Bulletin of Environmental Contamination and Toxicology
https://doi.org/10.1007/s00128-021-03260-1

Potential Ecological Impacts of Heavy Metals in Sediments of Industrially Contaminated Perennial Drain of India

Salwinder Singh Dhaliwal[1] · **Raj K. Setia**[2] · **Sandip Singh Bhatti**[3] · **Jaswinder Singh**[4]

Received: 7 January 2020 / Accepted: 5 May 2021

Abstract

Globally, heavy metal contamination of natural waterways and surrounding environments due to anthropogenic activities has become a grave cause of concern. Therefore, the present study was conducted to analyze the ecological risk posed by heavy metals in sediment samples (N = 24) collected from different depths of Budha Nalah drain located in Ludhiana (Punjab, India). The concentration of As, Cd, Cr, Cu, Ni, Pb and Zn were found to be above the maximum permissible limits for metals in soils and sediments, which was attributed to anthropogenic activities (industrialization, urbanization and agriculture). The values observed for Contamination Factor, Enrichment Factor and Pollution Load Index revealed that sediment samples were highly contaminated by As, Cd, Cr and Pb. The ecological Risk Index (range: 212–1566) and Modified Risk Index (range: 2793–12,182) values indicated that high concentrations of metals (especially As, Cd, Cr and Pb) posed severe ecological risks in the areas around the drain.

Keywords Budha Nalah drain · Contamiantion · Ecological risks · Heavy metals · Sediments

The rapid development of industrialization and urbanization in the last few decades has severely contaminated the natural environmental components (such as soil, air, water etc.) with various pollutants throughout the globe (Dhaliwal et al. 2016; Cai et al. 2019). Heavy metal contamination of soils and sediments poses severe concerns for human health because majority of our food is grown on soils and the plants can accumulate heavy metals from the contaminated soils (Mazumdar and Das 2015). Although few heavy metals such as iron (Fe), copper (Cu), cobalt (Co) and manganese (Mn) are required for metabolic processes in living beings at small amounts, but these metals can cause health complications at higher concentrations (Huang et al. 2019). Other heavy metals such as arsenic (As), cadmium (Cd) and lead (Pb) can cause severe effects even at very low concentrations (Aschale et al. 2017).

The main source of heavy metals in soils and sediments is parent rock material and the natural concentration of heavy metals in soils and sediments is usually low (Chandrasekaran et al. 2015), but due to anthropogenic activities (such as extensive agrochemicals based agriculture, industrial and urban wastewater discharges water sources used for irrigation), groundwater pollution and air pollution (which results in aerial deposition of metals etc.), the heavy metal contents in soils and sediments increases many fold (Tian et al. 2017; Bhatti et al. 2018a). The natural waterways such as rivers or tributaries get constantly contaminated due to urban sewage and industrial effluent discharges which contains excessive amounts of heavy metals (Miao et al. 2019). The sediments around these contaminated waterways can get polluted due to flooding also. The soils and sediments in urban areas are also exposed to heavy metal contamination due to aerial deposition of particles from different point and non-point sources (Bhatti et al. 2018b). The heavy metals contents in the soils and sediments vary at different depths (Troeh and Thompson 2005). While monitoring the metal contents, uppermost layer (0–15 cm) of soils and sediments is considered for evaluation, but assessment of metal contamination in subsurface layers of soils and sediments is also

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✉ Salwinder Singh Dhaliwal
dhaliwalss764@gmail.com

[1] Department of Soil Science, Punjab Agricultural University, Ludhiana, India

[2] Punjab Remote Sensing Center, Ludhiana, India

[3] Department of Botanical and Environmental Sciences, Guru Nanak Dev University, Amritsar, India

[4] Department of Zoology, Khalsa College, Amritsar, India

required because significant amount of heavy metals leach to lower layer of soils with water and can affect the groundwater aquifers (Bouaroudj et al. 2019). Therefore, heavy metal contents in sediments must be analyzed at different depths to assess the extent of metal contamination which is required for sustainable management of water resources.

Considering the severity and complexity of heavy metal contamination in urban soils and sediments around natural waterways, the present study was conducted to analyze the heavy metal concentration in sediments around Budah Nalah drain in Ludhiana city of Punjab, India. Ludhiana is the biggest industrial city of Indian Punjab and has the factories of various industries (electroplating, tannery, textile, pharmaceuticals etc.) (Kaur et al. 2018). These industries discharges contaminated wastewater in the Budah Nalah drain passing through Ludhiana, which further joins Sutlej river which is one of the most prominent river of Punjab downstream (Bhatti et al. 2017). The contamination of water in BudahNalah causes severe pollution in Sutlej river which leads to deterioration of the flora and fauna in Sutlej and adjoining areas. The sediments around BudahNalah drain are at severe risk of contamination. Although several researchers have reported the heavy metal contamination of water in BudahNalah drain and its effects on Sutlej river (Dhaliwal et al. 2016; Kaur et al. 2017, 2018), but very few studies have analyzed the metal contamination of sediments around this drain.

Materials and Methods

The sediment samples were taken from BudhaNalah drain, Ludhiana district of Punjab, India. The soils in this area are of utsifluvent and ustochrepts type. The annual rainfall is in the range of 600–681 mm with semi-arid to sub-humid climate. BudhaNalah drain flows in Ludhiana district and ultimately falls in Sutlej River near Maniawal village in Ludhiana district. Twenty four (24) sites on the banks of Buddha Nalah were selected and the locations of these sites were marked using Global Positioning System (GPS) (Fig. 1 and Supplementary Table 1).

Sediment samples upto 150 cm depth were collected with post-hole auger from six depths (0–15, 15–30, 30–60, 60–90, 90–120, 120–150 cm). These samples were collected in zip lock polythene bags during April, 2016. These samples were air dried, sieved through 1 mm sieve and processed for chemical analysis.

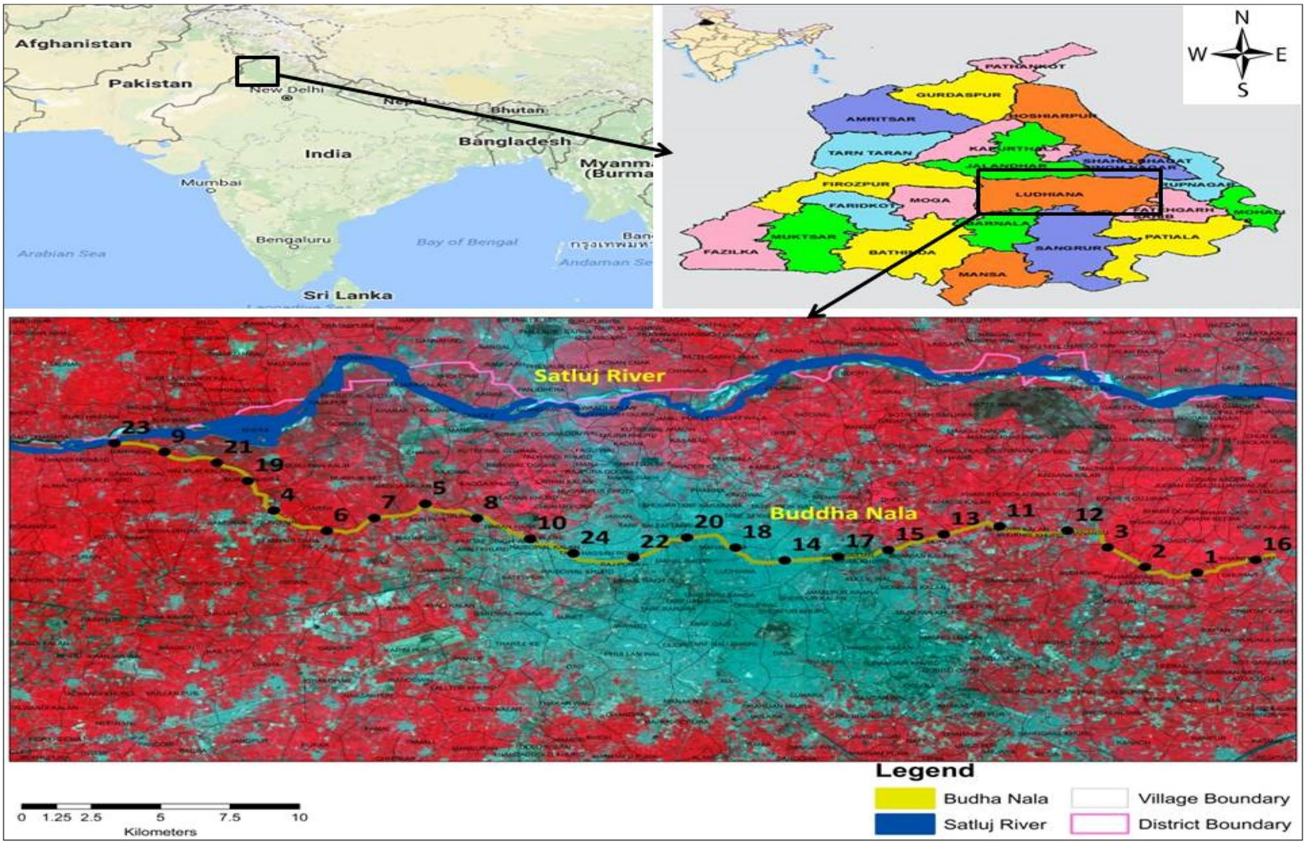


Fig. 1 Map of sediment sampling sites around Budha Nalah drain, Ludhiana, Punjab (N = 24)

For heavy metal analysis, one gm of sediment sample was digested in di-acid mixture (HNO_3: $HClO_4$:: 4:1) till the clear aliquot was appeared. The content in the digesting bottles were further diluted with 6 N HCl to make its final volume to 50 ml. The concentrations of Zn, Cu. Fe, Mn, Ni, Cd, Pb, Co, Cr and As were determined using Atomic Absorption Spectrophotometer (Varian AAS FS 240 Model) fitted with graphite furnace.

In order to analyze the level of contamination of sediments by heavy metals, three indices were calculated: Contamination Factor (CF), Pollution Load Index (PLI) and Enrichment Factor (EF). These factors are based upon the metal pollution assessment in study area in comparison to a reference/background environment (Nazzal et al. 2016; Luo et al. 2019). Since negligible sources were available regarding the background metal data in soils of the study area, the concentration of elements in the earth's crust (Taylor and McLennan 1995) were taken as the background values as done previously by Bhatti et al. (2018b). The CF, PLI and EF were determined as follows:

Contamination Factor (CF) is a reflection of anthropogenic inputs of metals (Miao et al. 2019). CF was defined by Hakanson (1980) as:

$$CF = C_0^i / C_n^i \tag{1}$$

where, C_0^i is the concentration of metal i from the sampling site, and C_n^i is the concentration of metal in reference/background soil environment (Taylor and McLennan 1995). The CF is classified into four categories by Hankson (1980): $CF < 1$ for low, $1 \le CF < 3$ for moderate, $3 \le CF < 6$ for considerable and $CF \ge 6$ for very high contamination.

Pollution load index is a parameter which assesses the contamination caused by metals in combined form in a soil or sediment sample (Ahmed et al. 2016; Appiah-Adjei et al. 2019). PLI was determined as the nth root of the product of the n CF (Chandrasekaran et al. 2015) as follows:

$$PLI = \left(CF_1 \times CF_2 \times CF_3 \times CF_4 \times \ldots\ldots\ldots\ CF_n\right)^{1/n} \tag{2}$$

where, CF is the contamination factor values of upto n number of metals in soil/sediment samples. If the value of PLI is greater than 1, it means the soils are contaminated by heavy metals but if PLI is less than 1, there is no heavy metal contamination in soils.

Enrichment Factor (EF) assesses the enrichment of an element of interest against the concentration of a reference element (Chandrasekaran et al. 2015). An element which is geochemically distinguishing with high concentration in the environment and is incapable of showing antagonism or synergism towards the other elements can be used as a reference element (Gonzalez-Macias et al. 2006; Huang et al. 2019). We used iron (Fe) as the reference element, which has been widely used for normalization by many researchers (Chandrasekaran et al. 2015). The EF can be calculated as follows:

$$EF = \left(C_{sample}/Fe_{sample}\right)/\left(C_{reference}/Fe_{reference}\right) \tag{3}$$

where, C_{sample} represents the concentration of the element in soil sample, Fe_{sample} is the Fe concentration in sample, $C_{reference}$ is the concentration of the element in reference environment (Taylor and McLennan 1995) and $Fe_{reference}$ is the Fe concentration in the reference environment. Sutherland (2000) proposed five categories of enrichment (pollution) of elements in soils: $EF < 2$ for minimal, $EF > 2–5$ for moderate, $EF > 5–20$ for significant, $EF > 20–40$ for very high and $EF > 40$ for extreme pollution in soils.

The CF and EF provides contamination status soil/sediments due to different metals in comparison to a reference environment. But these factors do not represent the ecological risks or environmental hazards posed by the metals. Therefore, in order to analyze the ecological risks of metals in soil, Hakanson (1980) proposed the Potential ecological risk index (RI) (Nazzal et al. 2016). RI takes into consideration CF of metals, their potential ecological risk factors (Er), and their toxicological response factors (Tr) which are 30 for Cd, 5 for Cu, Co and Pb, 2 for Cr and 1 for Mn and Zn (Hakanson 1980; Zheng-Qi et al. 2008; Duodu et al. 2017). The equation to calculate RI is as follows:

$$RI = \sum_{i=1}^{n} Er^i = \sum_{i=1}^{n} Tr^i \times CF^i \tag{4}$$

where, Er^i is the potential ecological risk of an individual metal, Tr^i represents the toxic response factor of an individual metal and CF^i represents the contamination factor of the metal i.

For quantitative ecological risk assessment, RI is a widely recognized index based upon CF which accounts mainly for anthropogenic input of metals into soil environment. But CF does not account for natural factors such as lithogenic and sedimentary inputs of elements of interest. In order to analyze the ecological risks of the anthropogenic as well as lithogenic inputs of metals, the use of EF is proposed for calculation of ecological risk index. The ecological risk index devised using EF is called as Modified potential ecological risk index (MRI) and used by researchers for sediments (Brady et al. 2015; Duodu et al. 2016). The following equation was used to calculate MRI:

$$MRI = \sum_{i=1}^{n} mEr^i = \sum_{i=1}^{n} Tr^i \times EF^i \tag{5}$$

where, mEr^i is the potential ecological risk of an individual metal, Tr^i represents the toxic response factor of an individual metal and EF^i represents the enrichment factor of the metal.

Spatial distribution of heavy metal concentration, mEr and MRI values were generated using kriging in Arc GIS 10.4

The descriptive statistics of heavy metals was analyzed using PAST software version 3.06 (Hammer et al. 2001). Pearson's correlation coefficients were calculated to analyze the correlation among different metals in sediments using Minitab version 14.0 (Pennsylvania, USA) computer software.

Results and Discussion

The descriptive statistics of heavy metal concentration in sediments collected from Budha Nalah drain at five depths is given in Table 1. Among different heavy metals, the concentration of Fe was maximum and the concentration of Cd was minimum at all the depths which can be attributed to the high content of Fe and low content of Cd in the parent rock material. The concentrations of As, Cd, Cr and Pb, which are considered to be highly toxic metals were found to be above

Table 1 Descriptive statistics of metal contents in riverbank soil at different depths around Budha Nalah drain, Ludhiana, Punjab (N = 24)

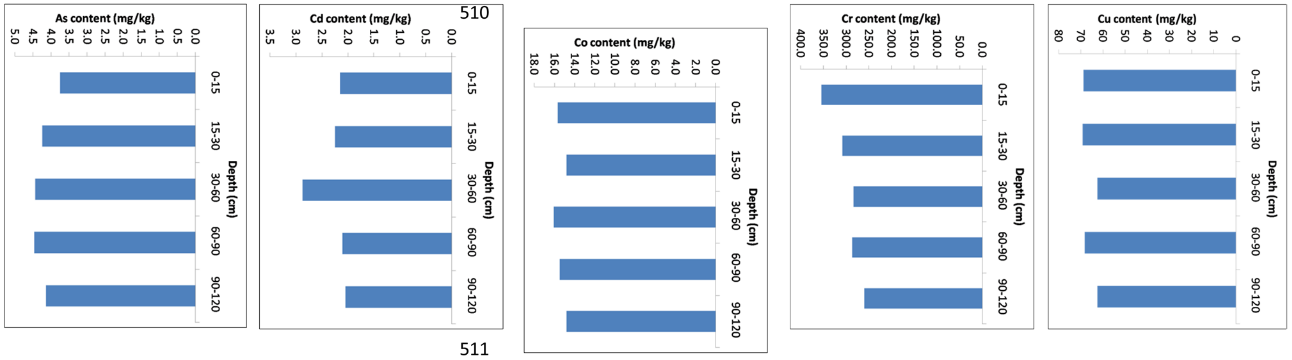
Depth	As	Cd	Co	Cr	Cu	Fe	Mn	Ni	Pb	Zn
0–15 cm										
Min	0.64	0.45	5.3	29.5	8.0	2335.0	100.0	4.0	95.0	11.0
Max	8.77	4.25	28.2	1685.0	198.0	5010.0	730.0	67.5	687.0	550.0
Mean	3.75	2.15	15.7	353.9	68.8	3789.8	318.5	20.7	328.3	129.8
Std. error	0.40	0.20	1.4	85.3	12.8	187.3	24.2	3.8	36.0	31.6
Coeff. var (%)	51.6	45.99	42.8	118.1	91.1	24.2	37.2	89.5	53.7	119.4
15–30 cm										
Min	0.81	0.15	6.5	28.5	9.0	1540.0	200.0	1.3	55.0	13.0
Max	8.70	4.99	24.8	1335.0	196.0	5025.0	520.0	71.0	636.0	575.0
Mean	4.24	2.25	14.8	307.9	69.2	3474.4	330.8	22.7	283.4	125.5
Std. error	0.41	0.25	1.2	71.6	13.4	214.7	19.0	4.0	39.0	32.6
Coeff. var (%)	47.6	53.87	39.4	113.5	94.7	30.2	28.1	86.0	67.4	127.1
30–60 cm										
Min	0.56	0.55	1.3	14.5	8.0	1580.0	30.0	1.1	93.5	10.0
Max	11.09	13.50	52.1	1696.0	177.0	4990.0	785.0	68.0	610.5	550.0
Mean	4.44	2.87	16.1	283.2	62.5	3540.6	334.6	20.8	269.2	118.8
Std. error	0.44	0.53	2.1	80.2	11.8	215.1	27.7	3.8	33.6	35.1
Coeff. var (%)	48.2	90.04	64.4	138.8	92.3	29.8	40.6	88.6	61.1	144.9
60–90 cm										
Min	0.68	0.40	6.5	30.0	8.0	2045.0	215.0	2.1	65.5	11.0
Max	9.07	4.99	33.6	1226.0	184.0	4980.0	820.0	68.5	787.5	525.0
Mean	4.46	2.10	15.5	286.3	68.2	3483.3	353.1	19.2	267.2	102.0
Std. error	0.51	0.24	1.6	79.0	12.5	195.1	27.7	3.6	40.2	28.9
Coeff. var (%)	55.4	54.86	50.2	135.1	90.0	27.4	38.4	93.1	73.7	138.8
90–120 cm										
Min	0.95	0.35	6.0	25.5	8.0	1795.0	190.0	2.4	49.5	11.0
Max	9.08	3.90	34.2	1521.0	194.0	4915.0	540.0	69.0	652.0	585.0
Mean	4.14	2.05	14.8	260.0	62.5	3529.6	338.3	15.7	239.5	104.7
Std. error	0.43	0.20	1.3	87.4	12.9	181.4	16.4	3.2	31.9	32.8
Coeff. var (%)	50.6	48.89	44.1	164.6	101.4	25.2	23.7	100.4	65.3	153.3
Indian Limit of metal (mg/kg)[a]	–	3.0–6.0	–	–	137–270	–	–	75–150	250–500	300–600
European Union limits of metals (mg/kg)[b]	20	1.0	50.0	100	100		2000	50.0	100	300

[a] Awasthi (2000)

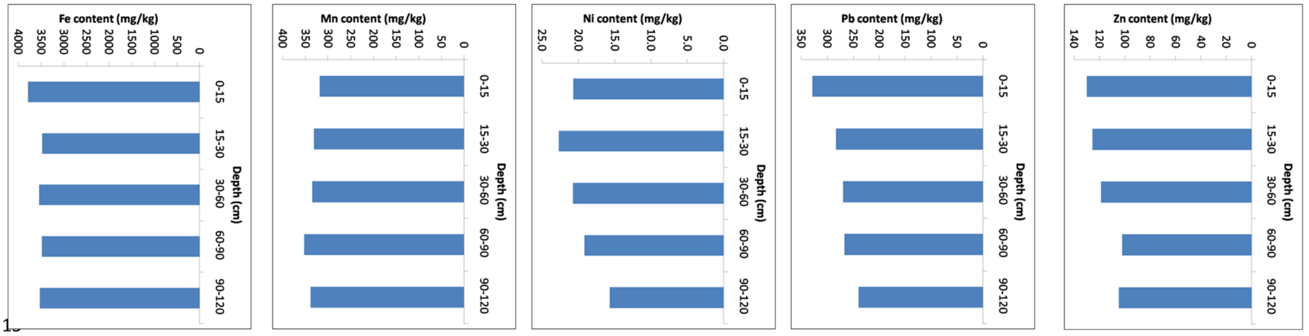
[b] European Union (2009)

the Indian (Awashthi, 2000) and International (European Union, 2009) maximum permissible limits at all the depths at several sites. The concentrations of Cu, Ni and Zn were found to be above International maximum permissible limits at all the depths at several sites. The high levels of the heavy metals observed in the sediments of Budha Nalah can be attributed to different sources. The primary source of these metals is not only lithogenic origins, but also anthropogenic factors of industrialization, urbanization and extensive agrochemical based agriculture have increased the concentration of metals (Wang et al. 2019). Several large scale industries are situated in Ludhiana which includes electroplating, textile, food processing, paints, leather tanning, furniture, plastic and electronics. The effluents from these industries contain significant amounts of different metals including As, Cd, Cr, Cu, Ni, Pb and Zn (Mishra et al. 2019; Yao et al. 2019). The effluents from these industries are discharged into Budha Nalah drain which not only pollutes riverbank soils, but also surrounding fields where the water from the drain is sometimes used for irrigation. The other source of metals (including As, Cd, Cr and Cu etc.) in the sediments can be attributed to agrochemical (fertilizers, pesticides, herbicides etc.) based cropping practices in the surrounding areas (Bhatti et al. 2018a). Several sites around the Budha Nalah had agricultural fields where vegetables were cultivated at the time of sampling (details in Supplementary Table 1). The mixing of runoff from these agricultural fields in BudhaNalah during precipitation or excessive irrigation can lead to further addition of metals in the sediments. A significant positive correlation ($p \leq 0.05$) among different metals at all the depths (Supplemantary Table 2) indicates the common sources of these metals in sediments of Budha Nalah drain. Several other researchers also reported industrial sources as major contaminants of natural water bodies and surrounding soils (Cai et al. 2019; Huang et al. 2019; Luo et al. 2019).

In this study, a specific trend of heavy metals concentrations with increasing depths was not observed (Fig. 2), which can be attributed to leaching, bioturbation, variation in sources and dissolvability of the metals water (Alloway 2013). The sediments are usually porous due to very high levels of sand contents, and have less organic matter contents which can cause leaching of metals to lower layers (Troeh and Thompson 2005). The higher concentration of Cr, Cu, Fe, Pb and Zn in the uppermost layers (0–15 cm and 15–30 cm) was due to higher contents of soil organic matter usually present in uppermost layers which can retain the heavy metals (Bhatti et al. 2017). Several other studies in different parts of world also observed an unclear trend of heavy metals distribution with increasing soil depth (Bai et al. 2019).



(a) As (b) Cd (c) Co (d) Cr (e) Cu



(f) Fe (g) Mn (h) Ni (i) Pb (j) Zn

Fig. 2 Average metal contents at different depths in riverbank soil around Budha Nalah drain, Ludhiana, Punjab (N = 24)

Though a clear trend of heavy metal variations with soil depth was not observed in the present study, but the higher levels of heavy metals (above the national and international maximum permissible limits) in sediment samples at lower depths indicated the leaching of heavy metals (Thanh-Nho et al. 2019). The movement (or leaching) of metals to lower layers can contaminate the groundwater aquifer (Kabata-Pendias 2010), on which the local population is dependent for variety of needs including drinking, domestic and irrigations purposes.

Among different metals analyzed, As, Cd, Cr and Pb are highly toxic and the high concentration in the sediments of Budha Nalah can pose severe toxic risks to groundwater due to movement of heavy metals from contaminated sediments to lower depths which affect soil–plant–human continuum. The presence of As in groundwater water can cause several metabolic disorders such as skin damage, neurobehavioral sicknesses, developmental abnormalities, cardiovascular diseases, and cancer (Mishra et al. 2019). Likewise, Cd toxicity can lead severe effects in plants including chlorosis, growth inhibition, reduction in absorption of nitrate and its transport from roots to shoots, browning of root tips and finally death (Nagajyoti et al. 2010). In human, excessive Cd exposure can many health related problems such as obstructive lung disease, bone defects, cadmium pneumonitis, pulmonary and renal defects (Duruibe et al. 2007). Excessive Cr contents in soils causes absorption of Cr in plants to dangerous levels which can lead to wilting of tops of plants, root injury, chlorosis in young leaves, brownish–red leaves, chlorotic bands on cereals and detrimental effects on photosynthesis (Kabata-Pendias 2010). In human, excessive Cr contents can lead to production of reactive oxygen species such as hydrogen peroxide, superoxide ion and hydroxyl radical, which can cause to oxidative stress in the cell causing damage to DNA and proteins (Jaishankar et al. 2014). Pb is a highly toxic non-essential metal which can cause severe toxic effects in plants such as production of reactive oxygen species (ROS), causing lipid membrane damage which can result in damage to chlorophyll and photosynthetic processes and suppression of overall growth of the plant (Mishra et al. 2019). In human systems, Pb toxicity can lead to diminished intelligence, impaired neurobehavioral development, growth retardation, poor attention span, various reproductive effects, such as decreased sperm count in men and spontaneous abortions in women kidney damage, and gastrointestinal diseases (Tchounwou et al. 2012). The other metals (Cu, Ni and Zn) which were found to be above the maximum permissible limits are essential metals for living beings and are required in trace amounts for metabolic functions, but at very high concentrations, these can pose severe toxicological effects (Bhatti et al. 2018a). Excessive exposure of plants to Cu can induces stress and cause injury to plants leading to plant growth retardation and leaf chlorosis, while very high levels of Ni in plants can cause defects such as impairment of nutrient balance resulting in disorder of cell membrane function, chlorosis and necrosis (Nagajyoti et al. 2010). Human exposure to excessive levels of Cu can cause damage to brain and kidney, liver cirrhosis, chronic anemia, stomach and intestine irritation, whereas Ni toxicity in human can lead to lung cancer, allergic disease such as itching, neurotoxic, immunotoxic, teratogenic, carcinogenic, genotoxic, and mutagenic effects and hair loss (Mishra et al. 2019). Excessive accumulation of Zn by plants can cause toxic effects such as hindrance in root and shoot developments, chlorosis of leaves, oxidative damages to various plant tissues and Mn and Cu deficiencies in plants (Nagajyoti et al. 2010; Bhatti et al. 2018b), whereas in humans excessive Zn contents can lead to fatigue, dizziness, renal damage, vomiting and cramps (Duruibe et al. 2007). Therefore, high levels of heavy metal contents can pose severe toxicological risks to the microflora, plants and animals and human beings in the vicinity of contaminated soils (Yao et al. 2019).

The individual concentrations of heavy metals do not show the level of contamination in soils and sediments. The comparative analysis of heavy metal concentration in sediments must be carried out with a reference/background uncontaminated soil environment to evaluate the level of contamination of soils (Cai et al. 2019). Therefore, three indices were calculated (CF, PLI and EF) to analyze the contamination status of sediments due to heavy metals. The results of heavy metal contamination and ecological risk assessment in sediments of Budha Nalah drain in the present study are given in Fig. 3 (CF, EF, PLI, RI and MRI). In the present study, these indices for heavy metal contamination assessment were calculated for 0–15 cm depth only because living beings (microflora, plants, animals and human beings) are primarily in contact with this region of soil and sediments (Brady and Weil 2008).

The CF compares the contamination in local environment to a global background level (Khorshid and Thiele-Bruhn 2016). In the present study, comparatively higher values of CF values were observed for As, Cd, Cr and Pb than the Co, Cu, Fe, Mn, Ni and Zn (Fig. 3b). In majority of the sediment samples, considerable to very high contamination was observed for Cd (CF range: 4.59–43.4), Cr (CF range: 0.84–48.1) and Pb (CF range: 4.75–34.4), whereas moderate to considerable contamination was observed for As (CF range: 0.42–5.85) and Cu (CF range: 0.32–7.32). The CF values were low to moderate in majority of the sediment samples forCo (CF range: 0.5–2.82), Ni (CF range: 0.20–3.38), Fe (CF range: 0.07–0.14), Mn (CF range: 0.17–1.22) and Zn (CF range: 0.15–7.75).

In order to assess the contamination of sediments by heavy metals in combined form, PLI was calculated. The PLI values were found to be above 1 (PLI range: 0.62–3.76) for majority of sediment samples which indicated that the

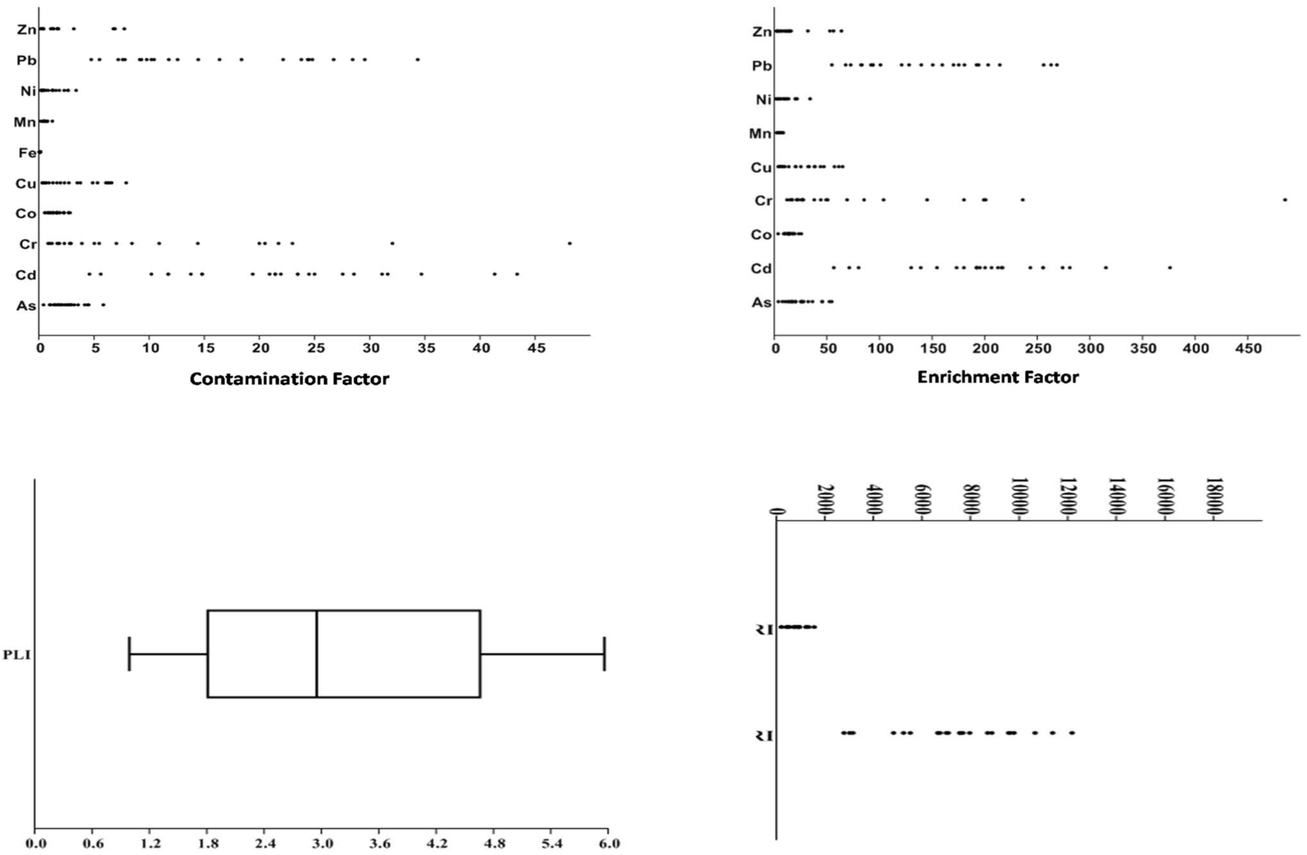


Fig. 3 Contamination Factor, Enrichment Factor, PLI and and Ecological Risk analysis values for heavy metals in riverbank soil (0–15 cm) around Budha Nalah drain, LLudhiana, Punjab (N = 24)

sediment samples were highly contaminated by heavy metals due to high concentrations.

In order to analyze the inputs of metals in sediment samples due to both anthropogenic and geogenic inputs, EF was calculated (Khorshid and Thiele-Bruhn 2016). In most drain sediment samples, very high to extreme enrichment was observed for Cd (EF range: 56.59–376), Cr (EF range: 12.11–486) and Pb (EF range: 54.7–268), whereas significant to very high enrichment was observed for As (EF range: 3.92–54.6), Cu (EF range: 3.75–64.9) and Ni (EF range: 1.76–34.0). There was moderate to significant enrichment in the sediment samples around Budha Nalah drain for Co (EF range: 3.70–25.6), Mn (EF range: 2.39–8.52) and Zn (EF range: 2.32–63.8). The high values of CF and EF for As, Cd, Cr, Cu and Pb in the sediment samples indicated that the sediments of Budha Nalah drain were highly contaminated by these metals which can be attributed to the different anthropogenic inputs of industrialization, urbanization and agriculture. The effluents from several industries (textile, leather tanning, paints, alloys and electroplating etc.) situated in Ludhiana which is discharged in Budha Nalah drain is the primary source of contamination of the sediments. The very high levels of metals due to these anthropogenic inputs results in excessive contamination and enrichment of sediments with metals, which can cause severe ecological impacts in local environment (Bhatti et al. 2018b; Yao et al. 2019).

In order to assess the potential ecological risks posed by heavy metals in combined form in sediments of Budha Nalah drain, ecological Risk Index (RI) and Modified Risk Index (MRI) were calculated (Fig. 3). For assessment of potential ecological risk posed by individual metal, Er (based upon CF) for RI and mEr (based upon EF) for MRI were calculated (Table 2). The grading standards of RI and MRI are presented in Supplementary Table 3.

Among all the metals, Cd posed considerable to very high risk (Er values > 320), Cr and Pb posed moderate to high risk (Er values ranged from 80 to > 320) and As posed low to moderate risk (Er values ranged between < 40 and 80) in most sediment samples. The Er values were less than 40 for Co, Cu, Ni, Mn and Zn, thereby suggesting the low ecological risks in most of the sediment samples. These results indicated that high concentration of Cd, Cr and Pb in the sediment samples of BudhaNalah were most dangerous for overall ecological system of the area. The RI values observed in the present study ranged from 212 to 1566,

Table 2 Ecological risk assessment of individual metals in riverbank soil (0–15 cm) around Budha Nalah drain, Ludhiana, Punjab (N = 24)

	Potential ecological risk of individual metals (Er^i)								
	As	Cd	Cr	Co	Cu	Mn	Ni	Pb	Zn
Min	4.23	137.76	1.69	2.65	1.60	0.17	0.60	23.75	0.15
Max	58.47	1301.02	96.29	14.10	39.60	1.22	10.13	171.75	7.75
Mean	25.02	658.80	20.22	7.84	13.76	0.53	3.10	82.08	1.83
	Modified potential ecological risk of individual metals (mEr^i)								
	As	Cd	Cr	Co	Cu	Mn	Ni	Pb	Zn
Min	39.25	1697.69	24.23	18.49	18.75	2.39	5.28	273.56	2.32
Max	545.76	11,285.53	971.18	128.22	324.72	8.52	102.13	1343.36	63.82
Mean	244.68	6015.19	176.83	71.90	117.97	5.00	27.55	741.45	15.70

which indicated that the concentration of metals observed in the sediments posed moderate to very high ecological risks.

The mEr values (based upon EF) observed in this study indicated that the concentrations of Cd and Pb posed very high ecological risk, Cr and Cu posed considerable to high risk and As posed moderate to high risk in most sediment samples analyzed in present study. There was low to considerable ecological risk due to Co, Mn, Ni and Zn. The MRI values in the present study indicated that the concentration of metals in sediment samples posed very high ecological risk (MRI range: 2793–12,181) and can be potentially dangerous to overall ecological system in the study area[30]. The RI and MRI values indicated that ecological risk assessment based upon EF is better than CF because EF considers both the lithogenic and anthropogenic inputs of metals, whereas CF mainly accounts for anthropogenic inputs (Brady et al. 2015; Duodu et al. 2016). Several studies from India and world also observed high values of RI and MRI for metals in sediment and soil samples which indicated that soil ecosystems worldwide faced severe ecological risks due to heavy metal contamination (Duodu et al. 2016; Bhatti et al. 2018b; Yao et al. 2019).

As explained above, MRI showed the metal contamination and ecological risk in sediment samples around Budha Nalah drain more efficiently, therefore the spatial distribution of mEr of metals posing high risks (As, Cd, Cr, Co, Cu, Ni, Pb ad Zn) and MRI was studied to analyze the site specific contamination due to metals (Fig. 4). The spatial distribution of mEr showed that majority of metals (especially As, Cd, Cr, Cu and Pb) posed maximum risks in sediment samples collected from the downstream areas of Budha Nalah before the confluence of Budha Nalah drain in Sutlej river (Fig. 4i). The high values of mEr and MRI at these sites are a result of high levels metals observed at these sites (Supplementary Fig. 1). But the mEr at these sites is lower which can be attributed to presence of natural vegetation (water hyacinth, natural weeds, sarkanda etc.) at these sites, which leads to phytoremediation of metals from water and sediments. These results suggest that the heavy metal contamination of Budha Nalah drain by anthropogenic activities poses very significant ecological risks to the environment particularly the surrounding soils and sediments. Therefore, steps must be taken to reduce the heavy metal contamination in the study area by regularization and checking of the urban and industrial of effluents discharged in the drain. Further analysis must also be carried out to assess the heavy metal accumulation in soils, natural vegetation, groundwater and crops grown in the vicinity of the Budha Nalah drain.

In the present study, contents of ten metals (As, Cd, Co, Cr, Cu, Fe, Mn, Ni, Pb and Zn) were analyzed in sediment samples (N = 24) collected from Budha Nalah drain located in Ludhiana, Punjab, India at five depths (0–15, 15–30, 30–60, 60–90 and 90–120 cm) The drain is contaminated by discharge of industrial and urban effluents from the surrounding areas. The results of this study showed that the concentration of As, Cd, Cr, Cu, Ni, Pb and Zn were above the maximum permissible limits for metals in sediments collected from Budha Nalah drain at the five depths, which could be attributed to anthropogenic factors of industrialization, urbanization and agriculture. The different indices (CF, EF and PLI) calculated (for 0–15 cm samples) to assess the contamination and enrichment of metals in the sediments showed that the sediment environment in the study area was highly contaminated by As, Cd, Cr and Pb. The factors (RI and MRI) calculated to analyze the ecological risks posed by metals in the study area indicated that the high concentrations of metals (especially As, Cd, Cr and Pb) posed severe ecological risks in the areas around the drain. The spatial distribution maps prepared to analyze the site specific contamination due to metals revealed that the threat of maximum contamination and ecological risks was in areas having higher industrial and urban activities and the ecological risks were lower in areas having higher vegetation cover. It can be concluded from the study that the sediments around the Budha Nalah

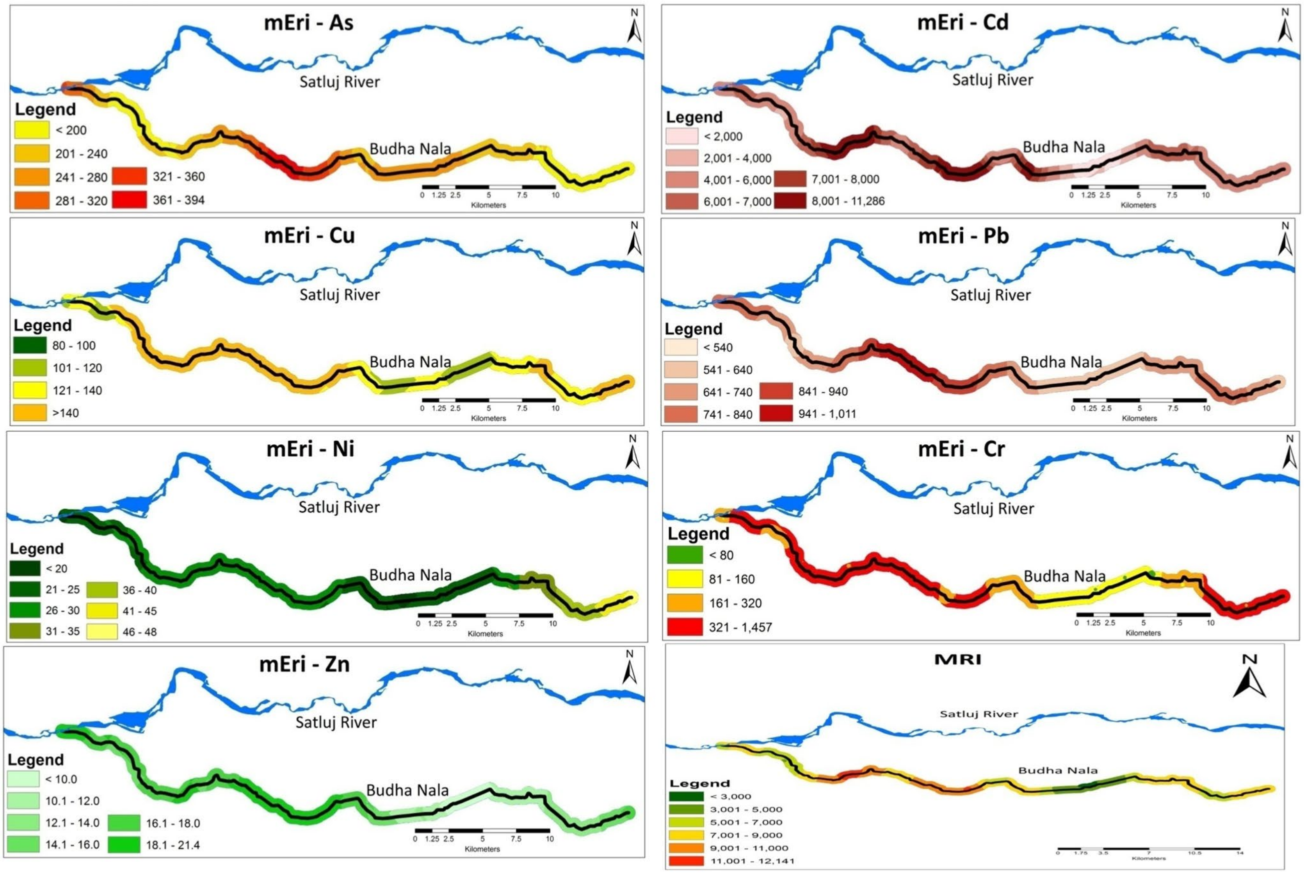


Fig. 4 Spatial variation of modified risk index (mEri) of individual metals and combined Modified risk index (MRI) of all metals (**i**) in riverbank soils around Budha Nalah, Ludhiana (N = 24)

drain in Ludhiana were highly contaminated by heavy metals and the steps must be taken to reduce the levels of these metals in the study area.

Supplementary Information The online version contains supplementary material available at https://doi.org/10.1007/s00128-021-03260-1.

Acknowledgements We are thankful to Indian Council of Agricultural Research, New Delhi for providing financial assistance in the form of project.

Author Contributions SSD was involved in conception and design of sampling, the chemical analysis, acquisition interpretation of data, drafting of the manuscript and overall supervision. RS was involved in remote sensing analysis and drafting of the manuscript. SSB was involved in statistical analysis and drafting of the manuscript. JS was involved in revising the manuscript critically for important intellectual content.

Declarations

Conflict of interest All the authors display no financial or any other conflict of interest. The author(s) declare that they have no competing interests.

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