



# Heavy metals pollution assessment and its associated human health risk evaluation of urban soils from Indian cities: a review

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**Abstract** Urban soils of 32 Indian cities were collected from literature-based data for the period of 2001–2019 to measure the contamination levels of six heavy metals including arsenic (As), chromium (Cr), copper (Cu), zinc (Zn), nickel (Ni), and lead (Pb) and also evaluated the potential human health risk for adults and children. The results indicated that concentrations of six heavy metals in the urban soils were much higher than both geochemical background values (Grade-I) and also Canadian soil quality guideline values (Grade-II) in most of the cities in India. Higher concentration of Cr and Ni was in cities mainly located in southern (Karnataka), northern (Uttar Pradesh), and eastern (Odisha); As and Pb primarily in central (Telangana), while Zn and Cu largely in western (Maharashtra) and eastern

(Jharkhand) states of India, respectively. The index of geo-accumulation ( $I_{geo}$ ) values varied largely and showed moderately polluted to extremely polluted levels, possibly caused/influenced by anthropogenic activity in the urban regions in India. The non-carcinogenic health risk due to Cu, Zn, Ni, and Pb in most urban regions was lower than the threshold value ( $HI < 1$ ), indicating no non-carcinogenic health risk for adults and children. As and Cr on children, non-carcinogenic risk was very higher than that of adults, and their risk values were also exceeded the threshold value, indicating that As and Cr in the urban soils posed considerable non-carcinogenic health risks on urban residents. The total carcinogenic/cancer risk due to Pb in most urban regions was lower than the recommended limit of  $1.00E-04$ , while Cr and As have shown potential cancer risk for both adults and children. Therefore, As and Cr are the sole heavy metals that cause potential health risk in an urban region residents in India, which needs to be paid more attention and also controlling measures should be initiated.

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## Introduction

The rapid development of urbanization and expansion of industrial sectors in and around urban cities are characteristically caused by the accumulation and contamination of urban soil heavy metals, which are greatly affected by the urban soil environment. Typically, soil heavy metals are extremely introduced into the urban environment through urban waste, waste disposal, industrial effluents, vehicle emissions, construction waste, and huge usage of agrochemicals (Adimalla et al. 2019; Dong et al. 2019; Sun et al. 2019; Zhao et al. 2019). As the results, larger than five million sites are severely contaminated by various soil heavy metals around the world (Liu et al. 2018; Sun et al. 2019). This finding provides a comprehensive view and also the severity of soil heavy metals pollution all over the world. In other words, long-term exposure of soil heavy metals (toxic metals) has mainly caused acute threat to environment pollution and also harm to human health, since heavy metals are essentially engrossed by human body through three potential pathways such as ingestion, inhalation, and dermal contacts (Adimalla 2019; Hu et al. 2017; Keshav Krishna and Rama Mohan 2016; Liu et al. 2018; Pan et al. 2018; Zhaoyong et al. 2018, 2019).

Generally, accumulation of heavy metals in urban soil is primarily shown its effects on human health. Therefore, wide attention has been paid on urban soil heavy metals pollution, occurrence, distribution, and its profound impact on human health risks in various regions. For instance, Wang et al. (2019) extensively studied soil heavy metals pollution and its spatial distribution pattern in a typical county of Guangdong Province, China, found that heavy metals Pb, Zn, and Cu are typically originated from vehicle emission, and Hg and Cu are mainly derived from industrial effluents and urban wastes. In most recently, Pan et al. (2018) reviewed on soil heavy metals pollution and its associated human health risks in the typical urban Chinese cities. They found through the literature review, the concentrations of heavy metals in urban soils are generally higher than the farmland soil and also peri-urban soils. Furthermore, they also noticed that urban soils can certainly be transferred into humans and also exposure to heavy metals in soils largely through ingestion/oral intake, and inhalation, which are portentously considered to be foremost pathways (Adimalla 2019; Adimalla and Wang 2018;

Pan et al. 2018). In a study, Rapant et al. (2011) carried out an application of health risk assessment at national and regional scales to evaluate the pollution of soil heavy metals and its profound impact on children health. Their achieved results show that children of southern European states (France, Spain, and Greece) were higher prone to health risk when compared to northern European countries such as Denmark, Finland, Norway, Sweden, and Poland (Rapant et al. 2011), due to extreme exposure to soil heavy metals over a period of time. Similarly, Adimalla and Wang (2018), Stevanović et al. (2018), Tepanosyan et al. (2017), Rastegari Mehr et al. (2017), and Kolo et al. (2018) assessed the contamination levels of soil riskiest heavy metals and its impact on human health risk in the local regions of northern Telangana, South Serbia, Armenia, Iran, and Nigeria, respectively. Results of these studies divulge that the gradually increasing the concentrations of heavy metals in urban soils by various anthropogenic sources and resulting in the detrimental effects on human health risks could be due to constant exposure at higher and even at lower concentrations. It has been noticed through literature review is that anthropogenic or human activities are the principal reason for increasing urban soil pollution and also residence has severely been suffering from various health problems (Adimalla and Wang 2018; Kolo et al. 2018; Rastegari Mehr et al. 2017; Stevanović et al. 2018; Tepanosyan et al. 2017). Therefore, it is most essential to understanding the pollution levels of heavy metals in urban soils and its detrimental effect on human health and also spatial distribution pattern in any region.

A number of studies have been conducted on heavy metal contamination in urban soils of various Indian cities during the last decade (Adimalla 2019; Adimalla et al. 2019; Dantu 2010, 2014; Kashyap et al. 2019; Kumar et al. 2019; Machender et al. 2013; Paul et al. 2015), which indicated that contamination levels of heavy metals were very high in several urban cities. Consequently, a systematic and comprehensive nationwide evaluation of heavy metal contamination in urban soils of India is mostly needed. Therefore, in this research, we focused on the spatial distributions of heavy metals in the 32 urban cities soils from India. The main objectives of this study are (1) to the determination of heavy metals pollution levels by using index of geo-accumulation ( $I_{geo}$ ), (2) to understand the spatial distribution pattern of heavy metals,

and (3) to assess the health risks posed by heavy metals in urban soils in India. The outcome of this study will be helpful to the decision maker to take necessary steps to control the urban soil heavy metals pollution.

### Soil types in India

Typically, six types of soils (DAC 2011) are identified in India according to soil taxonomy and chemical property which are (a) Red soil: red loams and yellow earths which occupy about 200,000 Sq.miles and spread over a large part of Tamil Nadu, Mysore, Southeast Maharashtra, and eastern part of Madhya Pradesh to Nagpur and Orissa, (b) Lateritic soil: lateritic soil occupy an area of 49,000 Sq.miles in India which is well occupied in the Deccan hills, Central India, Madhya Pradesh, Rajmahal hills, the eastern Ghats, certain plains of Orissa, Maharashtra, Malabar, and Assam, (c) Black soil: black soil cover a large area throughout the southern half of the peninsula, (d) Alluvial soil: the alluvial soil ensue mainly in the southern, northwestern, and northeastern parts of India, (e) Desert soil: desert soil mainly occupied of the arid region in Rajasthan and part of Haryana, and (f) Forest and hill soils (DAC 2011).

## Methods

### Data collection

In this review, the data of heavy metals contaminated soil was obtained from the published literature from 2001 to 2019, which were focused on 32 major cities from 15 states (Assam, Bihar, Gujarat, Himachal Pradesh, Jharkhand, Karnataka, Madhya Pradesh, Odisha, Panjab, Rajasthan, Tamil Nadu, Telangana, Uttar Pradesh, and West Bengal) of India (Fig. 1). Six heavy metals including arsenic (As), chromium (Cr), copper (Cu), zinc (Zn), nickel (Ni), and lead (Pb) were considered as a potentially toxic heavy metal for human health by US Environmental Protection Agency (USEPA). Literature was conducted from the Web of Science, Springer Link (Germany), Science Direct (Elsevier Science, Netherlands), and Taylor & Francis (UK) using the search terms of “urban soil,” “heavy metals,” “soil pollution,” “health risk of heavy metals,” and “India.” Details about soil sampling urban cities, number of soil

samples, analytical methods, concentrations of heavy metals and references are listed in Table S1 as Supplementary information.

### Assessment of pollution levels

#### *Index of geo-accumulation ( $I_{geo}$ )*

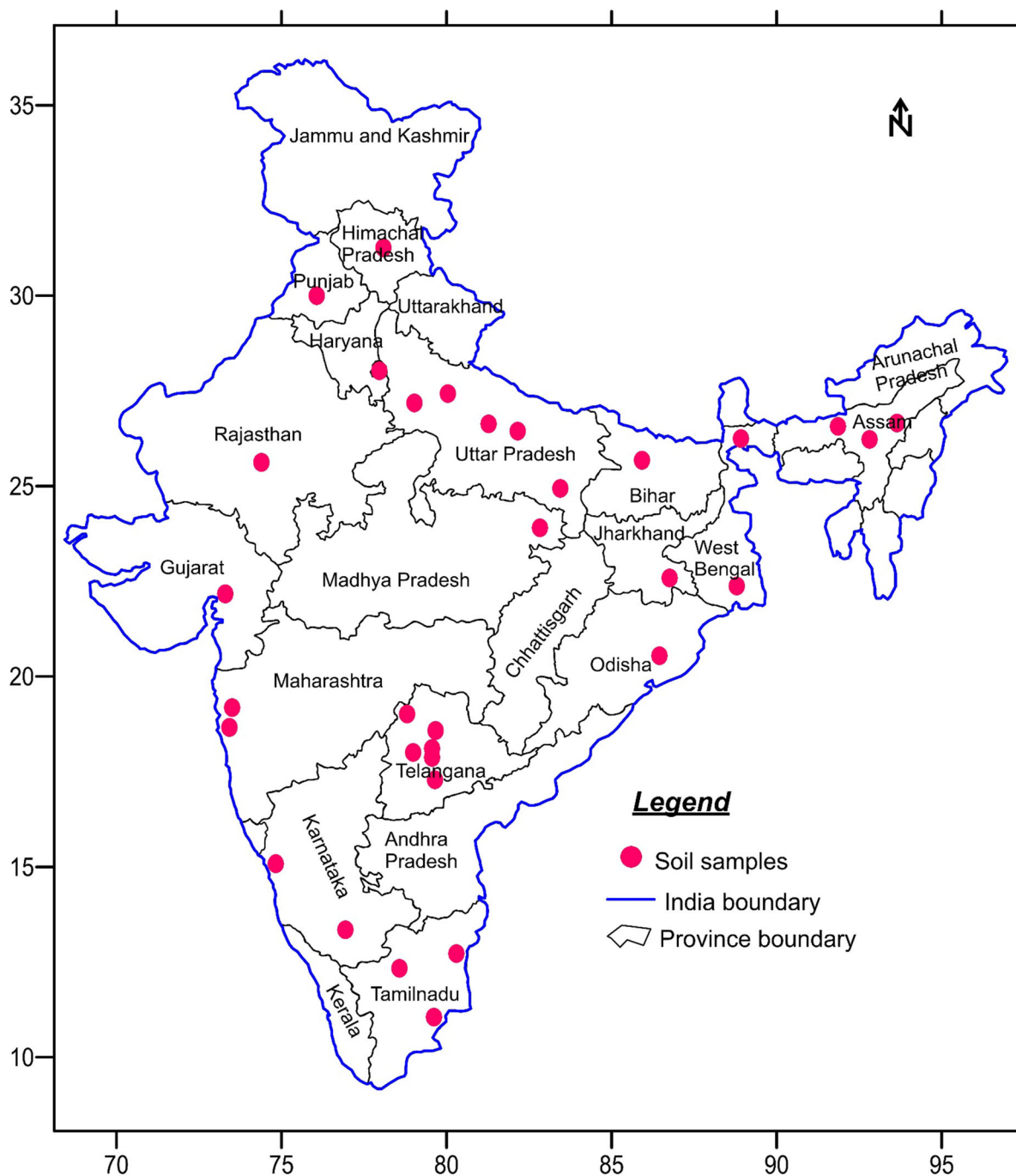
The index of geo-accumulation ( $I_{geo}$ ) is a mathematical calculation method introduced by Muller in 1969, which has comprehensively been applied to assess the contamination levels of soil heavy metals in all over the world (Adimalla and Wang 2018; Kowalska et al. 2018; Pan et al. 2018; Zhaoyong et al. 2019).  $I_{geo}$  is calculated by using the following equation:

$$I_{geo} = \log_2 \left[ \frac{C_i}{1.5 \times BGV_i} \right] \quad (1)$$

where  $C_i$  is the measured concentration of the soil heavy metal “ $i$ ”;  $BGV_i$  is the geochemical background value of the individual soil heavy metal or element “ $i$ ” and 1.5 is the constant value of a given substance in the environment and also allowing for an analysis of the variability of heavy metals as a result of natural processes (Kowalska et al. 2018; Loska et al. 2004; Muller 1969). The list of geochemical background values was summarized in Table 1 (Hans Wedepohl 1995; Kabata-Pendias 2011). Typically, the index of geo-accumulation ( $I_{geo}$ ) can be classified into seven classes which are as follows: class 0: unpolluted ( $I_{geo} \leq 0$ ); class 1: unpolluted to moderately polluted ( $0 \leq I_{geo} \leq 1$ ); class 2: moderately polluted ( $1 \leq I_{geo} \leq 2$ ); class 3: moderately polluted to heavily polluted ( $2 \leq I_{geo} \leq 3$ ); class 4: heavily polluted ( $3 \leq I_{geo} \leq 4$ ); class 5: heavily polluted to extremely polluted ( $4 \leq I_{geo} \leq 5$ ); class 6: extremely polluted ( $I_{geo} \geq 5$ ) (Muller 1969).

#### *Health risk assessment*

US Environmental Protection Agency (USEPA) has introduced a significant exposure risk model that can allow us to evaluate the degree of human health risk in various age groups in an investigated region. The potential for exposure to contaminants via ingestion, inhalation, and dermal contacts is recognized (USEPA 1997) as a substantial pathway which can fundamentally influence human health. For these three pathways



**Fig. 1** The schematic map of India reporting the soils sampling locations and cities reviewed in this study

(ingestion, inhalation, and dermal), the average daily dose (ADD) of heavy metals in soils is computed by using the following Eqs. (2–4):

$$ADD_{\text{ingestion}} = \frac{C_s^h \times IR_i^f \times EF_y^d \times ED_y}{BW \times AT} \times 10^{-6} \quad (2)$$

**Table 1** Reported geochemical background values in the literature and soil guideline values

Heavy metals	Grade-I	Grade-II	K-P	CCC	LCC	K
Cr	35	64	59.5	92	85	–
Cu	25	63	38.9	28	25	100
As	70	250	0.67	4.8	1.6	20
Zn	20	70	70	67	71	300
Pb	20	45	27	17	17	100
Ni	1.8	12	29	47	44	100

K-P: Kabata-Pendias (2011), average content in surface horizons worldwide

CCC: Rudnick and Gao (2003), composition of the continental crust

LCC: CLCC: McLennan (2001), composition of lower continental crust

K: Kloke (1979), tolerable levels in soils

Grade-I: Geochemical background values

Grade-II: Canadian soil quality guidelines values

$$ADD_{inhalation} = \frac{C_s^h \times IR_{ih}^r \times EF_y^d \times ED_y}{PEF \times BW \times AT} \tag{3}$$

$$ADD_{dermal} = \frac{C_s^h \times ESA_e^a \times SAF \times DAF \times EF_y^d \times ED_y}{BW \times AT} \times 10^{-6} \tag{4}$$

where  $ADD_{ingestion}$ ,  $ADD_{inhalation}$ , and  $ADD_{dermal}$  are the average daily dose or amount of exposure to heavy metals ( $mg (kg day)^{-1}$ ) via ingestion or oral intake, inhalation and dermal contacts, respectively.  $C_s^h$  is the concentration of the heavy metals in soil ( $mg kg^{-1}$ );  $IR_i^r$  is the ingestion rate ( $mg day^{-1}$ );  $EF_y^d$  is the exposure frequency of the people ( $day year^{-1}$ );  $ED_y$  is the exposure duration (years);  $IR_{ih}^r$  is the inhalation rate ( $m^3 day^{-1}$ );  $PEF$  is the particulate emission factors ( $m^3 kg^{-1}$ );  $ESA_e^a$  is the exposed skin area ( $cm^2$ );  $SAF$  is the skin adherence factor ( $mg cm^{-2}$ );  $DAF$  is the dermal absorption factor;  $BW$  and  $AT$  are the body weight (kg) and average exposed time (years), respectively. The detailed exposure risk model parameters and its factors are presented in Table 2.

*Non-carcinogenic risk assessment*

Reference dose (RfD) is a key factor to estimate the non-carcinogenic health risk of a single heavy metal

which is traditionally characterized by the hazard quotient (HQ). Therefore, HQ is computed as the ratio of the average daily dose (ADD) and a reference dose (RfD). The equation of HQ is defined as follows (USEPA 1989, 2002):

$$HQ = \frac{ADD_{ne}}{RfD_{ne}} \tag{5}$$

where  $ADD_{ne}$  is the average daily dose of heavy metals  $n$  through  $e$  exposed (ingestion, inhalation, and dermal contact) pathways ( $mg (kg day)^{-1}$ ) and  $RfD_{ne}$  is the reference dose of heavy metal  $n$  through  $e$  (ingestion, inhalation, and dermal contact) pathways ( $mg (kg day)^{-1}$ ). The reference dose (RfD) for six selected heavy metals is listed in Table 3.

Eventually, to assess the overall non-carcinogenic risk of six heavy metals that can be evaluated by the sum of the HQ values of multiple exposure pathways is also expressed as a hazard index (HI). The equation of HI is as follows:

$$HI = \sum HQ_i = \sum \frac{ADD_{ne}}{RfD_{ne}} \tag{6}$$

There is no non-carcinogenic health risk for humans if the value of HI is smaller than one, while if it is larger than one, it is assumed to be an adverse non-carcinogenic health risk occur (Adimalla and Wang 2018; USEPA 1997, 2002).

*Carcinogenic risk assessment*

The carcinogenic risk is assessed by calculating the incremental probability of an individual developing cancer over a lifetime as a result of exposure to the potential carcinogen (Li et al. 2014; Pan et al. 2018). Carcinogenic risk and total carcinogenic risks are computed using the following equation:

$$CR = ADD \times SF \tag{7}$$

$$TCR = \sum CR \tag{8}$$

where  $CR$  is the carcinogenic risk;  $ADD$  is the average daily dose;  $TCR$  is the total carcinogenic risk; and  $SF$  is the carcinogenicity slope factor over a lifetime ( $mg (kg day)^{-1}$ ). Carcinogenic risk values ranging from  $1 \times 10^{-6}$  to  $1 \times 10^{-4}$  are typically considered as a safe limit for human health (USEPA 1989, 2002). If

**Table 2** Definition and reference value of some parameters for health risk assessment of heavy metal in urban soils

Indicators	Parameters	Definition	Units	Adult	Children	References
Exposure factors	$EF_y^d$	Exposure frequency	days year <sup>-1</sup>	365	365	USEPA (2002)
	$ED_y$	Exposure duration	years	30	6	USEPA (2002)
	BW	Body weight	kg	70	20	USEPA (2002)
	AT	Average exposed time	years	8760	2190	USEPA (2002)
	$C_s^h$	Concentration of heavy metals	mg kg <sup>-1</sup>	–	–	The present study
Ingestion	$IR_i^f$	Ingestion rate of soil	mg day <sup>-1</sup>	100	200	USEPA (2002, 1989)
Inhalation	$IR_{ih}^f$	Inhalation rate of soil	m <sup>3</sup> day <sup>-1</sup>	12.8	7.63	USEPA (2002)
	PEF	Particle emission factor	m <sup>3</sup> kg <sup>-1</sup>	$1.36 \times 10^9$	$1.36 \times 10^9$	USEPA (2002)
Skin contact	$ESA_e^a$	Exposed skin surface area	cm <sup>2</sup>	4350	1600	USEPA (2002)
	SAF	Skin adherence factor	mg cm <sup>2</sup>	0.7	0.2	USEPA (2002)
	DAF	Dermal absorption factor	–	0.001	0.001	USEPA (2002)

**Table 3** Summary of reference doses (RfD) and slope factors (SF) of heavy metals

Heavy metals (mg kg <sup>-1</sup> )	Reference dose (RfD)			Slope factor (SF)		
	Ingestion	Inhalation	Dermal	Ingestion	Inhalation	Dermal
Cu	4.00E–02	4.00E–02	1.20E–02	–	–	–
Cr	3.00E–03	2.86E–05	3.00E–03	5.01E–01	4.20E+01	2.00E+01
As	3.00E–04	1.23E–04	1.23E–04	1.50E+00	4.30E–03	3.66E+00
Ni	2.00E–02	2.06E–02	5.40E–03	1.70E+00	–	4.25E+01
Pb	1.40E–03	3.52E–03	5.24E–04	8.50E–03	–	–
Zn	3.00E–01	0.30	6.00E–02	–	–	–

carcinogenic risk value exceeds the limit of  $1 \times 10^{-4}$ , resulting in a lifetime cancer risk to the human body (USEPA 1989, 1997).

### Spatial distribution

The spatial distribution maps are helpful and also an effective tool to understand and identify the graphically vulnerable zones in terms of high concentration of the particular elements in the examined region. The results of health risk assessment, index of geo-accumulation ( $I_{geo}$ ), and six heavy metals (Cu, Cr, As, Zn, Ni, and Pb) spatial distribution pattern in the urban soils of Indian cities were classified using Surfer 15 software (Golden Software, LLC, USA). The spatial distributions for soil heavy metals in the investigated region were obtained by the ordinary kriging method. All other scatter plots and figures were generated by using Grapher 12 software (Golden Software, LLC, USA).

## Results and discussion

### Spatial distribution and heavy metal concentrations in urban soils

The statistical summary (minimum, maximum, arithmetic mean, the coefficient of variation, 25<sup>th</sup> percentiles, 75<sup>th</sup> percentiles, standard deviation, kurtosis, and skewness) of selected six heavy metals concentrations in the urban soils of the 32 different cities in India was presented in Table 4. As can be seen from Table 4, the concentrations of heavy metals varied a large range. The ranges (arithmetic mean) of tested heavy metals concentrations of Cr, Cu, Zn, Pb, Ni, and As in urban soils among the 32 different cities were displayed as follows: 1.16 to 3194.80 mg kg<sup>-1</sup> (412.28 mg kg<sup>-1</sup>), 5.06 to 1684.35 mg kg<sup>-1</sup> (159.78 mg kg<sup>-1</sup>), 14.05 to 3591.35 mg kg<sup>-1</sup> (437.44 mg kg<sup>-1</sup>), 0.86 to 665.75 mg kg<sup>-1</sup> (77.25 mg kg<sup>-1</sup>), 2.26 to 7163.2 mg kg<sup>-1</sup>

**Table 4** Statistical summary of six heavy metals (mg kg<sup>-1</sup>) in urban soil of 32 cities in India

Heavy metals	Minimum	Maximum	AM	Median	25th percentile	75th percentile	SD	CV %	Skewness	Kurtosis
Cr	1.16	3194.80	412.28	147.05	67.38	401.75	734.37	178.13	3.02	9.08
Cu	5.06	1684.35	159.78	79.07	42.39	129.69	321.45	201.18	4.47	21.24
Zn	14.05	3591.35	437.44	178.50	98.48	358.46	812.44	185.73	3.33	10.74
Pb	0.86	665.75	77.25	41.80	16.35	70.85	125.43	162.37	3.90	17.47
Ni	2.26	7163.2	370.69	52.46	21.39	133	1392.98	375.78	5.013	25.367
As	0.20	400.35	38.61	9.99	4.29	16.24	101.28	262.33	3.73	14.13

AM: Arithmetic mean

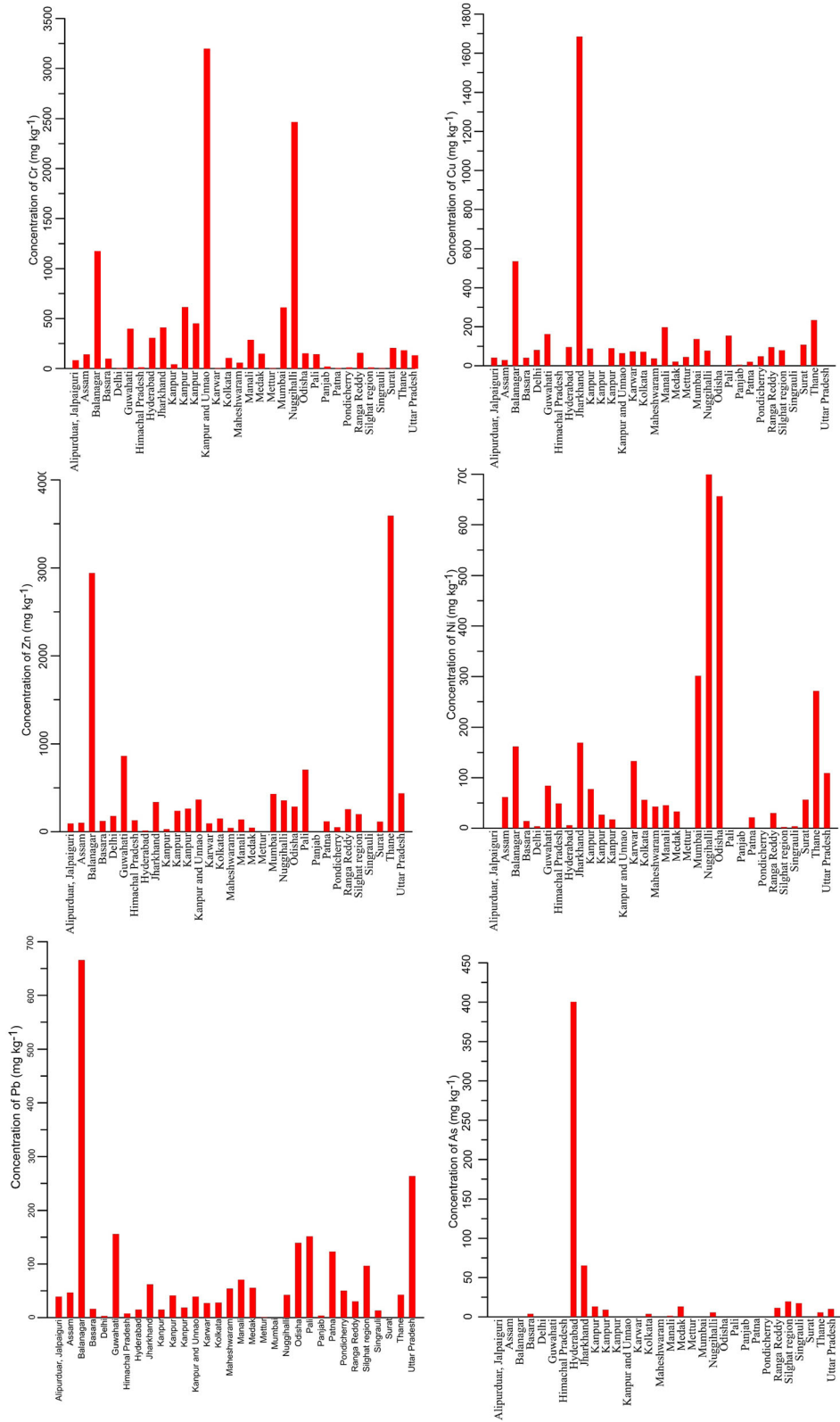
SD: Standard deviation

CV %: Coefficient of variation

(370.69 mg kg<sup>-1</sup>), and 0.20 to 400.35 mg kg<sup>-1</sup> (38.61 mg kg<sup>-1</sup>), respectively (Table 4).

The heavy metal concentrations in the urban soils of the investigated region were compared with soil guideline values for environmental protection as recommended by geochemical background values (Grade-I) and Canadian soil quality guideline values (Grade-II). As can be seen from Table 4, the mean concentration of Cr was 11.77 times higher than the Grade-I (Kabata-Pendias and Mukherjee 2007; Taylor and McLennan 1995), and also 6.44 times larger than the Grade-II (CCME 2007). The high concentration of Cr was reported in the three cities, i.e., *Kanpur and Unnao* (3194.80 mg kg<sup>-1</sup>), *Nuggihalli* (2463.50 mg kg<sup>-1</sup>), and *Balanagar* (1173.10 mg kg<sup>-1</sup>) and the remaining cities Cr content was below the 850 mg kg<sup>-1</sup> (Fig. 2). Relatively, very low content of Cr was observed in the Patna (1.16 mg kg<sup>-1</sup>), Bihar state in India. The higher concentration of Cu was noted only in the *Jharkhand* (1684.65 mg kg<sup>-1</sup>) and *Balanagar* (535.65 mg kg<sup>-1</sup>), which were 9.36 to 2.97 times larger than the remaining 30 cities soil concentrations in India (Fig. 2). In addition to this, the mean concentration of Cu was 6.39 and 2.54 times larger than the Grade-I and Grade-II, respectively. Zn was notably high at the *Thane* (3591.35 mg kg<sup>-1</sup>), *Balanagar* (2943.50 mg kg<sup>-1</sup>), *Guwahati* (861.80 mg kg<sup>-1</sup>), *Pali* (706.00 mg kg<sup>-1</sup>), *Mumbai* (429.90 mg kg<sup>-1</sup>), *Uttar Pradesh* (436.18 mg kg<sup>-1</sup>), *Jharkhand* (337.15 mg kg<sup>-1</sup>), *Nuggihalli* (356.10 mg kg<sup>-1</sup>), *Kanpur and Unnao* (365.55 mg kg<sup>-1</sup>), *Odisha* (285.15 mg kg<sup>-1</sup>),

*Kanpur* (262.45 mg kg<sup>-1</sup>), *Ranga Reddy* (255.30 mg kg<sup>-1</sup>), *Kanpur* (265.45 mg kg<sup>-1</sup>) and *Odisha* (286.15 mg kg<sup>-1</sup>) (Fig. 2). Overall, the mean concentration of Zn was 6.25 and 1.75 times larger than the Grade-I and Grade-II, respectively. The concentration of Ni at *Nuggihalli* (699.50 mg kg<sup>-1</sup>), *Odisha* (656.50 mg kg<sup>-1</sup>), *Mumbai* (301.10 mg kg<sup>-1</sup>), *Thane* (271.10 mg kg<sup>-1</sup>), *Jharkhand* (169.30 mg kg<sup>-1</sup>), *Balanagar* (161.85 mg kg<sup>-1</sup>), *Karwar* (133.00 mg kg<sup>-1</sup>), *Uttar Pradesh* (109.15 mg kg<sup>-1</sup>), *Guwahati* (84.15 mg kg<sup>-1</sup>), *Kanpur* (77.30 mg kg<sup>-1</sup>), *Assam* (61.75 mg kg<sup>-1</sup>), *Surat* (56.35 mg kg<sup>-1</sup>), *Kolkata* (56.18 mg kg<sup>-1</sup>), *Himachal Pradesh* (48.75 mg kg<sup>-1</sup>), *Manali* (45.30 mg kg<sup>-1</sup>), *Maheshwaram* (42.60 mg kg<sup>-1</sup>), *Medak* (33.00 mg kg<sup>-1</sup>), *Ranga Reddy* (29.85 mg kg<sup>-1</sup>), *Kanpur* (26.50 mg kg<sup>-1</sup>), and *Patna* (21.39 mg kg<sup>-1</sup>) (Fig. 2) greatly exceeded the geochemical background value by 34.98, 32.83, 15.06, 13.56, 8.47, 8.09, 6.65, 5.46, 4.21, 3.87, 3.09, 2.82, 2.81, 2.44, 2.27, 2.13, 1.65, 1.49, 1.33, and 1.07 times, respectively. The concentrations of Pb in soils varied greatly, which was about 3.86 and 1.10 times transcended the Grade-I and Grade-II standard values (CCME 2007; Kabata-Pendias and Mukherjee 2007; Taylor and McLennan 1995), respectively. The high concentration of As was mainly found in the soils of rapidly developing cities, such as *Hyderabad* (400.35 mg kg<sup>-1</sup>) and *Jharkhand* (65.35 mg kg<sup>-1</sup>), respectively while remaining cities were relatively smaller than 20 mg kg<sup>-1</sup> (Fig. 2). Furthermore, the mean concentration of As was 21.45





◀ **Fig. 2** Concentration of heavy metals in the urban soils of Indian cities

and 3.22 times greater than the Grade-I and Grade-II, respectively.

The spatial distribution of heavy metals in the urban soils of the investigated region reveals their dissimilar geographical distribution patterns (Fig. 3). The spatial distribution maps of As and Pb show similar geographical trends, with very high concentrations, appear in the province of Jharkhand, Uttar Pradesh, and Telangana. Previous studies divulged that the high concentration of As in Jharkhand, Uttar Pradesh, and Telangana soils was due to anthropogenic sources from industrial activity and pesticides (Adimalla and Wang 2018; Giri and Singh 2017; Keshav Krishna and Rama Mohan 2016; Machender et al. 2011; Machender et al. 2013). As can be seen from Fig. 3, the larger concentration of Cr was found in the Karnataka, Kerala, and Uttar Pradesh while Ni was at the Karnataka, Kerala, and Odisha. It is noticed that the concentration of Cu in most of the urban zones is lower than its background value, which indicates no contamination. Furthermore, a higher concentration of Cu was recorded in the Jharkhand province soils in India (Fig. 3). Soils in India are highly contaminated by Zn, and the spatial distribution of Zn (Fig. 3) indicates that the contamination of Zn in the urban soil is more serious in the Gujarat and Maharashtra (Fig. 3).

#### Heavy metal pollution levels in urban soils

As shown in Table 5 and Fig S1,  $I_{geo}$  values for Cr, Cu, Zn, Pb, Ni, and As are in the ranges of – 5.51 to 5.93, – 2.89 to 5.49, – 2.92 to 5.08, – 5.12 to 4.47, – 3.73 to 4.54, and – 3.52 to 7.48 with mean values of 1.13, 0.90, 0.76, 0.23, 0.64, and 0.93, respectively. This indicates the  $I_{geo}$  values of six heavy metals varied extensively, ranging from moderately polluted to extremely polluted levels in the urban soils of India. Spatial distribution of  $I_{geo}$ -Cr (Fig. 4a) indicated that the pollution levels of the urban soils ranged from unpolluted to highly polluted and extremely polluted cities were found in southern (*Nuggihalli*: 5.55) and northern (*Kanpur and Unnao*: 5.93) part of India. As can be seen from Fig. 4b, the highest  $I_{geo}$  value for Cu was noticed in the eastern part (*Jharkhand*: 5.49) of

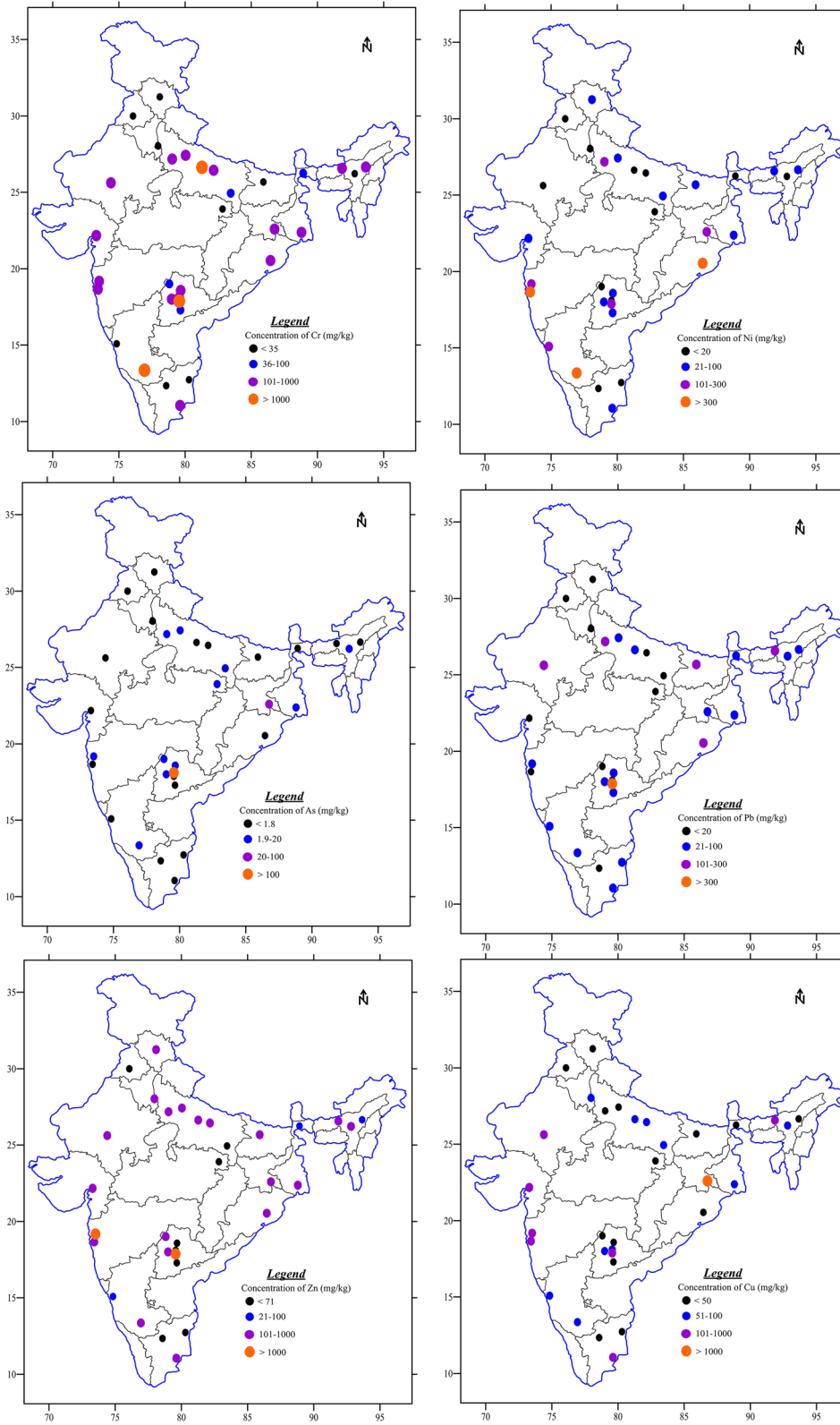
India. Spatial distribution of  $I_{geo}$ -Zn (Fig. 4c) showed that unpolluted to moderately polluted and larger  $I_{geo}$  value for Zn was found in the western part region (*Thane*: 5.08) of India. It is found that the highest  $I_{geo}$  value for As is found in the *Hyderabad* (7.48) and *Jharkhand* (4.86), and the distribution of  $I_{geo}$ -As is depicted in Fig. 4d. From Fig. 4e and 4f, it can be noted that more than half the urban soils were unpolluted to moderately polluted by Ni and Pb in India. For Ni, the urban soils in the cities investigated can be found as heavily polluted to extremely polluted in the cities of *Alipurduar*, *Jalpaiguri*, and *Nuggihalli* (Fig. 4e).

#### Comparison of heavy metals contaminate in the urban soils of the world

In order to compare the Indian urban soils heavy metals concentrations with studies from the other countries (Italy, Iran, China, Norway, USA, and Nigeria) in the world are listed in Table 6. The comparison study (Table 6) indicates that the Cu concentrations were higher than those in Iran (111 mg kg<sup>-1</sup>), Italy (74 mg kg<sup>-1</sup>), China (40.77 mg kg<sup>-1</sup>), Norway (32 mg kg<sup>-1</sup>), and USA (59 mg kg<sup>-1</sup>), but lower than Nigeria (516 mg kg<sup>-1</sup>). More specifically, the Pb concentrations were lower than those in China (50.13 mg kg<sup>-1</sup>) and Norway (32 mg kg<sup>-1</sup>), but higher than those found in Italy (141 mg kg<sup>-1</sup>), USA (198 mg kg<sup>-1</sup>), Nigeria (568 mg kg<sup>-1</sup>), and Iran (93.16 mg kg<sup>-1</sup>). Moreover, the Ni content in the India soils is higher than that of Iran (105.21 mg kg<sup>-1</sup>), Italy (89 mg kg<sup>-1</sup>), China (31.14 mg kg<sup>-1</sup>), Norway (43 mg kg<sup>-1</sup>), USA (31 mg kg<sup>-1</sup>), and Nigeria (16.5 mg kg<sup>-1</sup>). Furthermore, As and Zn concentrations of urban soils in India are higher than those reported in other countries which are clearly illustrated in Table 6. However, Indian cities and their influenced soil contamination sources such as agriculture and industrial are obviously listed in Table 7.

#### Human health risk evaluation of heavy metals in urban soils of Indian cities

The non-carcinogenic, hazard quotient (HQ) and hazard index (HI) of six heavy metals through three potential exposure pathways (ingestion, inhalation, and dermal contact) for adults and children were computed and results were listed in Table 8. Results



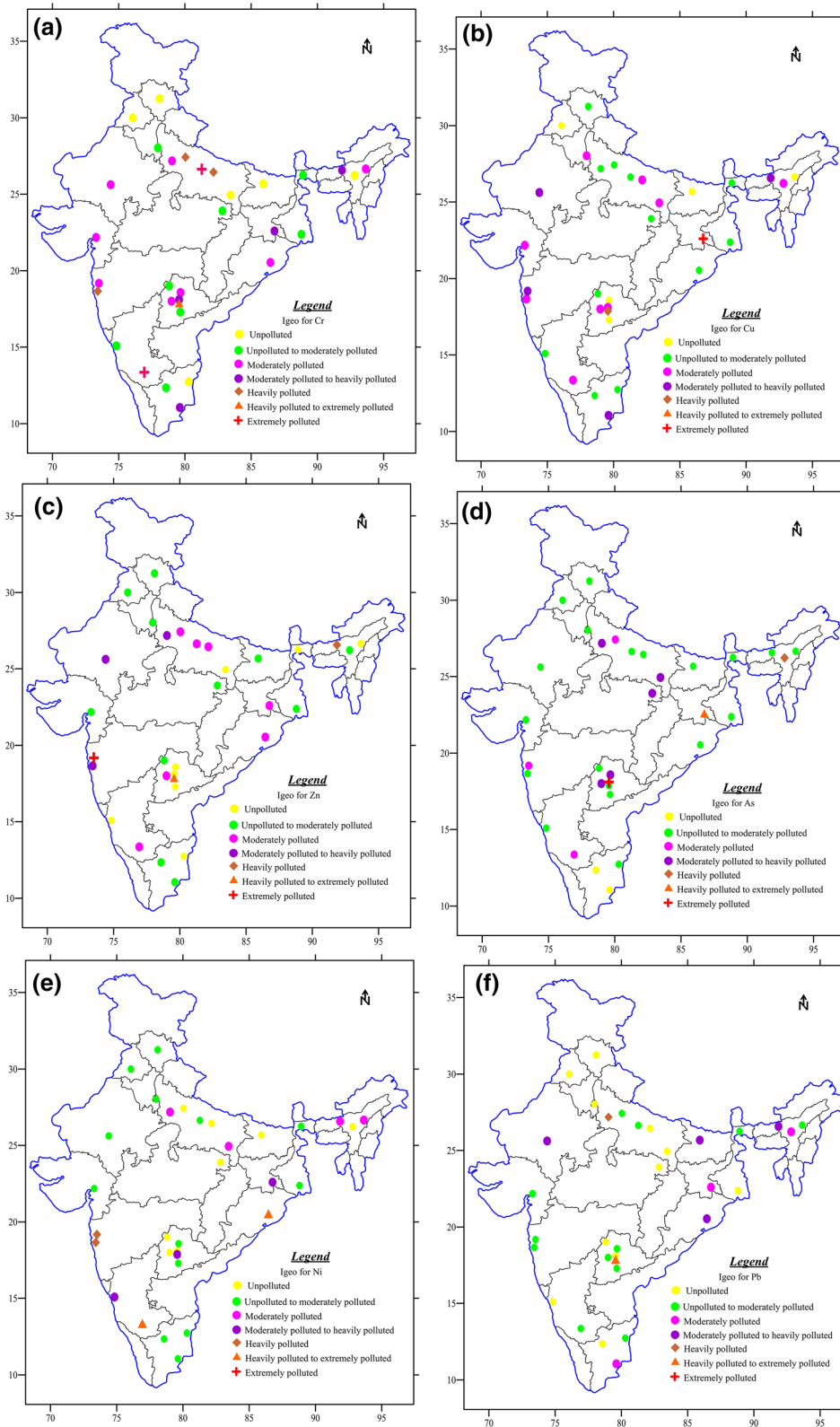
◀ **Fig. 3** Spatial distribution of heavy metals (Cr, Ni, As, Pb, Zn, and Cu) in the urban soils of India

show that the  $HQ_{dermal}$  and  $HQ_{inhalation}$  values for all heavy metals are quite lower than  $HQ_{ingestion}$  for both adults and children. This finding manifests that the inhalation and dermal contacts of heavy metals in urban soils are not shown significant health effects to

the adults and children in the 32 urban cities in India. Moreover,  $HQ_{ingestion}$  values for Cr ranged from  $5.50E-04$  to  $1.52E+00$  and  $3.85E-03$  to  $1.06E+01$  for adults and children, respectively.  $HQ_{ingestion}$  values for As varied from  $9.36E-04$  to  $1.91E+00$  and  $6.55E-03$  to  $1.33E+01$  with a mean value of  $1.84-01$  and  $1.29E+00$  for adults and children, respectively. It is noticed that the  $HQ_{ingestion}$  values for Cr and As for children are seven times higher than

**Table 5** Geo-accumulation index ( $I_{geo}$ ) of heavy metals in urban soils in the cities in India

City	Cr	Cu	Zn	Pb	Ni	As
Medak	1.95	- 0.30	- 0.65	1.45	0.86	3.46
Ranga Reddy	2.43	2.31	2.22	0.74	0.93	3.01
Basara	1.37	0.89	0.70	- 0.16	- 0.12	1.24
Hyderabad	3.51	2.29	- 2.16	- 0.25	- 1.56	8.47
Maheshwaram	1.02	0.74	- 0.82	1.25	1.32	-
Balanagar	5.43	4.79	5.77	5.41	3.27	-
Pondicherry	- 1.77	0.76	- 0.49	1.30	-	-
Manali	2.99	3.31	1.00	2.22	1.39	0.03
Mettur	-	1.20	-	- 4.13	-	- 2.73
Nuggihalli	6.53	2.03	2.62	1.49	5.54	2.32
Karwar	-	1.73	0.35	0.62	2.58	-
Thane	2.41	3.31	6.06	0.71	3.95	2.32
Mumbai	4.31	2.85	2.84	-	4.16	-
Surat	2.54	1.87	0.38	0.00	1.40	0.00
Singrauli	-	-	-	- 1.18	- 3.08	2.94
Odisha	2.22	-	1.71	2.80	8.21	-
Alipurduar, Jalpaiguri	1.24	0.92	0.42	1.02	-	-
Kolkata	1.32	1.26	1.09	0.19	1.26	1.09
Patna	- 4.64	- 0.27	1.03	2.65	0.45	-
Kanpur and Unnao	6.89	1.75	2.69	1.18	0.00	-
Kanpur	0.56	1.72	- 0.96	- 0.04	2.30	3.54
Kanpur	4.21	-	1.67	0.97	0.00	2.29
Kanpur	4.03	2.02	2.16	- 0.09	- 0.09	-
Uttar Pradesh	2.21	-	2.56	4.00	2.64	2.77
Delhi	-	1.78	1.30	- 3.23	-	-
Panjab	- 0.83	- 2.05	-	- 2.36	-	-
Himachal Pradesh	- 1.46	-	1.15	- 0.96	1.70	-
Jharkhand	3.84	6.47	2.54	1.77	3.34	5.75
Pali	2.19	2.99	3.68	3.29	-	-
Silghat region	- 2.39	1.26	1.06	2.06	- 2.87	3.54
Guwahati	3.80	2.72	3.91	3.25	2.27	-
Assam	1.49	- 0.20	0.08	0.90	1.22	-
Minimum	- 5.51	- 2.89	- 2.92	- 5.12	- 3.73	- 3.52
Maximum	5.93	5.49	5.08	4.47	4.54	7.48
Mean	1.13	0.90	0.76	0.23	0.64	0.93



◀ **Fig. 4** Spatial distribution of index of geo-accumulation ( $I_{geo}$ ) for studied heavy metals in Indian cities

adults and also its contribution is much higher than the other heavy metals, i.e., 39.76 and 49.82, respectively. Therefore, pollution of Cr and As in the urban soils poses a severe health risk in the local residence. As can be seen from Table 8, the non-carcinogenic health risks exposure routes in the order of ingestion > dermal contact > inhalation. The similar results were found in other regions of the world (Adimalla and Wang 2018; Chen et al. 2017; Pan et al. 2018; Zhaoyong et al. 2019).

The results of non-carcinogenic risk, HI values for Cu range from  $1.83E-04$  to  $6.10E-02$  ( $5.78E-03$ ) for adults and  $1.28E-03$  to  $4.25E-01$  ( $4.03E-02$ ) for children. Similarly, Zn ranges from  $4.85E-04$  to  $1.74E-02$  ( $2.12E-03$ ) for adults and  $4.75E-04$  to  $1.21E-01$  ( $1.48E-02$ ) for children; Ni ranges from  $1.64E-04$  to  $5.07E-02$  ( $8.11E-03$ ) for adults and  $1.14E-03$  to  $3.53E-01$  ( $6.08E-02$ ) for children; Pb varies from  $1.47E-03$  to  $2.79E-01$  ( $3.24E-02$ ) for adults and  $2.51E-03$  to  $1.94E+00$  ( $2.25E-01$ ) for children, respectively (Table 8). It can be understood that non-carcinogenic health risk through Cu, Zn, Pb, and Ni heavy metals in urban soils across 32 Indian cities typically has no potential for non-carcinogenic health risks for adults and children. The non-carcinogenic risk, HI values for Cr ranges from  $4.31E-03$  to  $1.84E+00$  and  $4.39E-03$  to  $1.21E+01$  with a mean value of  $2.37E-01$  and  $1.57E+00$  for adults and children, respectively (Table 8). This finding indicates that children are facing acute health risk than adults

through soil concentration of Cr which contribution is about 40 times higher than the other heavy metals. In particularly, non-carcinogenic risk, HI values for As varied from  $9.36E-02$  to  $1.91E+00$  and  $6.57E-03$  to  $1.34E+01$  with an average value of  $1.85E-01$  and  $1.29E+00$  for adults and children, respectively. The contribution of soil As exposure for adults and children was quite larger than remaining heavy metals, about 47.17%, and 45.99%, respectively. However, this study also determines that non-carcinogenic health risk to the local residence mainly caused by the higher concentrations of Cr and As in the urban soils of the 32 Indian cities. The spatial distribution of the potential non-carcinogenic health risk in terms of HI values for Cr and As for adults and children was illustrated in Fig S2. As can be seen from Fig S2, children were more vulnerable to non-carcinogenic health risk ( $HI > 1$ ) than adults in the urban soils of India. As discussed above, elevated concentration of Cr and As in the urban soils could be due to the principal reason for potential non-carcinogenic health risk for adults and children in India.

The carcinogenic health risk in terms of CR (carcinogenic risk) and TCR (total carcinogenic risk) of As, Pb, and Cr through potential exposure pathways for adults and children was assessed according to Eqs. (7) and (8); and results were presented in Table S2. The tolerable carcinogenic/cancer risk levels should be below the range of  $1.00E-06$  to  $1.00E-04$  which has been established by the US Environmental Protection Agency (USEPA) for protecting human health. If cancer risk levels exceed the  $1.00E-04$  are considered as unacceptable for human health, which typically causes for potential life time

**Table 6** Concentration of heavy metals contaminated in the urban soils of the world

Region	Cu	Cr	Pb	Ni	As	Zn	References
Iran	111	115	93.18	105.21	18.94	133.86	Modabberi et al. (2018), Jamshidi-Zanjani and Saeedi (2013), Salehi et al. (2014)
Italy	74	11.2	141	89	11.9	158	Cicchella et al. (2008)
China	40.77	73.00	50.13	31.14	12.15	155.33	Pan et al. (2018)
Norway	32	81	32	43	3.3	80	Andersson et al. (2010), Lu et al. (2013)
USA	59	65	198	31	13.2	235	Cannon and Horton (2009)
Nigeria	516	55.5	568	16.5	3	93.5	Odewande and Abimbola (2008), Nwachukwu et al. (2010)
India	159.78	412.28	77.25	120.43	38.61	437.44	This research

**Table 7** Cities with their influenced soil pollution sources

City	Agricultural	Industrial
Ranga Reddy	✓	×
Medak	✓	✓
Basara	✓	×
Hyderabad	×	✓
Maheshwaram	✓	×
Balanagar	×	✓
Pondicherry	✓	×
Manali	×	✓
Mettur	×	✓
Nuggihalli	×	✓
Panjab/Beas and Sutlej	✓	×
Karwar	×	✓
Thane	×	✓
Mumbai	×	✓
Surat	×	✓
Singrauli	✓	×
Kanpur	✓	×
Odisha/Sukinda	×	✓
Alipurduar, Jalpaiguri	✓	×
Kolkata	✓	×
Patna	×	✓
Kanpur and Unnao	×	✓
Kanpur	✓	×
Uttar Pradesh/Firozabad	×	✓
Delhi	×	✓
Kanpur	✓	×
Himachal Pradesh/Kullu and Mandi	×	✓
Jharkhand/Singhbhum shear zone	✓	×
Pali	×	✓
Silghat region	×	✓
Guwahati	✓	✓
Lakwa	×	✓

cancer risk to the residence (Adimalla and Wang 2018; USEPA 1997, 2002). However, the mean CR values of As and Pb show the quite lower than the tolerable limit of  $1.00E-04$ , indicates individual pathways have no significant health effects to the local residents (adults and children) in the 32 urban cities in India. The TCR and CR of Cr, As, and Pb by ingestion, inhalation, and dermal contact were depicted in Table S2. It is noticed from the analysis of carcinogenic health risk (Table S2), that ingestion is the foremost exposure

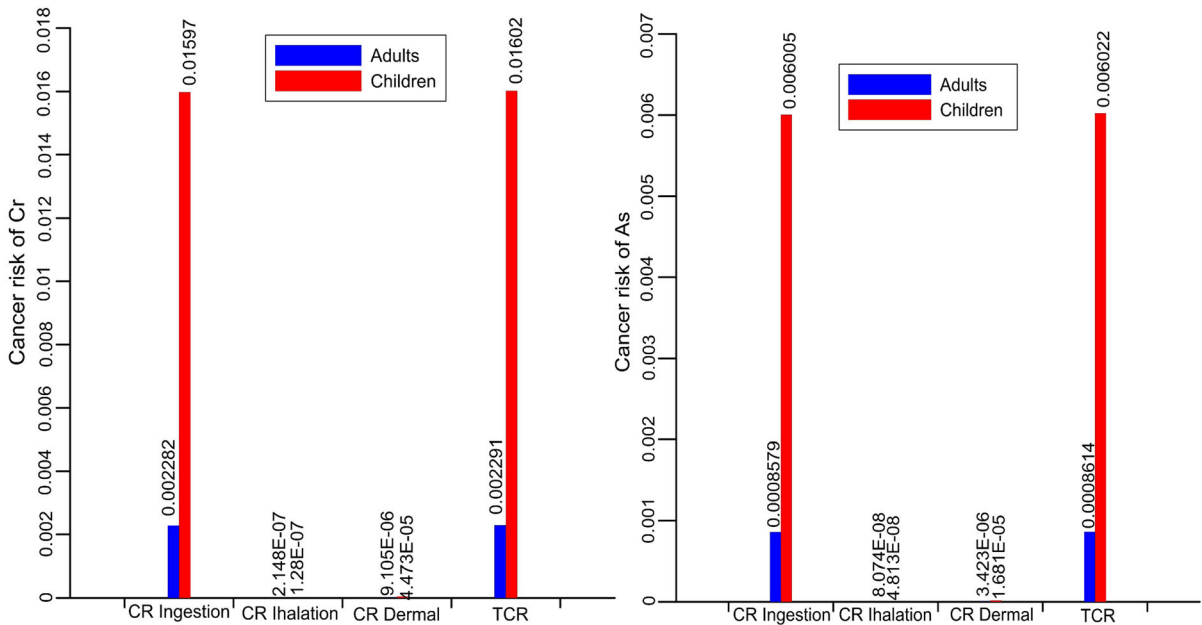
pathway that can harm adults and children health in the urban cities of India. Similar conclusions have been achieved in the urban soils of various regions (Adimalla 2019; Adimalla and Wang 2018; Chen et al. 2017; Deng et al. 2019; Zhu et al. 2018). However, results of  $CR_{\text{ingestion}}$  and TCR of Cr ranged from  $8.25E-07$  to  $2.28E-03$  ( $2.94E-04$ ) and  $8.28E-07$  to  $2.29E-03$  ( $2.96E-04$ ) for adults and  $5.78E-06$  to  $1.60E-02$  ( $2.06E-03$ ) and  $5.79E-06$  to  $1.60E-02$  ( $2.07E-03$ ) for children, respectively (Fig. 5 and Table S2), indicating that children were 6.99 times more possible carcinogenic lifetime health risks than adults. Furthermore, results of  $CR_{\text{ingestion}}$  and TCR of As varied from  $4.21E-07$  to  $8.58E-04$  ( $8.27E-05$ ) and  $4.23E-07$  to  $8.61E-04$  ( $8.31E-05$ ) for adults and  $2.95E-06$  to  $6.01E-03$  ( $5.79E-04$ ) and  $2.96E-06$  to  $6.02E-03$  ( $5.81E-04$ ) for children, respectively (Fig. 5 and Table S2). The  $CR_{\text{ingestion}}$  and TCR of Pb values were below the  $1.00E-04$ , suggesting that soil pollution of Pb has shown no significant carcinogenic lifetime health risks on local residents in India. Particularly, Cr and As should be paid more attention to the potential occurrence of cancer risk to the local residents in the urban regions of India. However, further studies are much more essential to mitigate urban soil pollution and control human health risks in urban regions.

## Conclusions

The data regarding six heavy metals (As, Cr, Cu, Zn, Ni, and Pb) in the urban soils from 32 Indian cities was obtained for this study through literature review for the period of 2001–2019. Based on the results, all these six heavy metals were exceeded both geochemical background values (Grade-I) and Canadian soil quality guideline values (Grade-II) of soils from urban regions in India. Highly polluted urban regions were identified in the southern, northern, and eastern parts of India. It was also noticed that  $I_{\text{geo}}$  values reflecting that the moderately polluted to extremely polluted levels in the urban soils of 32 cities in India. Particularly, highly polluted cities *Nuggihalli* ( $I_{\text{geo}} = 5.55$ ), *Jharkhand* ( $I_{\text{geo}} = 5.49$ ), *Thane* ( $I_{\text{geo}} = 5.08$ ), *Hyderabad* ( $I_{\text{geo}} = 7.48$ ), *Kanpur and Unnao* ( $I_{\text{geo}} = 5.93$ ). Health risk assessment analysis showed that heavy metals in the urban soils typically posed insignificant non-carcinogenic health risks for adults and children in the

**Table 8** Exposure values for non-carcinogenic risks for adults and children in the investigated region

Heavy metals		Adults				Children			
		Ingestion	Inhalation	Dermal	HI	Ingestion	Inhalation	Dermal	HI
Cr	Minimum	5.50E−04	5.43E−06	1.10E−04	4.31E−03	3.85E−03	3.24E−06	5.39E−04	4.39E−03
	Maximum	1.52E+00	1.50E−02	3.04E−01	1.84E+00	1.06E+01	8.95E−03	1.49E+00	1.21E+01
	Mean	1.96E−01	1.94E−03	3.92E−02	2.37E−01	1.37E+00	1.16E−03	1.92E−01	1.57E+00
Cu	Minimum	1.81E−04	1.70E−08	2.40E−06	1.83E−04	1.26E−03	1.01E−08	1.18E−05	1.28E−03
	Maximum	6.02E−02	5.66E−06	8.00E−04	6.10E−02	4.21E−01	3.37E−06	3.93E−03	4.25E−01
	Mean	5.71E−03	5.37E−07	7.59E−05	5.78E−03	3.99E−02	3.20E−07	3.73E−04	4.03E−02
Zn	Minimum	6.69E−05	6.30E−09	1.33E−06	4.85E−04	4.68E−04	3.75E−09	6.56E−06	4.75E−04
	Maximum	1.71E−02	1.61E−06	3.41E−04	1.74E−02	1.20E−01	9.59E−07	1.68E−03	1.21E−01
	Mean	2.08E−03	1.96E−07	4.16E−05	2.12E−03	1.46E−02	1.17E−07	2.04E−04	1.48E−02
Pb	Minimum	3.53E−04	3.30E−08	9.38E−06	1.47E−03	2.47E−03	1.97E−08	4.61E−05	2.51E−03
	Maximum	2.72E−01	2.54E−05	7.23E−03	2.79E−01	1.90E+00	1.52E−05	3.55E−02	1.94E+00
	Mean	3.15E−02	2.95E−06	8.39E−04	3.24E−02	2.21E−01	1.76E−06	4.12E−03	2.25E−01
Ni	Minimum	1.62E−04	1.48E−08	2.39E−06	1.64E−04	1.13E−03	8.81E−09	1.17E−05	1.14E−03
	Maximum	5.00E−02	4.57E−06	7.38E−04	5.07E−02	3.50E−01	2.72E−06	3.63E−03	3.53E−01
	Mean	8.60E−03	7.86E−07	1.27E−04	8.11E−03	6.02E−02	4.69E−07	6.24E−04	6.08E−02
As	Minimum	9.36E−04	2.15E−07	3.73E−06	9.36E−02	6.55E−03	1.28E−07	1.83E−05	6.57E−03
	Maximum	1.91E+00	4.38E−04	7.61E−03	1.91E+00	1.33E+01	2.61E−04	3.74E−02	1.34E+01
	Mean	1.84E−01	4.22E−05	7.34E−04	1.85E−01	1.29E+00	2.52E−05	3.60E−03	1.29E+00



**Fig. 5** Distribution of carcinogenic risk for adults and children in urban soils of India

investigated region. However, carcinogenic/cancer risk was very higher than the non-carcinogenic risk for both adults and children in most of the urban cities. Moreover, As and Cr carcinogenic/cancer risks were at a relatively unacceptable range in both adults and children. Therefore, pollution of As and Cr in the urban soils needs to be paid more attention and initiated to controlling measures in a particular region.

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