Assessment of Heavy Metal Pollution in Soil of Different Land Uses of in Semi-Arid Region of Jaipur, Rajasthan

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Abstract: Due to extensive farming, urbanization and rapid growth, heavy metal contamination in soil has now a major issue in India. The semi-arid Jaipur region of Rajasthan underwent an environmental geochemistry assessment to ascertain the impact of pollution in the study area seasonally in the 2022. Soil samples collected from agriculture, industrial and forest area (as a control) in Jaipur were examined for soil physicochemical characteristics and heavy metal content, i.e., Cr, Pb, Ni, Cd, Zn, Cu, Mn and Fe by using the APHA method through an atomic absorption spectrophotometer. The determined mean metal concentration is in the order of Zn > Fe > Mn > Ni > Pb > Cr > Cu > Cd. Heavy metal contamination is also assessed using pollution indices like contamination factor , contamination degree, geoaccumulation index, enrichment factor and potential ecological risk index. Conclusively, the concentration of heavy metals in the soil samples is within permissible limits according to prescribed standards.

Keywords: Heavy metals, Pollution indices, Seasonal variation, Semiarid

Soil on the earth's surface is formed naturally, carries specific chemical, physical, mineralogical and biological characteristics, and varies from the earth's surface to its depths (Thakre et al 2012). In urban ecosystems, changes in land use have significantly impact soil properties. The origin of metals in soils could be geological (weathering and erosion) or anthropogenic (Sahu et al 2024), which could be differentiated as point sources (domestic, mining, refining, industrial and manufacturing) and non-point sources (fertilization, surface runoff, irrigation and agriculture). In semi-arid areas, where the supply of fresh water for irrigation continues to decline, the use of sewage water for cultivation is now a common practice, resulting in increased levels of heavy metals (trace elements) such as nickel (Ni), mercury (Hg), iron (Fe), manganese (Mn), zinc (Zn), copper (Cu), lead (Pb), chromium (Cr), arsenic (As), and cadmium (Cd), which have toxicity and extreme persistence, causing serious harm to humans and the environment (Kurniawan et al 2006, Singh et al 2020). In recent studies, various indices have been used to measure the level of metal contamination and understand its sources, distribution and allocation in soil including the geo-accumulation index (Igeo), enrichment factor (EF) and others like contamination factor, potential ecological risk index.

Jaipur, the state's capital city, has seen significant economic growth in the past two decades due to various industries such as textile, printing, dyeing, gems, jewellery, ready-made garments and marbles. However, the city poses a serious environmental risk because of the large amounts of water, chemicals and dyes required for production and commercial use (Chavan 2001). Dyes, bleaching chemicals, salts, acids and heavy metals like Cr, Cu, Pb, Zn and Fe are dumped constantly into Amanishah Nalla without treatment, mainly originating from the textile and dyes industries located in the Sanganer area of Jaipur (Marwari et al 2012). The present study aims to estimate the spatial and seasonal soil concentrations of eight heavy metals, viz. chromium, lead, nickel, cadmium, zinc, iron, manganese and copper and to assess the contamination level in soil using geochemical indices.

MATERIAL AND METHODS

Jaipur extends from 26°47'0.21" to 27°1'36.84" N and 75°41'15.19" to 75°54'36.27" and has hot summers with temperatures ranging from 20–32° C, low rainfall and low relative humidity. The minimum recorded temperature is 5°C in January and the maximum is 46°C in May and the average rainfall was 74.81 mm during the study period (IMD 2022). The Nahargarh forest range of Jaipur, which covers 52.40 km^2, is mostly dominated by Dhok (*Anogeissus pendula,* which covers 80% of the total vegetation). The other associated tree species are *Jatropha curcas, Maytenus emarginata, Adina cordifolia, Prosopis cineraria, Balanites aegyptiaca, Acacia nilotica, Acacia senegal, and Tecomella unduleta.* For the present study, seven sampling sites were selected based on land use activities, level of contamination and water use for irrigation (Table 1).

Soil sampling and analysis: Soil samples were collected

for three seasons, i.e., pre-monsoon (March to May), monsoon (June to September) and post-monsoon (October to February) during 2022. Permanent 10×10 quadrats were used to gather soil samples from five different sites at a depth of 0 to 10 cm in each land use to make composites. To sample stainless-steel trowels were used to prevent metal contamination. Soil samples were manually cleaned, combined, and stored in zipper polythene bags. Therefore, three locations were selected for each land use at some distance, for a total of 20 samples, and each sample was tested in a triplicate manner. Soil samples were air dry, grounded and sieved to evaluate the physicochemical parameter and trace elements as per the recommended procedures (Table 2).

Environmental pollution indices: In study predicted heavy metal contamination risks using soil trace element concentrations and Shale's trace element values as baseline data: Cr=90, Pb=20, Ni=68, Cd=0.30, Zn=95, Fe=47,200, Mn=850 and Cu=45 (Turekian and Wedepohl 1961).

Geoaccumulation index: Muller (1969) devised the geoaccumulation index (Igeo) to analyse the heavy metal pollution in soil. Compare trace element amounts with background values to see contamination.

$$\mathrm{Igeo} = \log 2 \frac{\mathrm{Cn}}{1.5 \mathrm{Bn}}$$

Where Bn is the average upper crust's (Turekian and Wedepohl 1961) trace element concentration, and Cn is the concentration in soil samples. The constant 1.5 accounts for environmental changes and human impact.

Enrichment factor (EF): The enrichment factor (EF) is used to measure the impact of human activity on soil composition. Sinex and Helz's (1981) equation was used to calculate EF by comparing the concentration of the element being studied (Cn) to the concentration of a reference element (CRef) in the

Table 1. Sampling sites description

Site name	Latitude	Longitude	Elevation (mm)	Vegetation	Site description
Sitapura	N26º47'32.04"	E75º49'39.36"	314	*Azadirachta indica, Acacia nilotica, Nerium oleander*	Industrial area
Bagru	N26º49'14.17"	E75º32'39.25"	308	Rabi: *Sinapis alba* L. (Sarso) Kharif: *Cenchrus americanus* L. Morrone (Bajra)	Industrial area, rainfed
Muhana	N26º47'36.52"	E75º45'4.59"	321	Rabi: *Coriandrum sativum* L. (Dhaniya), *Medicago sativa* L. (Ranjaka) Kharif: *Spinacia oleracea* L. (Palak), *Abelmoschus esculentus* (L.) Moench (Bhindi)	Agriculture field irrigated with nala's water
Vidhani	N26º46'7.40"	E75º52'4.73"	292	Rabi: *Solanum melongena* L. (Bengan), *Sinapis alba* L. (Sarso), *Triticum aestivum* L. (Wheat) Kharif: *Cenchrus americanus* L. Morrone (Bajra), *Sorghum bicolor* L. (Jwar)	Agriculture field irrigated with nala's water
Begas	N26º52'26.69"	E75º33'8.04"	344	Rabi: *Triticum aestivum* L. (Wheat), *Allium cepa* L. (Pyaj), *Medicago sativa* L. (Ranjaka), *Lathyrus oleraceus Lam. (1779)* (Pea) Kharif: *Arachis hypogaea* L. (Peanut), *Cenchrus americanus* L. Morrone (Bajra)	Agriculture field irrigated with tank's water
Chomu	N27º10'24.31"	E75º40'55.02"	405	Rabi: *Triticum aestivum* L. (Wheat), *Allium cepa* L. (Pyaj), *Medicago sativa* L. (Ranjaka) Kharif: *Praecitrullus fistulosus* (Tinda), *Cenchrus americanus* L. Morrone (Bajra)	Agriculture field irrigated with tank's water
Nahargarh	N26º58'56.0"	E75º48'01.0"	490	*Anogeissus* dominated	Forest area

Table 2. Procedure for soil parameter analysis

Parameter	Method used	References
Trace elements	AAS (Analytikjena ZEEnit 700 P)	(APHA 2005)
SM	Gravimetric (Oven dry)	
pH (1:2)	Potentiometry (Eutech model 510)	(Jackson 1973)
EC (1:2)	Conductometry (EI model 602)	(Jackson 1973)
SOC	Rapid titration method	(Walkley and Black 1934)
SN	Micro-kjeldhal method (Kelplus classic dxvatse)	(Subbiah and Asija 1956)
SP	Spectrophotometry (Systronics 1203)	(Olsen et al 1954)
Soil texture	Sieve analysis	(Gee and Bauder 1979)

SM soil moisture, EC electrical conductivity, SOC soil organic carbon, SN soil nitrogen, SP soil phosphorus, AAS atomic absorption spectrophotometer

soil. Common reference elements used are Al (Islam et al 2015) and Fe (Parvez et al 2023), and Mn (Fabretti et al 2009, Sakata et al 2011). In this study, Mn was used to calculate enrichment.

$$EF = \frac{\left(\frac{Cn}{CRef}\right) sample}{\left(\frac{Cn}{CRef}\right) Background}$$

Contamination factor and degree of contamination: Soil pollution is evaluated using two measures (Hakanson 1980): the contamination factor (CF) and the contamination degree (CD). The CF measures the concentration of a heavy metal in a soil sample compared to the normal level of that same metal in the environment. The CD determines the overall contamination level by adding up the values of all the contaminants present in the sample.

$$F = \frac{(Sample\ concentration)\ sample}{(Sample\ concentration)\ background}$$

Potential ecological risk index: This index reflects the toxicity of soil heavy metals, and the response of the environment is computed (Hakanson 1980):

$$RI = \sum_{i}^{n} E_r^i$$

$$E_r^i = T_r^i * C_r^i$$

Where Er is the potential ecological risk factor for heavy metals, Tr is the biological toxic metal response factor, and CF is the single element CF of the metal. The toxic response factors for Pb, Cd, Cu, Zn, Fe, Ni and Cr are 5, 30, 5, 1, 1, 1, 5 and 2, respectively (Gbadamosi et al 2018) and for Mn, 1 (Sinex and Helz 1981). Table 3 shows the categorization of pollution indices.

Statistical analysis: MS Excel was used to compile the data, and XLSTAT ver. 2023 was used to do Pearson's correlation matrix between intermetal and physicochemical parameters.

RESULT AND DISCUSSION

Physicochemical properties of soils: Soil pH ranges from slightly alkaline to moderately alkaline (Table 4). The electrical conductivity varies from 0.08 to 0.24 ms/m. The soil moisture was higher in agriculture land (S4) where sewage water was used for irrigation as compared to other land uses. The mean soil organic carbon concentration was higher in industrial soil (S1) and sewage-irrigated agricultural land (S4). The soil nitrogen was highest in forest soil (S7). The soil phosphorus ranged from 14.57 to 44.81 kg/ha in all land use. The soil texture varies from sandy loam to clay.

Seasonal and spatial variations of heavy metals in soil: The spatial and seasonal mean metal concentration in the soil follows the order as Zn > Fe > Mn > Ni > Pb > Cr > Cu > Cd, respectively (Fig. 1, A-H).

The average seasonal concentrations of most of the metals were maximum during the post-monsoon for Cr, Pb, Ni, Cd and Zn (1.58, 1.60, 5.21, 0.35 and 31.40 mg/kg, respectively), and Fe, Mn and Cu (3.72, 2.65 and 0.48 mg/kg, respectively) was maximum during the monsoon (Fig. 1). During post-monsoon, the nonpoint sources mainly fertilization, surface runoff, irrigation, and agriculture after the rainy period could have added the metal load in the soils which eventually settled to the bottom (Hossain et al 2020). The spatial variations showed that the average maximum metal concentrations for Cr, Ni and Zn, i.e., 1.85, 3.54 and 17.52 mg/kg at the industrial site (S1). In agriculture soils, the highest concentrations were obtained for Cd and Pb (S3:

Table 3. Soil quality classification for multiple indices to assess heavy metals

Enrichment factor (EF)[1]		Geoaccumulation index (Igeo)[2]			Contamination factor (CF)[3]		Potential ecological risk index (PERI)[4]	
EF classes	Sediment quality	Igeo value	Igeo class	Sediment quality	CF Value	Pollution level	PERI	Indication
EF < 1	No enrichment	0-0	0	Unpolluted	CF < 1	Low	PER < 50	Low risk
EF < 3	Minor enrichment	0-1	1	Unpolluted to moderately polluted	$1 \leq CF \geq 3$	Moderate	50 < PER> 100	Moderate risk
EF 3-5	Moderate enrichment	1-2	2	Moderately polluted	$3 \leq CF \geq 6$	Considerable	100 < PER > 150	High risk
EF 5-10	Moderate severe enrichment	2-3	3	Moderately to highly polluted	CF > 6	Very high	150 < PER > 200	Very high risk
EF 10-25	Severe enrichment	3-4	4	Highly polluted			PER > 200	Extreme risk
EF 25-50	Extremely severe enrichment	4-5	5	Highly polluted to very highly polluted				
		5-6	> 5	Very highly polluted				

[1 and 2] Birch and Olmos 2008, [3] Hakanson 1980, [4] Guan et al 2014

1.26; 3.72 mg/kg), and Cu and Mn (S6: 0.55; 2.75 mg/kg), respectively. However, at forest was highest for Fe (4.33mg/kg).

During the pre-monsoon, the maximum concentrations of most of the metals (Cr, Cd, Cu: S3; Pb, Ni: S5) were in agricultural land uses. However, in monsoon season a higher concentration of Cr, Cd, Mn and Fe was reported from forest soils. In post-monsoon season also, an increased metal concentrations were observed from agriculture land uses. This increased levels of heavy metals in agriculture soil could be explained by the overuse of fertilisers, and proximity to textile industries adding the Cd load in the soils of sewage-
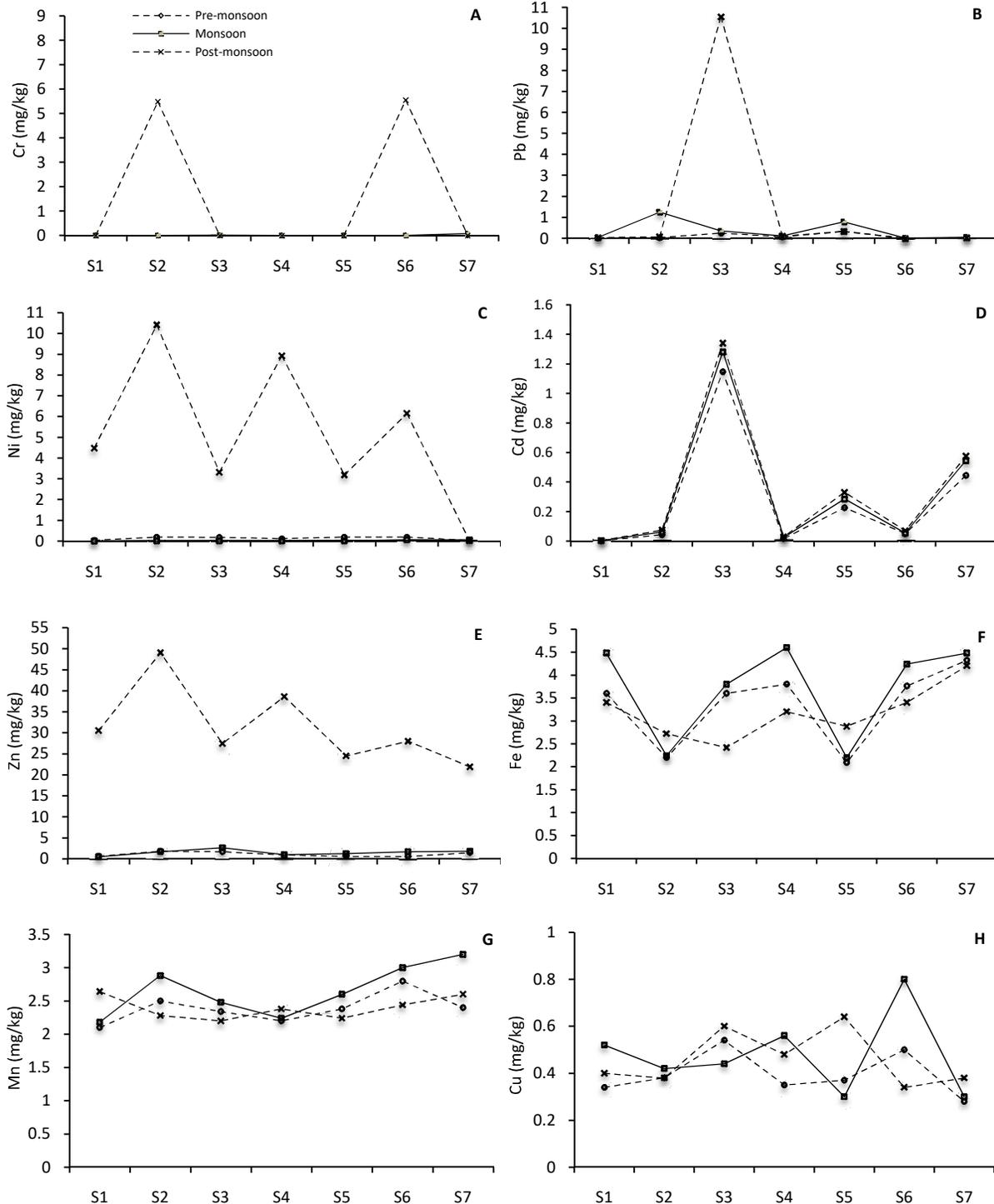

Fig. 1. (A-H) Seasonal and spatial variation in heavy metal concentration in the soil sample

irrigated agriculture lands (Bhuiyan et al 2011, Edogbo et al 2020). The higher values of Mn, Fe and Cu in Chomu agriculture site of Jaipur were also observed by Sharma (2023). The concentrations of Cd, Ni, Pb at industrial sites were in the range as reported by peri-urban soils of Bengaluru (Altaf and Subbarayappa 2022). The high Zn, Ni, and Mn content near Bagru industrial sites may be due to the wastewater generated by textile organizations (Pajot et al 2011).

The concentration recorded in this study was below the allowable limits, concerning the Indian (Awashthi 2000) and European (EU 2002) standard values. This could be explained by then the rejuvenation of the Dravyavati River (August 2016–August 2018), the ban on wastewater and garbage dumping and, five sewage treatment plants (STP) and cleaning the water of river. The limited anthropogenic and industrial activity during the COVID-19 pandemic could have resulted in reducing water and soil pollution sources, and diminish transfer of metal from water (river) to agriculture soil (sewage water irrigated).

Pollution Indices

Enrichment factor (EF): The mean enrichment (EF) factor for metals in the soil followed the order of Fe < Mn < Cr < Cu < Ni < Pb < Zn < Cd. The EF values indicated extremely severe enrichment of Cd and Zn (EF >25), severe enrichment of Pb (10-25), moderately severe enrichment for Ni (5-10), moderate enrichment of Cu (3-5), slightly Cr enrichment (EF < 3), Mn and Fe with no enrichment (EF < 1) (Table 3).

Geoaccumulation index (Igeo): The Igeo values indicated no contamination for Cr, Pb, Ni, Zn, Fe, Mn and Cu (≤ 0), while moderate contamination for Cd (0-2) in all seasons for forest land use (S7) and sewage irrigated agriculture land (S3) (Table 3). The mean Igeo values for heavy metals followed an order: Cr > Cd > Zn > Cu > Pb > Mn > Ni > Fe. The average value of Cf< 1 indicated no pollution in the studied soils across various land uses. However, the Cf for Cd ≥ 3 showed moderate contamination in soils.

Contamination factor (Cd): The average contamination factor (Cd) value for most of the metals, i.e., Cr, Pb, Ni, Zn, Fe, Mn, and Cu, was < 6, indicating a low degree of contamination, whereas the Cd values of cadmium lie between 6-12, indicating a moderate degree of contamination.

Potential ecological risk: The samples have a low potential ecological risk for Cr, Pb, Ni, Zn, Fe, Mn and Cu interpretd by the RI (risk index) value of less than 50 for these metals for all land uses in all seasons. However, the potential ecological RI of Cd lies between 190 and 380 (219), showing low to moderate pollution (Table 3).

During the monsoon season, metal levels decrease due to rainwater. The deposit of metals in the soil causes maximum enrichment during the post-monsoon. Distinct land use patterns, anthropogenic interruptions, past pollution record and its sources impact the soil pollution in various degree (Lee et al 2006). Previous study reports on increased EF values in urban soils are mostly due to industrial and road traffic emissions (Loska et al 2004, Ali and Malik 2010). The low metal background value (0.3 mg/kg) suggests an anthropogenic origin for the increased Cd concentration in the soil sample (Wedepohl 1991).

Intermetal correlation analysis: The inter-metal correlation analysis determined a significant positive correlation of Cr with Ni, Zn and Mn. In addition, a strong positive correlation was found between Cd, Pb, Ni, and Zn (R^2> 0.8). However, there is a weak positive correlation between Pb and Cu (Table 5). The SOC shows a positive correlation with microelements (Fe, Zn and Cu) similar to the agriculture land of N.T.R district in Andhra Pradesh (Prasad et al 2023). A significant correealtion of Fe with SOC indicated pedogenic origin of Fe. The positive correlations between Cd, Pb, Ni and Zn indicate these metals come from similar anthropogenic sources, which could be the nearby industries, automobiles, Pb-Ni-based batteries, fertilizers etc. which might have contributed to the presence of these metals in the soil (Pajot et al 2011, Marwari et al 2012). The discharge of untreated wastewater into nearby land and water systems,

Table 4. Physicochemical characteristics of soil in semiarid region of Jaipur

Site code	Site name	pH	EC (ms/m)	SM (%)	SOC (kg/ha)	SN (kg/ha)	SP (kg/ha)	Soil texture
S1	Sitapura	8.20±0.02	0.24±0	4.12±0.16	65.83±1.81	172.36±4.74	25.82±0.4	Clay
S2	Bagru	7.52±0.01	0.08±0	6.03±0.15	50.77±1.97	170.50±4.40	15.28±0.29	Clay
S3	Muhana	8.20±0.02	0.19±0	11.29±0.14	51.08±1.80	181.19±6.64	24.99±0.39	Clay loam
S4	Vidhani	7.53±0.03	0.20±0	11.46±0.23	65.52±2.25	183.51±4.06	44.81±0.39	Sandy loam
S5	Begas	7.79±0.04	0.16±0	5.91±0.16	50.66±1.91	165.85±5.46	32.93±0.33	Clay
S6	Chomu	8.24±0.02	0.16±0	8.53±0.12	56.38±1.59	175.15±4.99	26.26±0.42	Clay loam
S7	Nahargarh	7.64±0.02	0.08±0	10.12±0.11	43.75±1.74	194.43±5.20	14.57±0.31	Sandy loam

Values are in means ± standard error; EC electrical conductivity; SM soil moisture, SOC soil organic carbon, SN soil nitrogen, SP soil phosphorus

Table 5. Intermetal correlation with soil parameters

	pH	E.C	SM	SOC	SN	SP	Cr	Pb	Ni	Cd	Zn	Fe	Mn	Cu
pH	1	-0.02	-0.46	-0.01	-0.51	-0.52	0.67[a]	0.25	0.36[b]	0.00	0.43[b]	-0.41	0.14	0.29
E.C		1	-0.08	0.79	-0.26	0.64	-0.43	0.20	0.02	-0.00	-0.21	0.17	-0.74	0.55[a]
SM			1	-0.16	0.75	0.24	-0.21	0.40[b]	-0.11	0.52[a]	-0.10	0.43[b]	0.05	0.25
SOC				1	-0.25	0.67[a]	-0.11	-0.25	0.47[b]	-0.51	0.21	0.23	-0.60	0.36[b]
SN					1	-0.15	-0.32	0.07	-0.41	0.36[b]	-0.25	0.77[a]	0.27	-0.30
SP						1	-0.37	-0.06	0.27	-0.22	-0.04	0.04	-0.63	0.45
Cr							1	-0.23	0.58[a]	-0.37	0.52[a]	-0.27	0.59[a]	0.22
Pb								1	-0.18	0.90[a]	-0.04	-0.22	-0.33	0.44[b]
Ni									1	-0.52	0.89[a]	-0.37	-0.20	0.26
Cd										1	-0.32	-0.00	-0.09	0.19
Zn											1	-0.42	-0.16	-0.03
Fe												1	0.20	-0.07
Mn													1	-0.20
Cu														1

EC electrical conductivity; SM soil moisture, SOC soil organic carbon, SN soil nitrogen, SP soil phosphorus. [a]Correlation is significant at 0.01 level, [b]Correlation is significant at 0.05 level

contaminates the soils and poses a threat to human health and the environment.

CONCLUSION

The present study evaluated the spatial and seasonal concentrations of heavy metals (Cr, Pb, Ni, Cd, Zn, Fe, Mn and Cu) in the various land uses, i.e., industrial, agriculture and forests in the semiarid region of Jaipur. Pearson's correlation suggests a common source for metals Cd, Pb, Ni and Zn, could be anthropogenic, whereas for Fe is paedogenic. The geochemical approaches indicated a low degree of contamination for most of the metals except for Cd showing moderate pollution. The study suggests that wastewater containing domestic and industrial waste must be monitored periodically by various pollution control agencies. The untreated or partially treated waste from industrial effluents should be treated properly and efficiently by sewage treatment plants to maintain the metal concentrations at prescribed standards.

AUTHORS CONTRIBUTION

Sonali Tiwari: conducted field sampling, laboratory analysis, and manuscript preparation, Naveen Kumar: collected the data and edited the manuscript, Priyanka Jatav: reviewed and interpreted the result, Archana Meena: analyzed and supervised the data.

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