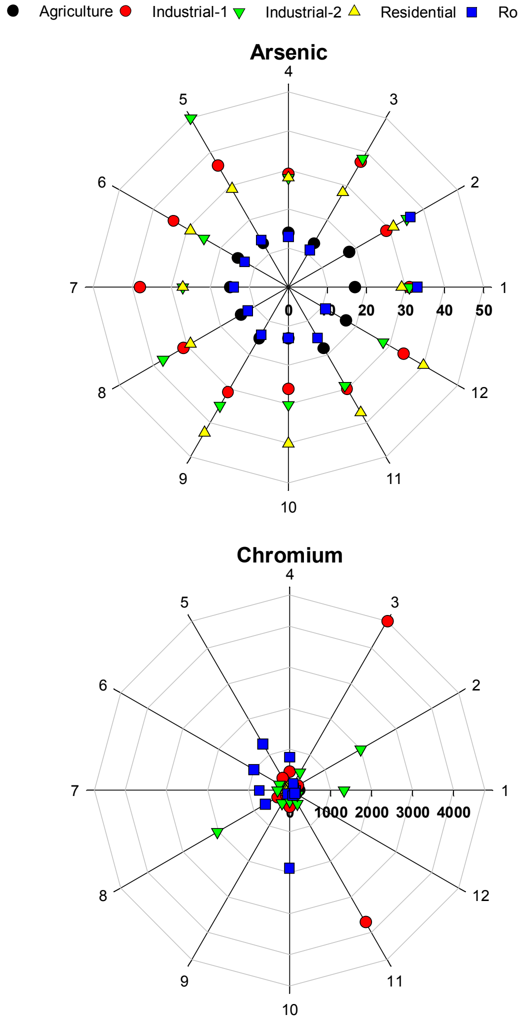

Fig. 1. Heavy metal concentration of arsenic and chromium (mg kg^{-1}) in urban soils of Chandigarh.

Similarly, copper exhibited a very high range in both industrial soils (18.00-4887.00 mg kg^{-1}), whereas, soils of residential (14.00-36.00 mg kg^{-1}), agriculture (21.00-27.00 mg kg^{-1}) and roadside (16.00-35.00 mg kg^{-1}) sites had very low Cu concentrations. Thus, the permissible limit of this metal was only exceeded in the case of samples collected from industrial areas (Figure 2). Analysis of variance has shown a significant effect of site ($F_{4,55}$ = 5.535, P= 0.001) on Cu concentration of soils. The present study focused on the top layers of soil; therefore, data predominantly reflects the contamination of soil by means of anthropogenic activities. Copper is found to be a major pollutant of soil due to industrial activities around the world (Krishna and Govil, 2008; Adimalla, 2020). Accumulation of Cu in the soils is reported to cause toxicity in the plants that can cause damage to roots and shoots and also reduces yield significantly (Anbazhagan, 2018).

Out of six, third element Nickel was observed to be one of the metals which did not exceed their permissible limit in most of the urban soils, but their concentration was very high in soils under industrial activities. In our study, Ni concentration of industrial soil ranged from 26.00-1096.00 mg kg^{-1} which was extremely in the higher range at industrial site-1 (average 206.73 mg kg^{-1}) in comparison to other urban soils where their respective values were substantially in the lower range (12.00-59.00 mg kg^{-1}). For example, Ni in residential soils was 20.00-34.00 mg kg^{-1}, while, few samples of agricultural and roadside soils exceeded values from permissible limit and ranged from 31.00-59.00, 12.00-55.00 mg kg^{-1}, respectively (Figure 2). Summary of ANOVA have indicated significant difference in Ni concentration ($F_{4,55}$ = 4.497, P= 0.003) due to site variation. Many studies across the world have found a similar or lower range of Ni concentration in various urban soils (Ungureanu *et al.*, 2017), such as Adimalla *et al.* (2020) found a much lower range of corresponding metal in the urban soils of Telangana, India. Industrial soils especially under steel and smelting industries are also reported to have a higher range of Ni (Krishna and Govil, 2005). Ni is not as hazardous as of As but its higher concentration may cause pulmonary diseases (Kabata-Pendias, 2000).

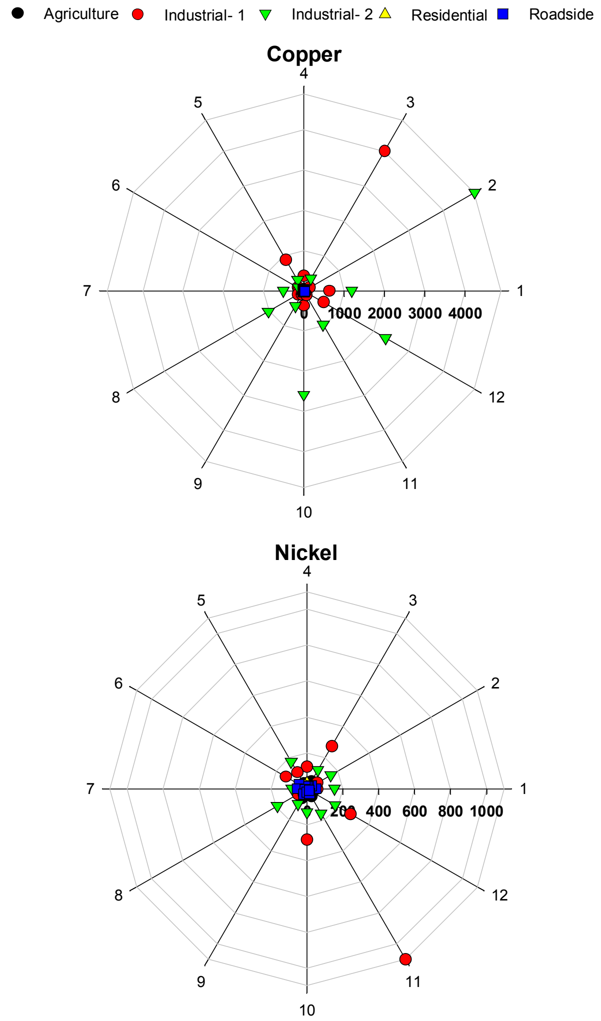

Fig. 2. Heavy metal concentration of copper and nickel (mg kg^{-1}) in urban soils of Chandigarh.

Heavy metal Lead (Pb) is one of the toxic metals, found in this study as the highest concentration in the industrial site-2 (2535.00 mg kg^{-1}) and lowest in the roadside soil (6.00 mg kg^{-1}). However, the average values of all the samples of selected sites were under permissible limit, few samples of industrial sites-1 and 2 were recorded to be higher (Figure 3). However, ANOVA indicated a significant variation in Pb concentration ($F_{4,55}$ = 3.954, P=0.007) due to site. Literature pertaining to this metal is however very rich and vast studies have been reported from the globe that described lead as a very toxic metal for human health and can severely affect the nervous system of children leading to mental impairment, while in adults, high exposure to lead can cause cardiovascular and kidney damages (Davies, 1997, Kabata-Pendias, 2000; Yaylali-Abanuz, 2011). In the present study, except few samples, no significant contamination of soils was observed. However, several studies have reported higher Pb concentrations in soils under industrial and transportation activities within urban skirts (Machender *et al.*, 2011; Alam *et al.*, 2015; Krishna and Mohan, 2016; Kashyap *et al.* 2019).

Similarly, zinc was also recorded in the highest concentrations in soils collected from industrial sites; whereas, no sample from residential, agriculture or roadside soils exhibited higher concentration. Values for this metal in the industrial site-2 ranged from 48.00 to 3034.00 mg kg^{-1} and 246.00-1393.00 mg kg^{-1} from industrial site-1 which exhibited higher input in the site-2 than site-1 due to more industrial activities (Figure 3). In conformity with this, the average concentration of Zn was observed two times in higher concentration in the industrial site-2 as compared to site-1. Moreover, Summary of ANOVA also favoured that with significant variation for this metal due to site ($F_{4,55}$ =14.891, P=0.000). In literature, a higher range (67-5820 mg kg^{-1}) of this metal was reported from Balanagar industrial area, Hyderabad, India, due to battery manufacturing, petrochemical and pharma-

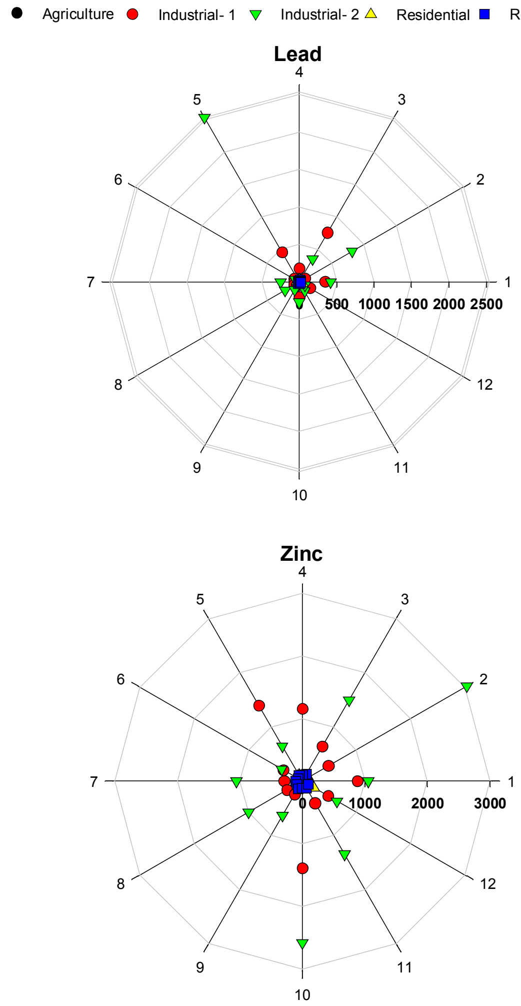

Fig. 3. Heavy metal concentration of nickel and zinc (mg kg^{-1}) in urban soils of Chandigarh.

ceutical industries (Machender *et al.*, 2011; Krishna and Mohan, 2016; Kashyap *et al.*, 2019). In general, these industries require those raw materials that contain high quantity of Zn metal. Since this metal is used as micronutrient for plant growth and development, but the excess amount in the soils can lead to toxicity into food-chain that reported to have carcinogenic effects and can further cause neurological, kidney and liver disorders in human beings (Yaylali-Abanuz, 2011).

Conclusion

Except industrial site-1 and 2, toxic levels of selected heavy metals (As, Cr, Cu, Ni and Zn) were somewhat in the lower range. The average value of chromium was under permissible limit only in soils of residential site, while all other sites have shown Cr contamination. On the other hand, Ni, Cu and Zn were above permissible limits only in the industrial sites. The average concentration of Pb was recorded under permissible limit in all urban sites that indicated poor augmentation of the metal in soil, while, arsenic was found to be in toxic levels in almost all the soil samples, it seems more alarming as increasing deposition of this metal in the residential soil may help in may cause diseases in humans of diseases in humans. In conclusion, the present findings supported the fact that even the well-planned urban areas are under significant risk of heavy metal contamination due to various anthropogenic activities. Some metals like chromium and arsenic are in toxic levels in residential and agricultural areas can augment potential health risk to the urban residents with increasing time. Therefore, more intensive studies are required to understand the mechanism of how these harmful metals mayget stabilize in the urban soils and their contamination could be controlled safely to reduce increasing hazardous levels of toxicity from all three dimensions i.e. human, ecosystem and the environment under changing climate.

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