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Assessment of heavy metal (HM) contamination in agricultural soil lands in northern Telangana, India: an approach of spatial distribution and multivariate statistical analysis

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Abstract The contamination of heavy metals (HMs) in agricultural soil lands has attracted the environmental world due to their abundance, persistence, and toxicity. A study has been conducted to evaluate the degree of HM contamination in the agricultural soils of northern Telangana, using geo-accumulation index (I_{geo}), pollution index (PI), pollution load index (PLI), enrichment factor (EF), statistical analysis, and also spatial distribution. In this study, a total of 15 surface agricultural soil samples were collected and analyzed for the concentration of HMs including Cr, Cu, Co, Ba, V, As, Ni, Pb, and Zn. Their average values vary from 3.5 to 778, which show the increasing order of their abundance: As < Ni < Pb < Co < Cu < Zn < Cr < V < Ba. The concentrations of Ba, V, Zn, and Cu are significantly higher than their guideline values, while Co, Ni, Pb, Zn, and As are within prescribed limits proposed by Canadian soil quality guidelines. The highest I_{geo} (1.04) indicated the extreme degree of contamination due to Cu. The estimated PI and PLI specified the low to moderate soil pollution, whereas EF showed the moderate soil pollution due to Cr, Co, V, Zn, and As. According to principal component analysis with eigenvalue, more than one account for 53.020% of the total variance, indicating the major source of anthropogenic activity. Spatial distribution maps of HMs displayed four highly polluted zones found in the agricultural sites such as *Oni*, *Yamcha*, *Bederelli*, and *Mudhol*, in northern Telangana.

Introduction

In recent years, soil heavy metal (HM) contamination has become a primary and severe problem in many regions of the world. The studies relating to agricultural and urban soil contamination received a special attention due to HMs caused by natural and anthropogenic sources (Song et al. 2018; Stevanović et al. 2018). However, the contribution of anthropogenic inputs to the HM contamination in soils is much higher than that of natural sources (Adimalla and Wang 2018). With the rapid growth of agricultural and industrial expansion in the world, HM contamination has aggravated through industrial effluents, residential wastes, huge usage of fertilizers, and automobile exhaust emissions (Song et al. 2018; Zheng et al. 2018; Adimalla 2019). Therefore, the studies on agricultural soil HMs are of much concern chiefly due to two reasons. Firstly, the polluted

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agricultural food chain is the main source of intake directly through the various food products such as vegetables, fruits, rice, and wheat, which might cause health hazards. Secondly, densely accumulated HMs percolate through the pore spaces and enter the groundwater system and consequently deteriorate the groundwater quality, which shows direct impacts on human health through its consumption (Adimalla 2018; Adimalla and Wang 2018; Keshavarzi et al. 2018). Thus, the soil pollution by HMs is now a global issue due to their toxicity (Adimalla and Wang 2018; Horváth et al. 2018; Li et al. 2016).

Extensive studies on HM contamination of agricultural soils and urban and semi-urban regions have widely been reported in the literature. Atafar et al. (2008) studied the effect of fertilizer application on soil HM concentration in the agricultural region of Mahidasht, Iran and found that HM concentration increases by excessive usage of manure and phosphate fertilizers. Li et al. (2014) identified the pollution sources of HMs in the soils mainly due to anthropogenic sources such as agriculture, urbanization, residential wastes, industrialization, and mining. Further, they also noticed that heavy metals leach, which lead to deteriorating the food quality, thereby inducing the environmental ecosystem hazards. Al-Wabel et al. (2017) studied on the accumulation of HMs in agricultural soils largely through synthetic fertilizers, pesticides, and manure application from the agricultural region of Saudi Arabia. Further, they also stated that higher levels of HMs show a potential threat to human health through the food chain and water consumption. Hu et al. (2018) stated that the large increase of the HMs in the agricultural soils of the Jiangxi province, China due to massive use of fertilizers, manures, and agricultural wastes, which degrade the soil quality and also damage the terrestrial ecosystem. They also pointed out that HMs have largely shown a negative impact on local populace health due to consumption of polluted agriculture products. Song et al. (2018) examined the HM concentration in the agricultural soils of Tai'an city, China and stated that soil geochemistry and anthropogenic impact are the principal point sources of HM contamination.

India is a developing country, where the HM contamination of agricultural soils has comprehensively been studied during the last one decade due to rapid growth of agricultural expansion. Paul et al. (2015) studied on HM pollution in agricultural soils from Jajmau, India and revealed that the chromium (Cr),

copper (Cu), zinc (Zn), lead (Pb), and cadmium (Cd) contents were significantly higher than the background values. The research was carried out by Machender et al. (2013) in the agricultural region of Chinnaeru river basin (CRB), India and found the higher contents of Ba (370–1710 mg/kg), Cr (8.7–543 mg/kg), Cu (7.7–96.6 mg/kg), nickel (Ni) (5.4–168 mg/kg), Zn (49–478 mg/kg), vanadium (V) (39.8–162.8 mg/kg), arsenic (As) (3.4–19.6 mg/kg), and Pb (4–66 mg/kg) are due to the excessive usage of fertilizers and pesticides. Kumar et al. (2019) recently reviewed HM contamination caused by natural and anthropogenic sources from parts of Maharashtra, Gujarat, and Telangana and found that more than 80% of HM pollution in soil cover is mainly contributed by an anthropogenic origin.

Nirmal City located in northern Telangana, India is a traditional belt of an agricultural region with different land use patterns, including urbanization and industrial sectors. However, there is no research on heavy metal contamination appraisal from the study area. Therefore, it is essential to evaluate the HM contamination and its distribution pattern in the Nirmal City with the following objectives: (a) to determine the concentration of Chromium (Cr), copper (Cu), cobalt (Co), barium (Ba), arsenic (As), nickel (Ni), lead (Pb), vanadium (V), and zinc (Zn), (b) to evaluate soil contamination, using varied pollution indices, (c) to identify the contamination sources through the application of multivariate statistical techniques, and (d) to demarcate the vulnerable zones. The present study results help to provide baseline information on HM contamination caused by agricultural soil quality status.

Study area

The investigated area is located in the southwestern part of Nirmal Province, Telangana, India (Fig. 1). It lies in between north latitudes from 18.99821 to 18.85043 and east longitudes from 77.99921 to 77.90838 and falls in Survey of India toposheet 56E/13. The mean daily minimum temperature is about 28 °C in winter and 42 °C in summer. The normal annual rainfall in the study region is 1157 mm.

Black soils (70%) and red soils (30%) are the dominant types in the Nirmal Province (Adimalla and Wang 2018; Narsimha and Sudarshan 2017). The study region is occupied by hard rocks. The main crops cultivated in this region include paddy, maize, turmeric, cotton, soya, red gram, and vegetables.

Materials and methods

Sampling and analysis

A total of 15 soil samples from 0 to 50 cm depth were collected in the vicinity of the agricultural region of Nirmal Province, Telangana, India. Each soil sample was collected, using wooden shovel and later packed into a self-locked polyethylene bags. The soil sampling locations were recorded by using GPS (Garman eTrex 30) and the positions of these samples are depicted in Fig. 1.

To avoid moisture content, soil samples were dried for 48 h at 60 °C and then dried soil samples were finely powdered and sieved to pass a − 200 mesh size, using swing grinding mill. A hydraulic press was used to prepare each soil sample pellet for applying boric acid (boric acid powder LR grade, Spectromelt C-20

cellulose and aluminum cups used to prepare the pellets) and pressing at 25 tonnes pressure. An X-ray spectrometer (Philips MagiXPRO-PW2440) was used to determine the heavy metals (Cr, Cu, Co, Ba, V, As, Ni, Pb, and Zn) in soil samples (Krishna and Govil 2007).

Pollution index assessment methods

Pollution levels of Cr, Cu, Co, Ba, V, Zn, Pb, Ni, and As in the soil samples were evaluated using various indices, such as pollution index (PI), pollution load index (PLI), enrichment factor (EF), and geo-accumulation index (I_{geo}), which are also widely used to estimate the contamination levels of heavy metals in the soils of the world (Adimalla and Wang 2018; Keshavarzi et al. 2018; Li et al. 2016; Muller 1969; Song et al. 2018; Stevanović et al. 2018).
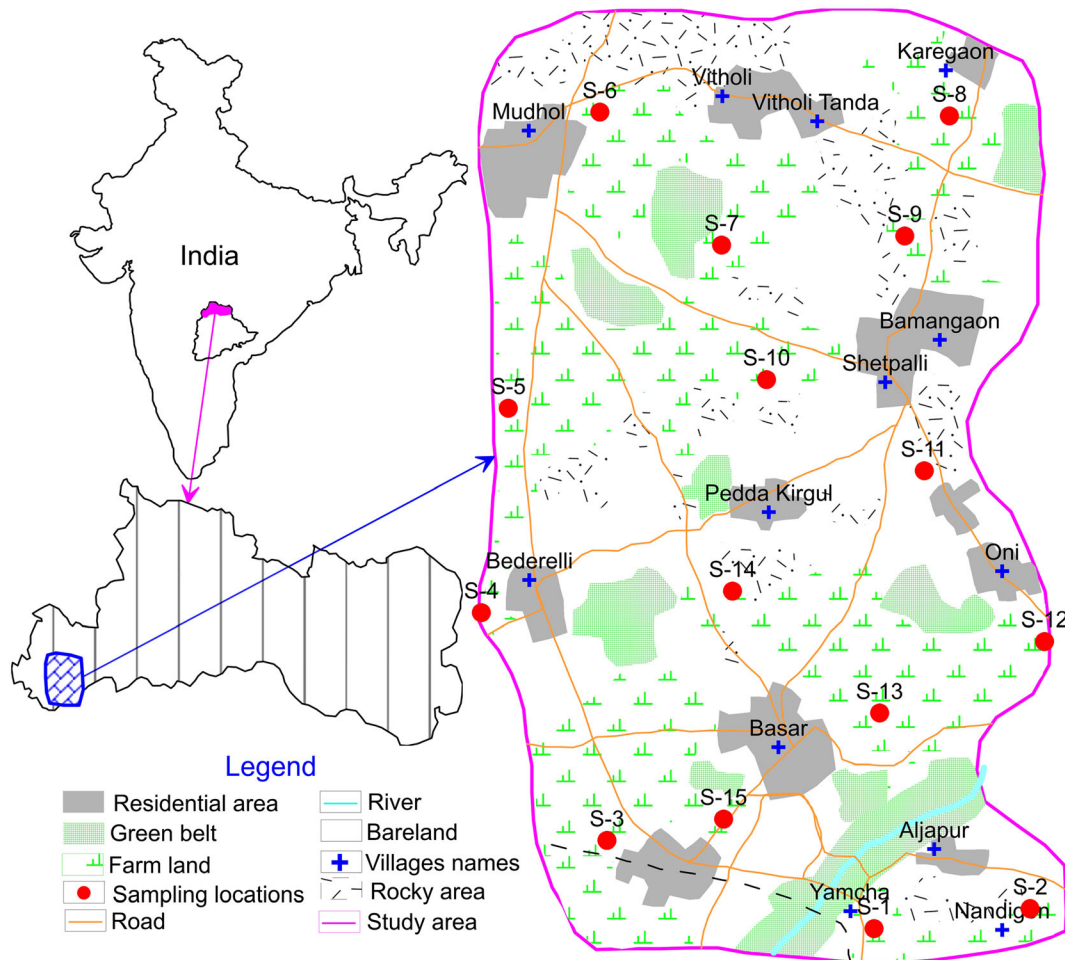
Fig. 1 Location map of the soil sampling sites in the study region

Table 1 Classification criteria of the PI, PLI, EF, and I_{geo} of heavy metals in the soils of the study region

PI	Degree of soil pollution[a]	PLI	Soil pollution classification[b]	EF	Degree of enrichment of classification[c]	I_{geo}	Soil quality[d]
< 1	Low pollution	< 1	Unpolluted	< 2	Deficiency to minimal enrichment	$I_{geo} < 0$	Practically uncontaminated
1 to 2	Low to moderately pollution	1 to 2	Unpolluted to moderately polluted	2 to 5	Moderate enrichment	$0 < I_{geo} < 1$	Uncontaminated to moderately contaminated
2 to 3	Moderately pollution	2 to 3	Moderately polluted	5 to 20	Significant enrichment	$1 < I_{geo} < 2$	Moderately contaminated
3 to 4	Moderately to highly polluted	3 to 4	Moderately to highly polluted	20 to 40	Very high enrichment	$2 < I_{geo} < 3$	Moderately to heavily contaminated
4 to 5	Highly polluted	4 to 5	Highly polluted	> 40	Extremely high enrichment	$3 < I_{geo} < 4$	Heavily contaminated
> 5	Very highly polluted	> 5	Very highly polluted	–	–	$4 < I_{geo} < 5$	Heavily to extremely contaminated
–	–	–	–	–	–	$I_{geo} > 5$	Extremely contaminated

PI pollution index, *PLI* pollution load index, *EF* enrichment factor, *I_{geo}* geo-accumulation index

[a] Li et al. (2016), Marrugo-Negrete et al. (2017), Stevanović et al. (2018)

[b] Cheng et al. (2014), Li et al. (2016))

[c] Sutherland (2000), Loska et al. (2004)

[d] Muller (1969))

The PI and PLI are computed according to Eqs. (1) and (2), respectively.

$$PI = \frac{C_{ems}}{C_{bgv}} \tag{1}$$

$$PLI = (PI_1 \times PI_2 \times PI_3 \times PI_4 \times \ldots\ldots \times PI_n)^{\frac{1}{n}} \tag{2}$$

where C_{ems} is the concentration of each metal in the soil samples (mg/kg), C_{bgv} is the concentration of background value (mg/kg), and n is the number of heavy metals.

The EF for each heavy metal was computed by dividing its ratio to the normalizing element by the same ratio found in the selected baseline (Marrugo-Negrete et al. 2017; Taylor 1964). Typically, a reference metal concentration for normalization is generally used (Al-Wabel et al. 2017). The most extensively used reference element for this purpose is Fe, because of its natural abundance and less interaction with other heavy metals (Al-Wabel et al. 2017). The EF is calculated using Eq. (3).

$$EF = \frac{\left(\frac{C_n}{C_{ref}}\right) \text{Sample}}{\left(\frac{B_n}{B_{ref}}\right) \text{Background}} \tag{3}$$

Table 2 Descriptive statistic for soil heavy metal concentrations (mg/kg)

Statistics	Ba	Co	Cr	Cu	Ni	Pb	Zn	As	V
Minimum	576.7	12.7	55.9	12.7	0.5	5.9	71.3	2.4	89.2
Maximum	895.2	35.6	135.8	69.6	27.6	26.8	173	5.3	220.2
Mean	778.0	23.8	100.6	31.2	13.7	18.2	92.4	3.5	150.8
Median	804.7	25.3	94.8	32	11.2	18.3	88.5	3.5	157.3
SD	92.10	7.56	23.97	16.23	9.87	5.09	25.05	0.66	51.38
Skewness	− 0.75	− 0.115	− 0.085	0.784	− 0.029	− 0.723	2.615	1.294	0.038
Kurtosis	− 0.054	− 1.495	− 1.036	0.494	− 1.658	1.58	8.22	3.865	− 1.874
CV%	11.84	31.72	23.81	51.99	71.93	28.03	27.11	19.17	34.07

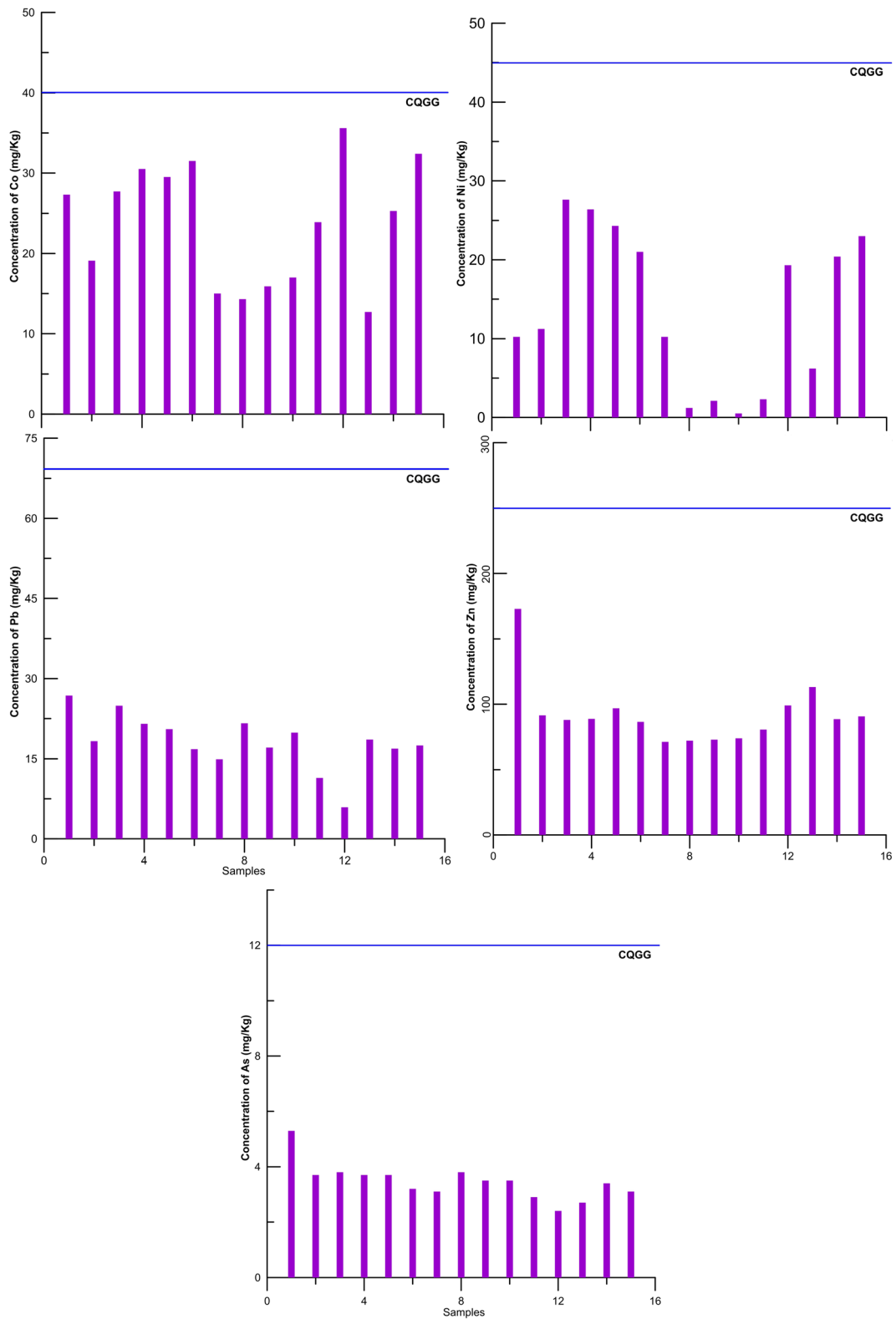*SD* standard deviation, *CV%* coefficient of variation
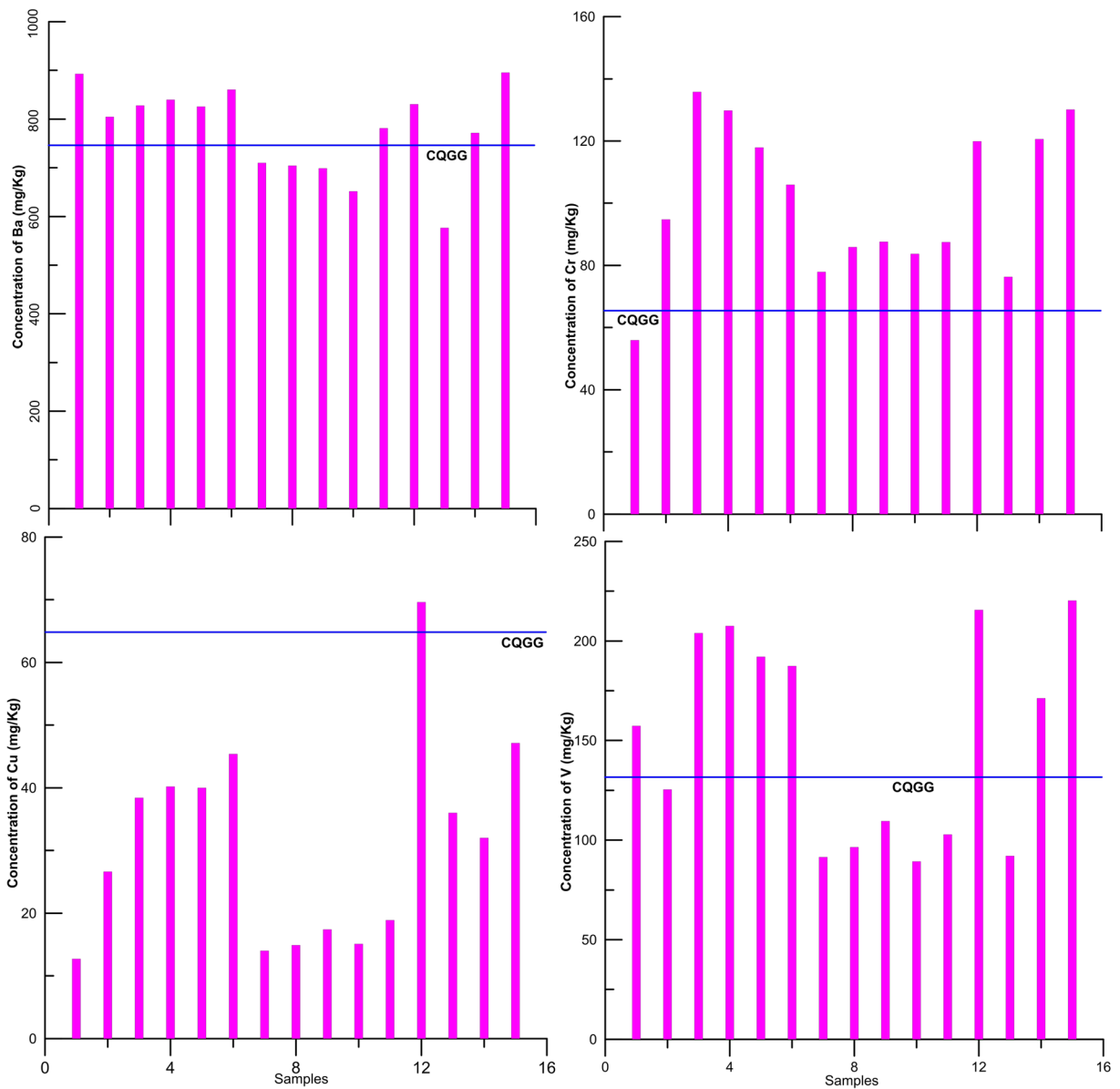
Fig. 2 Heavy metal (Ba, Cr, Cu, and V) concentrations in the agricultural soil as compared to the Canadian soil quality guidelines (CQGG)

where C_n is the concentration of examined heavy metals, C_{ref} is the reference element in the examined environment used for normalization in the soil sample, B_n is the concentration of examining heavy metal, and B_{ref} is the background concentrations of the reference heavy metal. Five categorizes of EF are detected according to Sutherland (2000) and Loska et al. (2004) (Table 1).

I_{geo} is a geochemical criterion to assess the contamination levels of soils. I_{geo} was originally introduced and defined by Muller in 1969. The I_{geo} is calculated by Eq. (4):

$$I_{geo} = \log_2 \left(\frac{C_h}{1.5 \times BV} \right) \qquad (4)$$

where C_h is the measured concentration of heavy metal in soils and BV is the geochemical background value of element n, and constant 1.5 allows to analyze natural fluctuations in the content of a given substance in the environment (Muller 1969).

Fig. 3 Heavy metal (Co, Ni, Pb, Zn, and As) concentrations in the agricultural soil as compared to the Canadian soil quality guidelines (CQGG)

Results and discussions

The representative descriptive statistics (minimum, maximum, mean, standard deviation, skewness, and kurtosis) of the concentrations of HMs in soils are presented in Table 2. The mean values of elemental contents in soils follow in a decreasing order as Ba > V > Cr > Zn > Cu > Co > Pb > Ni > As (Table 2). Heavy metal concentrations in the study region as compared to the Canadian quality guidelines for agricultural soils (CQGG) or threshold values (TVs) are depicted in Figs. 2 and 3 (CCME 2007).

Descriptive statistics

Barium is the relatively 14th most abundant in the earth's crust, which is typically found in the soil at concentrations ranging from 19 to 2300 mg/kg (Cappuyns 2018; Kabata-Pendias 2000). However, in the present study region soil, Ba showed considerable concentration variation ranging in between 576.6 and 895.2 mg/kg with an average of 778.05 mg/kg (Table 2). The threshold limit of Ba in soil is 750 mg/kg (CCME 2007). Accordingly, 67% of the total soil samples were above this limit in the present study area. The concentration of Cr in soils varied from 55.9 to 135.8 mg/kg with an average of
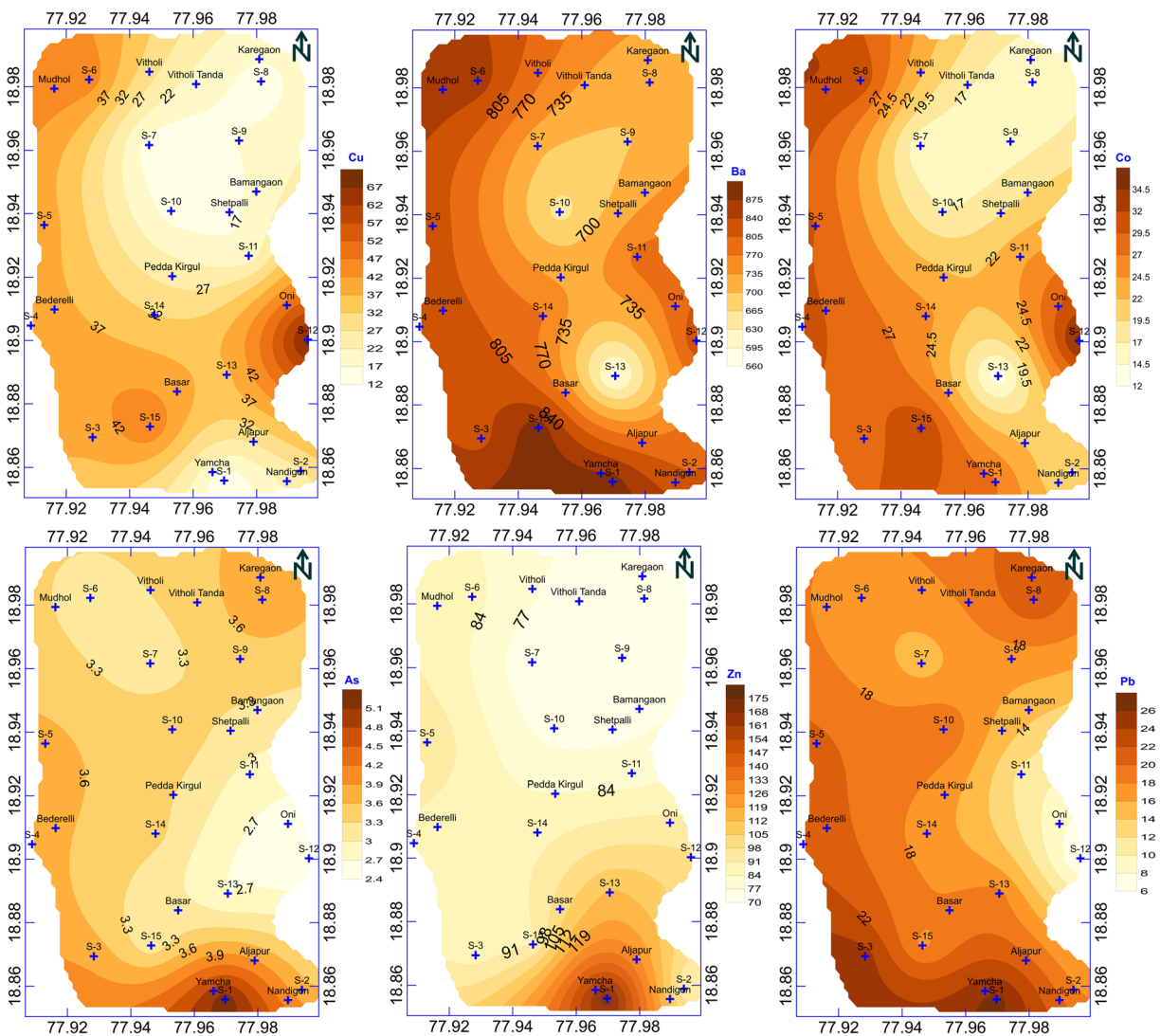
Fig. 4 Spatial distribution maps of heavy metals (Cu, Ba, Co, As, Zn, and Pb) in the agricultural soil samples, northern Telangana, India

100.64 mg/kg (Table 2 and Fig. 2). The maximum concentration of Cr was about two times higher than the threshold value of 64 mg/kg and 93% of soil samples also far exceeded its guideline value. This indicates the soil contamination by chromium. In the present study region, Cu in soil samples varied from 12.7 to 69.6 mg/kg with an average of 31.22 mg/kg (Table 2 and Fig. 2). Only one soil sample was above the guideline value of 63 mg/kg for Cu (CCME 2007). The concentration of V was in the range of 89.2 and 220.2 mg/kg and its average is 150.80 mg/kg (Table 2). In about 53% of the total soil samples, the V content is more than its guideline value of 130 mg/kg (Table 2 and Fig. 2). The total concentrations of Co in soils were from 12.7 to 35.6 mg/kg with an average of 23.85 mg/kg (Table 2), which is below its threshold value of 40 mg/kg (CCME 2007). In the present investigation, the value of Ni in the soil samples varied from 0.5 to 27.6 mg/kg with an average of 13.73 mg/kg, while that of Pb ranged from 5.9 to 26.8 mg/kg with an average of 18.17 mg/kg (Table 2). The value of Zn was observed from 71.3 to 173 mg/kg, with an average of 92.43 mg/kg, while that of As ranged from 2.4 to 5.3 mg/kg with an average of 3.45 mg/kg (Table 2). Further, the concentrations of Co, Ni, Pb, Zn, and As are within the Canadian quality guidelines of 40, 45, 70, 25, and 12 mg/kg, respectively, prescribed for agricultural soils (Fig. 3).

The coefficient of variation (CV) is mainly used for the description of variability. When the value of CV is from 10 to 100, it indicates moderate variation (Zhou et al. 2016). The computed values of CV for HMs that ranged from 11.84% to 71.93% (Table 2) indicate moderate variation, which shows heterogeneous occurrence (Zhou et al. 2016). Further, the values of Zn and As were positively skewed with skewness values of 2.165 and 1.294, respectively (Table 2).

Spatial distribution of HMs

The spatial distribution maps play a vital role in identifying the safe and unsafe zones and for providing baseline information necessary to prevent and control further contamination of soils (Adimalla 2019). In the present study region, the spatial distribution maps of As, Zn, Pb, V, Cr, Ni, Cu, Ba, and Co in the agricultural soils were illustrated in Figs. 4 and 5. The spatial patterns of Cu, Ba, and Co in the agricultural soils are dissimilar in their geographical distribution (Fig. 4). The higher values of Cu are spread in the eastern part (*Oni* agricultural area), while that of Co are observed from the vicinity of *Oni*, *Bederelli*, and *Mudhol* areas, where the paddy field is dominant. These indicate the source of Cu and Co from the higher usage of fertilizers in the irrigated area. The spatial distribution of Ba shows their more values, which are found in the southern region and northwestern part of the study region (Fig. 4). The spatial distribution maps of As, Zn, and Pb show almost similar distributions, with their higher concentrations, where the agricultural zones are spread over *Yamcha* and *Nandigon* in the southern part of the study region (Fig. 4). However, the concentrations of As, Zn, and Pb in the soils are within their recommended limits (CCME 2007). In case
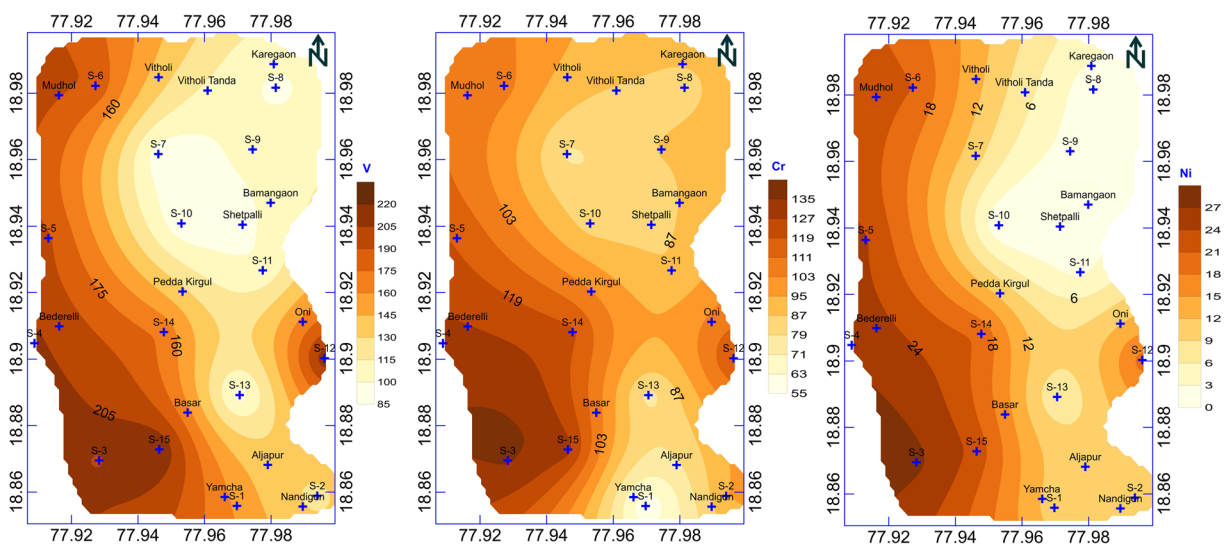
Fig. 5 Spatial distribution maps of heavy metals (V, Cr, and Ni) in the agricultural soil samples, northern Telangana, India

Table 3 Concentration and pollution indices (EF, enrichment factor; PI, pollution index; I_{geo}, geo-accumulation index) of soil heavy metals (HMs)

HMs	Statistics	Concentration mg/kg	Pollution indices		
			EF	PI	I_{geo}
Ba	Minimum	576.7	1.05	1.05	− 0.38
	Maximum	895.2	1.63	1.63	0.26
	Mean	778	1.41	1.41	0.04
Co	Minimum	12.7	1.27	1.27	− 1.50
	Maximum	35.6	3.56	3.56	− 0.02
	Mean	23.8	2.38	2.38	− 0.67
Cr	Minimum	55.9	1.60	1.60	− 0.91
	Maximum	135.8	3.88	3.88	0.37
	Mean	100.6	2.88	2.88	− 0.11
Cu	Minimum	12.7	0.51	0.51	− 1.42
	Maximum	69.6	2.78	2.78	1.04
	Mean	31.2	1.25	1.25	− 0.31
Ni	Minimum	0.5	0.03	0.03	− 6.33
	Maximum	27.6	1.38	1.38	− 0.55
	Mean	13.7	0.69	0.69	− 2.27
Pb	Minimum	5.9	0.30	0.30	− 2.26
	Maximum	26.8	1.34	1.34	− 0.07
	Mean	18.2	0.91	0.91	− 0.71
Zn	Minimum	71.3	1.00	1.00	− 0.53
	Maximum	173	2.44	2.44	0.75
	Mean	92.4	1.30	1.30	− 0.19
As	Minimum	2.4	1.60	1.60	− 2.55
	Maximum	5.3	3.53	3.53	− 1.41
	Mean	3.5	2.30	2.30	− 2.05
V	Minimum	89.2	1.49	1.49	− 0.35
	Maximum	220.2	3.67	3.67	0.95
	Mean	150.8	2.51	2.51	0.32

of the spatial distribution pattern of V, Cr, and Ni, they are mainly similarly distributed in the agricultural activity zones near *Basar* (Fig. 5). This suggests the primary role of application of fertilizers in the agricultural cropland as the main pollutant sources. Zeng et al. (2015) stated that soil contamination was mainly caused by the application of fertilizers and manure inputs in the agricultural cropland in Tianjin, Chain. However, the higher levels of HMs in the soils are also caused by municipal waste compost and manures in addition to chemical fertilizers (Adimalla and Wang 2018; Andersson et al. 2010; Atafar et al. 2008; Li et al. 2016).

Pollution status of soils

Pollution index and pollution load index

PI and PLI have been widely used to estimate the relative degree of contamination level of heavy metals in soils (Chen et al. 2015; Stevanović et al. 2018; Zheng et al. 2018). The minimum, maximum and average values of PI are listed in Table 3. The values of Cr, V, Co, Cu, As, Ba, Zn, Ni, and Pb of PI were from 1.60 to 3.88, 1.49 to 3.67, 1.27 to 3.56, 0.51 to 2.78, 1.60 to 3.53, 1.05 to 1.63, 1.00 to 2.44, 0.03 to 1.38, and 0.30 to 1.34, respectively. The average values of these metals are higher than 1 (Stevanović et al. 2018), indicating the contamination of agricultural soil by these metals.

The PLI values of the agricultural soils of the study region and their classification were illustrated in Fig. 6. The metals of PLI in the soils ranged from 0.86 to 1.97 with an average of 1.48, in which 13% of the total soil samples shows the PLI in between 0.86 and 0.96 and indicates that the agricultural soils are unpolluted by the HMs. The rest of the soil samples (87%) have PLI more than 1, which indicate that the soils are moderately polluted.

Enrichment factor

The EF is widely used to estimate the actual degree of contribution from anthropogenic sources of soil (Keshavarzi et al. 2018; Li et al. 2016). The computed values of EF of HMs are summarized in Tables 3 and 4 and Fig. 7a. The values EF of Ba, Ni, and Pb in the soils were from 1.05 to 1.63, 0.03 to 1.38, and 0.30 to 1.34, respectively. All soil sampling sites have HMs less than 2, which indicates the non-contribution of mineral in the soil contamination (Sutherland 2000; Loska et al. 2004). In case of the values of EF of Cr in the soil, it ranged from 1.60 to 3.88. Ninety three percent of the soil sampling sites come under moderate enrichment and the rest 7% under deficiency to minimal enrichment. The values of EF of Co, V, and As varied from 1.27 to 3.56, 1.49 to 3.67, and 1.60 to 3.53 respectively, which show moderate enrichment in 73%, 60%, and 80% of the soil samplings, respectively (Table 4). Further, the values of EF of Zn and Cu show more than 2 in 7% of total soil sampling sites, suggesting the moderate enrichment (Table 4).

Fig. 6 Classification and distribution of pollution load index (PLI)
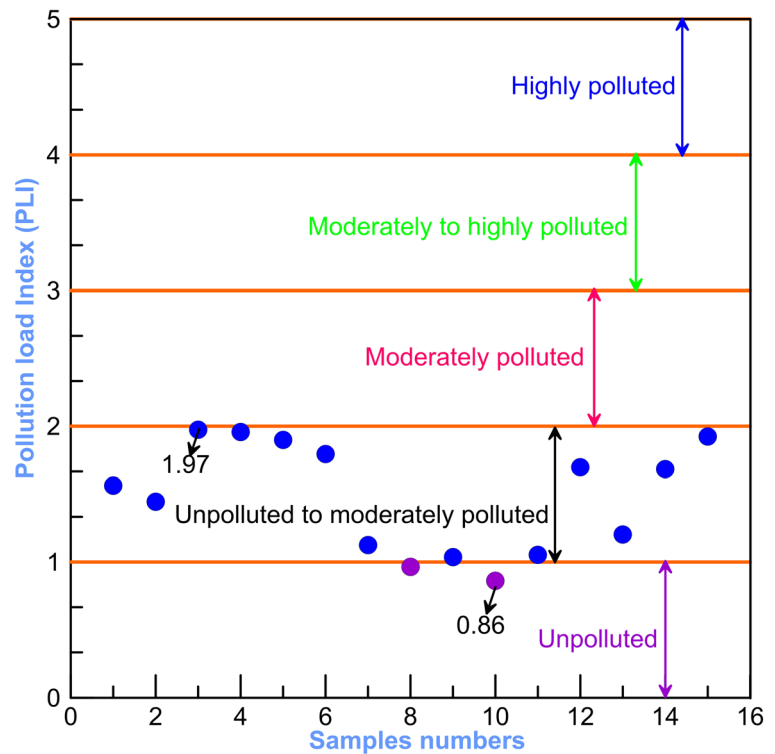
Geo-accumulation index

The I_{geo} is an effective numerical model, which has widely been used to evaluate the HM contamination in both agricultural and urban soils (Adimalla and Wang 2018; Kusin et al. 2018; Muller 1969; Oumenskou et al. 2018; Stevanović et al. 2018). The classification of I_{geo} (Ghazban et al. 2018; Muller 1969) was listed in Table 1 and its spatial distribution was illustrated in Fig. 7b. The I_{geo} values of As, Ni, Pb, and Co were from − 2.55 to − 1.41, − 6.33 to − 0.55, − 2.26 to − 0.07, and − 1.50 to − 0.02 with an average of − 2.05, − 2.27, − 0.71, and − 0.67, respectively (Table 3). They indicate the non-contamination of soils caused by agricultural sources. Further, the values of I_{geo} of Cu, V, Zn, Cr, and Ba in the agricultural soils of the present study area ranged from − 1.42 to 1.04, − 0.35 to 0.95, − 0.53 to 0.75, − 0.91 to 0.37, and − 0.38 to 0.26 with means of − 0.31, 0.32, − 0.19, − 0.11, and 0.04, respectively (Table 3). However, the highest I_{geo} value of Cu was observed from the *Oni* agricultural region, which indicates the adverse impact on agricultural activity, causing mainly the soil contamination in the study region. The I_{geo}

of Cu is ranked first, followed by V, Cr, and Ba, among all metal contaminants. Further, the I_{geo} values of Cu (S2, S3, S4, S5, S6, S13, and S15), V (S1 to S6, S12, S14, and S15), Cr (S3, S4, S5, S6, S12, S14, and S15), Ba (S1 to S6, S11, S12, S14, and S15), and Zn (S1, and S13) were found higher than 0 in the agricultural soils of the study region, indicating the uncontaminated to moderately contaminated of soils by agricultural inputs in the study region.

Correlation matrix and principal component analysis

Pearson's correlation matrix has widely been used to know the dimension of similarity and to evaluate the interrelationship of the analyzed elements. As listed in Table 5, Co was significantly correlated ($P < 0.01$) with Ba (0.865), Cr (0.662), Cu (0.736), V (0.932), and Ni (0.789). In addition, relatively significantly positive correlation ($P < 0.01$) was observed between Ni and Ba (0.682), Ni and Cr (0.827), Ni and Cu (0.712), Cu and Cr (0.725), Cu and V (0.784), As and Pb (0.827), and As and Zn (0.570). Further, relatively negative correlations were also noticed between Co and As (− 0.005), Co and Pb (− 0.0156), Cr and Zn (− 0.337), Cr and As (− 0.299),

Table 4 Enrichment factor (EF) classification and the range of heavy metals in agricultural soils of the northern Telangana, India

| EF	Ba (1.05–1.63)	Cr (1.60–3.88)	Cu (0.51–2.78)	V (1.49–3.67)	Co (1.27–3.56)	Ni (0.03–1.38)	Pb (0.30–1.34)	Zn (1.00–2.44)	As (1.60–3.53)
<2	S1 to S15	S1	S1 to S11, S13 to S15	S7 to S11, S13	S2, S7 to S10, S13	S1 to S15	S1 to S15	S2 to S15	S11, S12, S13
2 to 5	–	S2 to S15	S12	S2 to S6, S12, S14, S15	S1, S3 to S6, AST8, S9, S11, S12, S14, S15	–	–	S1	S1 to S10, S14, S15
5 to 20	–	–	–	–	–	–	–	–	–
20 to 40	–	–	–	–	–	–	–	–	–
>40	–	–	–	–	–	–	–	–	–

Cu and As (− 0.504), Cr and Pb (− 0.126), and Ni and As (− 0.002; Table 5). This implies the lack of significant correlations between these heavy metals, which could be due to the presence of various pollution sources (Chen et al. 2014; Yang et al. 2018; Zhou et al. 2014). The significant positive correlations between the HMs reveal a common source in the agricultural soil of the study region. Furthermore, the results indicated that Pb and As are accumulated in the agricultural soil, which could be due to the application of chemical fertilizer. Similar results were reported in the agricultural region of central Saudi Arabia (Al-Wabel et al. 2017).

The single correlation analysis is not adequate to understand the source of heavy metals. Therefore, principal component analysis (PCA) has extensively been used to identify the sources of heavy metals in soils (natural and anthropogenic) and their element characteristics (Al-Wabel et al. 2017; dos Santos et al. 2017; Li et al. 2016; Li and Feng 2012). In the present study region, the chemical variables (V, Co, Ni, Cu, Cr, Ba, As, Pb, and Zn) are used for PCA (Table 6). Two principal components (PC1 and PC2) having eigenvalues higher than 1 (2.570 to 4.772) were extracted and illustrated in Table 6 and Supplementary Fig. 1. PC1 accounts for 53.020% of the total variance of agricultural soils, which is characterized by high positive loadings of V (0.983), Co (0.941), Ni (0.921), Cu (0.840), Cr (0.838), and Ba (0.787). This signifies anthropogenic contamination, resulting from the agricultural activity, atmospheric deposition of fertilizers, and manure application in the soils (Chen et al. 2015). PC2 explained 28.561% of the total variance, which has high positive loading of As (0.961), Pb (0.823), and Zn (0.738). This is strongly suggestive of the common source of the HMs in the soils.

Conclusions

In the present study region, I_{geo}, PI, PLI, EF, and statistical analysis were performed for understanding the degree of HM contamination and its spatial distribution in the agricultural soils of northern Telangana. The following conclusions were drawn from the study:

• Concentration of As, Pb, Ni, Co, Cu, Cr, Zn, V, and Ba in the agricultural soils range from 2.4 to 5.3 mg/kg, 5.9 to 26.8 mg/kg, 0.5 to 27.6 mg/kg, 12.7 to 35.6 mg/kg, 12.7 to 69.6 mg/kg, 55.9 to
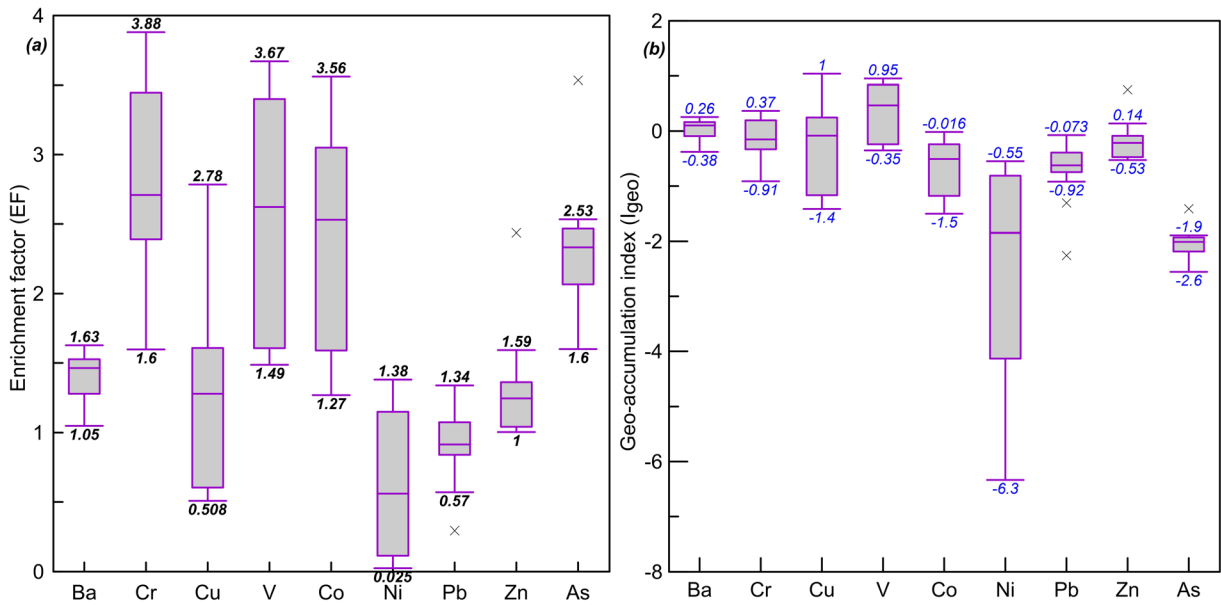
Fig. 7 Box and whisker plots display the distributions of the different contamination indexes: **a** enrichment factor and **b** geo-accumulation index

135.8 mg/kg, 71.3 to 173 mg/kg, 89.2 and 220.2 mg/kg, and 576.6 and 895.2 mg/kg, respectively. A noticeable increase in the concentrations of Cr, Ba, and V is shown in 93%, 67%, and 53% of the total soil samples, which are higher than the Canadian soil quality guidelines, due to the influence of agricultural fertilizers and manures in the intensively irrigated lands. The HM spatial distribution maps displayed four high polluted zones around the agricultural sites *Oni*, *Yamcha*, *Bederelli*, and *Mudhol*.

Further, the PC1 signifies anthropogenic contamination as a result of agricultural activity, atmospheric deposition of fertilizers, and manure application on the soils.

- The computed EF revealed moderate-heavy metal enrichment in the following order: Cr > V > Co > As > Ba > Ni > Pb > Zn > Cu. With the highest EF value of 3.88, Cr shows a significant enrichment among the other HMs. The PLI in soil samples ranges from 0.86 to 1.97 with an average of 1.48, which

Table 5 Pearson's correlations matrix for the heavy metals

	Ba	Co	Cr	Cu	Ni	Pb	Zn	As	V
Ba	1								
Co	0.865[b]	1							
Cr	0.471	0.662[b]	1						
Cu	0.413	0.736[b]	0.725[b]	1					
Ni	0.682[b]	0.789[b]	0.827[b]	0.712[b]	1				
Pb	0.082	− 0.156	− 0.126	− 0.424	0.097	1			
Zn	0.347	0.266	− 0.337	0.022	0.110	0.378	1		
As	0.332	− 0.005	− 0.299	− 0.504	− 0.002	0.827[b]	0.570[a]	1	
V	0.807[b]	0.932[b]	0.800[b]	0.784[b]	0.918[b]	0.007	0.218	0.028	1

[a] Correlation is significant at the 0.05 level (two-tailed)

[b] Correlation is significant at the 0.01 level (two-tailed)

Table 6 Total variance explained and component matrixes (two factors selected) for heavy metals in soils from agricultural region of northern Telangana

Component	Initial eigenvalues			Extraction sums of squared loadings		
	Total	% of variance	Cumulative %	Total	% of variance	Cumulative %
1	4.772	53.020	53.020	4.772	53.020	53.020
2	2.570	28.561	81.581	2.570	28.561	81.581
3	0.930	10.332	91.913			
4	0.485	5.390	97.303			
5	0.099	1.103	98.406			
6	0.053	0.588	98.994			
7	0.045	0.495	99.489			
8	0.036	0.401	99.890			
9	0.010	0.110	100.000			
Element	Component matrix					
	PC1	PC2				
V	**0.983**	0.14				
Co	**0.941**	0.114				
Ni	**0.921**	0.107				
Cu	**0.840**	− 0.368				
Cr	**0.838**	− 0.277				
Ba	**0.787**	0.411				
As	− 0.114	**0.961**				
Pb	− 0.131	**0.823**				
Zn	0.122	**0.738**				

PCA loadings > 0.5 are shown in bold. Extraction method: principal component analysis (PCA)

indicate the agricultural inputs on soils caused by non-pollution to moderately pollution of HMs. Based on the calculated PI, the soils show low to moderate pollution by HMs. The I_{geo} obtained are − 2.55 to − 1.41 for As, − 6.33 to − 0.55 for Ni, − 2.26 to − 0.07 for Pb, − 1.50 to − 0.02 for Co, − 1.42 to 1.04 for Cu, 0.35 to 0.95 for V, 0.53 to 0.75 for Zn, − 0.91 to 0.37 for Cr, and − 0.38 to 0.26 for Ba, suggesting the common source of the HMs in the soils.

Compliance with ethical standards

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

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