Assessment of spatial variability of heavy metal concentrations in soils under the influence of industrial wastewater discharge

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A B S T R A C T

Evaluation of the spatial variability of contaminants such as heavy metals (Pb, Cd, Cu, Ni, and Cr) in soils was conducted according to the effect of industrial wastewater discharge. High volumes of wastewater are produced daily in metropolitan areas due to increasing industrialization and population growth. Heavy metal soil contamination in agricultural lands that are cultivated using industrial effluents has become a detrimental environment issue. The degradation of the soil is brought through permeation of these contaminants through the soil. Deposition of pollutants on the soil surface is the prime cause of soil contamination. The objective of the current study was set to monitor and assess variations in heavy metal concentrations in wastewater (n=19) and soil samples (n=8) adjacent to natural drainage systems. Standard techniques were used to analyse each parameter under investigation. According to experimental results of physic-chemical properties, the pH ranged from 7.15 to 8.21, electrical conductivity was 430 to 650 µS/cm, and TDS was 274.2 to 429.5 mg/l. The sequence in which the average level (mg/l) of heavy metals (mean±SD) dropped in the analysed wastewater samples taken from the sampling locations was Cu (14.08±3.975) > Pb (5.412±2.361)> Ni (2.699±1.22)> Cr (2.415±1.271) > Cd (0.753±0.425). High levels of heavy metal concentrations were identified close to the wastewater channel which had a substantial impact on the soil samples that were studied. Chemical study results depicted that metal levels in soils declined with the distance from the source, or wastewater channel. Through outreach and education efforts, locals should be made aware of the potential health risks in association with exposure to untreated wastewater.

Keywords: Industrial wastewater · Heavy metals · Soil contamination · Environmental toxicity · Health risks

1. Introduction

Heavy metals are persistent soil contaminants that cause environmental toxicity by invading into the food web by biological accumulation and magnification. Heavy metals possess potential to degrade the equilibrium of the ecosystem components and functions and also have detrimental effects on human beings and biota. Once the heavy metals enter into the food chain, it results in bioaccumulation in the human body [1]. Irrigation and cultivation with wastewater is rather cost effective but is harmful for people [2]. Industrial effluents are the reservoirs of toxicogenic heavy metals released from various sources like chemical industries, power generation industries, agricultural pesticides, municipal and bio-medical solid wastes etc. The heavy metals abundant in the irrigated waste water persist in the contaminated soil for a long period and cause residual effect on crops and vegetables [3]. Heavy metals contaminate the soil and sub-soil system by both the natural phenomena and by different man-made activities. Soil environments gets contaminated by different treatment and disposal activities like waste sludge insertion, bio-medical and solid waste dumping, mining of metals, irrigation of wastewater etc. [4,5]. As per the US Environment Protection Agency (EPA) list of priority pollutants, among all the heavy metals, lead, cadmium, copper and zinc are important according to their toxicity [6].

The most important primary source of environmental toxicity is industrial effluent [7] discharged into water and soil systems. Human waste discharge into water bodies has harmed the water quality, rendering a sizeable proportion of water currently useless for a variety of uses [8]. In the major cities in Asia, Latin America and Africa, using sewage water to irrigate crops has been expressed as everyday practise. In megacities like Kolkata, Delhi, Mumbai *etc*. in India, untreated sewage water was frequently applied on a large scale. A notable amount of wastewater is generated by homes, businesses, and industries and is utilised directly in agriculture without being properly treated. Effluent solids can be either inorganic or organic in composition. Such solids can be present as suspended or dissolved particles. Since heavy metals show extreme solubility in watery environments, biological things can readily absorb them. Rapid industrialization and urbanization have caused environmental contamination and by heavy metal contamination is a threat for environment and is of serious concern [1, 9]. Anaemia and a disruption in haemoglobin synthesis may result from lead poisoning. Children who are exposed to trace levels of lead particles for a long time may become less intelligent. In contaminated water habitats, heavy metals present in the tissues of different muscles, gills and livers of fishes. Human kidney, liver, brain, heart, nervous system and bone damage cause from lead poisoning [10]. The amount, rate of emission, and duration of exposure all affect how toxic heavy metals are to humans. Drowsiness, memory loss, irritability and headache are some of the early signs of lead poisoning [11]. Human exposure to contaminated wastewater is frequently a possibility, particularly in densely populated urban areas or where the effluent is used for agricultural purposes. Heavy metals in wastewater from factories can build up over time in soil deposits along waste water routes and in the organisms that live there.

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The recent study was conducted to assess the spatial variance of the heavy metals (lead, cadmium, copper, nickel, and chromium) into soils under the influence of industrial wastewater outflow.

2. Materials and Methods

The sites of sampling were selected randomly from the main open wastewater channel and adjacent agricultural regions. For the purpose of collecting soil samples, eight locations close to open drainage channels were chosen. Samples of wastewater used for irrigation, were collected within plastic containers and cleansed with detergent and purified water before washing with the solution before being brought to the lab. Soil samples were collected from the selected plots by excavating 15 cm of dirt, and after unwanted material was removed, representative samples were made. After being filtered, samples of soil collected were then packaged in labelled plastic bags. Additionally, using a hand-held metallic soil scoop, triplicate soil samples were collected near the open channels, wrapped in brown paper bags, and labelled. Following each scooping operation, the dirt scoops were cleaned. The laboratory received both liquid and soil samples right away for additional examination. The moist soil specimens from every sampling location were spread out on brown papers in the laboratory to dry at room temperature. They were then sieved, crushed, and weighed before being placed in tiny brown envelopes and given labels. The usual techniques listed in APHA (2005) [12] were used to digest the conserved materials. In short, the samples were digested with strong HNO_3 till a pale yellow coloured clear solution was obtained. The digested materials were passed through using Whattman No. 42 filter paper and kept at 4°C until further examination in diluted acid washed sampling bottles. At the Central Instrumentation Laboratory, all the heavy metal samples were examined using an Atomic Absorption Spectrophotometer (Perkin Elmer, USA). For the study of wastewater and soil, only analytical-grade reagents were employed.

3. Results and discussion

3.1 Wastewater analysis

The quality of groundwater is impacted by the quantity concentration of different chemical components, the majority of which are received from the geological signature of the particular region and also significantly influenced by anthropogenic sources. Results of physicochemical parameters along with heavy metals are presented in table 1.

Table 1 pH, EC, TDS and metal concentrations of untreated wastewater

Sites	pH	EC	TDS	Pb	Cd	Cu	Ni	Cr
S1	7.48	580	372.5	8.259	0.563	15.353	1.253	3.965
S2	7.41	540	340.0	6.242	0.756	18.414	0.619	3.356
S3	7.15	650	424.6	8.336	1.574	14.211	4.221	1.215
S4	7.84	560	385.7	7.786	0.685	14.915	3.943	2.962
S5	8.21	520	334.5	1.562	0.314	9.854	0.686	0.715
S6	7.37	470	309.8	7.159	0.487	16.146	2.737	2.238
S7	7.47	570	374.5	7.336	0.567	12.251	3.844	2.617
S8	8.15	430	274.2	2.652	0.325	12.185	2.168	0.557
S9	7.86	460	297.3	5.885	0.457	16.229	1.965	3.162
S10	7.28	640	418.6	7.245	0.862	12.452	3.356	2.895
S11	8.00	450	291.8	2.417	0.334	18.642	0.628	0.415
S12	7.75	470	315.8	4.958	0.512	16.359	2.962	1.253
S13	7.31	600	386.4	6.494	1.457	12.853	3.615	0.941
S14	7.85	530	345.7	1.663	0.452	17.632	2.938	3.221
S15	7.18	640	429.5	8.596	1.541	16.414	4.617	4.943
S16	7.63	570	368.4	3.689	0.786	17.119	2.257	2.686
S17	7.75	460	291.6	2.89	0.572	10.832	3.162	2.737
S18	7.45	470	298.7	4.742	1.437	14.284	2.895	3.844
S19	7.52	540	343.3	4.921	0.628	1.368	3.415	2.168
Min	7.15	430	274.2	1.562	0.314	1.368	0.619	0.415
Max	8.21	650	429.5	8.596	1.574	18.642	4.617	4.943
Ave	7.61	534.2	347.5	5.412	0.753	14.080	2.699	2.415
SD	0.315	69.55	48.11	2.361	0.425	3.975	1.220	1.271

EC is expressed as µS/cm and TDS as mg/l, other parameters (except pH) are in mg/l

Leachate from disposal facilities of waste material has been found in several studies to contaminate sources of water used for drinking and other household purposes, posing serious concerns to the public health [13-20]. For instance, Hong et al. [20] 2006, calculated that between 160 and 180 m^3 of leachates per day were evaporating from waste dumps in Pudong (China). An adequately engineered facility for the treatment of waste, in other way, can safeguard public health, protect significant environmental resources, avoid drainage clogs, and stop leachates from migrating to contaminate surface and groundwater, farmland, animals, and the air from which they enter human bodies. The values of pH for the groundwater samples examined ranged from 7.15 to 8.21, with mean±SD value of 7.61±0.315. The low pH was observed along the study area. It may be for the direct impact of nearby the dumping ground municipal solid waste. It's a strong reflection of an acid producing phase during the decomposition of wastes. The low level of pH is an indicator of leachate undergoing anaerobic or methanogenic phase. The total soluble salts concentration in water is represented by electrical conductivity (EC). There is significant variation in the quantity of electrical conductivity (EC) among the groundwater samples, of which S3 has the highest value of 650 (µS/cm). An elevated level of EC in the groundwater indicates addition of some pollutants to it. Total Dissolved Solids (TDS) is a measurable amount of minerals dissolved in water that determines whether the water is appropriate for use. The quantitative values of total dissolved solid (TDS) among the 19 groundwater samples ranged from 274.2 to 429.5 mg/l.

Wastewater along with leachate from contaminated soil has an detrimental impact on environment, causing pollution in the soil and water. In addition to their toxic nature, heavy metals like Pb, Cd, As Cr, Hg, Cu, Zn, Mn and Ni are of particular concern to the environment [21-28], reduces plant growth [29,30]. It is well known that rodents and insects can transmit a diverse range of pathogenic agents (such as cholera, yellow fever, plague, typhoid fever, salmonellosis, various parasitic organisms, and amoebic and bacillary dysentery), it is frequently challenging to pinpoint how such transmission affects a particular population.

One of the most significant contaminants in landfill leachate is heavy metals. There is a significant variation in the concentration of lead (Pb) among the groundwater samples, of which S15 has the elevated value of 8.596mg/l. The most significant pollutant that enters the environment from several sources, in wastewater, solid waste and soil samples, is heavy metals. The cadmium concentration of groundwater samples ranged from 0.314-1.574mg/l. The highest concentration was observed at the site S3. There is significant variation in the values of chromium (Cr) among the 19 groundwater samples, of which S15 had the highest value of chromium 4.943mg/l, followed by S1, 3.965mg/l. As they enter into the food chain, these contaminants can affect humans and cause a bunch of ailments.

The values of nickel concentration (Ni) among the 19 groundwater samples ranged from 0.619 to 4.617mg/l, with a mean±SD value of 2.699±1.22mg/l. The prominence of heavy metals like Pb, Cd, Cr, and Ni in groundwater samples will cause pollution of soil and underground water resources. Therefore, there is a probability of soil and groundwater pollution in study areas affected by industrial wastewater.

3.2. Statistical analysis

Pearson correlation coefficient among the chemical constituents of wastewater is represented in table 2. Significant ($p<.01$) correlation was observed between EC and Pb (r=0.631), EC and Cd (r=0.622), TDS and Ni (r=0.543), TDS and Pb (r=0.664), TDS and Cd (r=0.603) indicating that all of them have the same origin. EC and TDS (r=0.987) showed a good correlation because conductivity increases as the concentration of all dissolved constituents/ions increases. Almost all metals analyzed in this study showed good correlation with conductivity because conductivity increases with dissolution of metals. Positive correlations exist between elemental pairs Pb and Cd (r=0.530), Cd and Ni (r=0.583) this suggests a common source and these may be from landfill contamination.

Table 2 Correlation matrix of physicochemical variables in wastewater

	pH	EC	TDS	Pb	Cd	Cu	Ni	Cr
pH	1							
EC	**-0.685**	1						
TDS	**-0.657**	**0.987**	1					
Pb	**-0.775**	**0.631**	**0.664**	1				
Cd	**-0.758**	**0.622**	**0.603**	**0.530**	1			
Cu	-0.028	-0.054	-0.005	0.097	0.044	1		
Ni	**-0.542**	0.483	**0.543**	0.488	**0.583**	-0.244	1	
Cr	-0.451	0.305	0.311	0.441	0.294	0.211	0.241	1

** Values in bold are significant p<.01*

3.3. Soil analysis

Pb contamination in soil is a severe environmental problem; it builds up with ageing in the liver, kidney, bones, spleen and aorta. Values of heavy metals in soil samples near open drainage channels are presented in table 3. The concentration of soil lead (Pb) among the 8 soil samples ranged from 6.475 to 63.825 mg/l. There is

Table 3 Accumulation of heavy metals (mg/kg dry soil) in soil samples near open drainage channels

		Min	Max	Ave	SD			Min	Max	Ave	SD
Site 1	Pb	22.472	51.425	36.835	9.174	Site 2	Pb	16.548	54.216	39.535	12.067
	Cd	0.355	4.274	2.367	1.247		Cd	0.847	3.756	2.458	0.965
	Ni	58.732	91.744	81.692	10.884		Ni	64.283	88.357	73.502	8.186
	Cu	10.124	34.715	26.343	7.866		Cu	6.547	28.226	19.220	6.834
	Cr	14.521	51.423	40.569	12.481		Cr	8.362	44.912	34.096	12.386
Site 3	Pb	6.475	47.928	27.810	14.556	Site 4	Pb	22.461	63.825	47.967	14.979
	Cd	0.642	5.849	2.799	1.870		Cd	0.398	6.524	3.183	2.086
	Ni	37.821	92.679	65.296	25.740		Ni	35.632	46.833	40.536	4.507
	Cu	12.443	41.259	31.585	9.745		Cu	12.348	46.592	33.610	12.021
	Cr	17.685	52.478	38.983	11.347		Cr	23.559	53.647	38.351	9.463
		Min	Max	Ave	SD			Min	Max	Ave	SD
Site 5	Pb	7.425	48.629	36.096	13.420	Site 6	Pb	15.471	52.264	33.791	14.055
	Cd	1.852	6.201	3.102	1.711		Cd	1.429	4.353	2.479	0.935
	Ni	25.465	76.335	56.316	16.716		Ni	34.196	67.531	52.128	11.228
	Cu	16.823	42.357	31.638	8.157		Cu	11.927	31.457	19.340	6.749
	Cr	8.966	45.152	35.320	12.246		Cr	9.876	46.934	28.971	12.607
Site 7	Pb	15.617	53.241	37.182	12.729	Site 8	Pb	26.169	59.242	48.071	11.018
	Cd	1.696	4.627	2.993	1.102		Cd	1.849	7.544	3.680	2.111
	Ni	45.284	81.346	63.412	14.236		Ni	27.397	52.267	40.405	9.419
	Cu	8.163	33.272	23.029	8.108		Cu	5.866	29.345	21.436	8.918
	Cr	7.849	42.361	28.161	11.814		Cr	14.354	62.152	42.102	17.485

a significant variation in the values of cadmium concentration (Cd) among the 8 soil samples, of which S8 had the pick average±SD value of 3.68±2.111mg/l, followed by S4 3.183±2.086mg/l.

Soil heavy metal concentration in high level indicates addition of some pollutants to it from the industrial waste and waste dumping ground. Therefore, the transfer of elements together with various pollutants, including heavy metals, to the soil resources near the industrial waste discharge channel is a serious environmental concern. Metals have the potential impacts on the ecology of the soil, the ground water quality and ultimately the health of all living organisms.

Due to their toxicity, long environmental half-lives, and capacity for bioaccumulation, heavy metals are widely recognised environmental contaminants. Their anthropogenic origins include mining and other industrial and agricultural processes, while their natural sources include the weathering of metal-bearing rocks and eruptions of volcanoes *etc*.

The extremely hazardous element cadmium is not known to bear any advantageous impacts. Several Cadmium compounds are thought to be carcinogenic in nature. The chromium concentration in the soil samples depict different values, in which S8 had the highest mean±SD value of 42.102±17.485mg/l , followed by S1 with the value of 40.569±12.481mg/l, while the lowest mean±SD value of 28.161±11.814mg/l was recorded for the S7 soil sample. The concentration of copper (Cu) among the 8 soil samples ranged from 5.866 to 46.592 mg/l. The nickel (Ni) concentration in the soil samples depict different values, in which S1 had the highest mean±SD value of 81.692±10.884mg/l, followed by S2 with the value of 73.502±8.186mg/l, while the lowest mean±SD value of 40.405±9.419mg/l was recorded for the S8 soil sample. Nickel has been regarded as a trace element that is essential to both human and animal health. It functions as a regulatory component for different enzyme systems and is connected to DNA and RNA molecules in living systems. Many soils around industry and landfills are contaminated and have severe environmental impacts, as per the findings of several researches [31, 32]. Effective waste management reduces negative effects on the surrounding environment and human health, conserves resources, and enhances city availability. However, unsustainable waste management practises have a detrimental effect on the general population and environmental sustainability, which is worsened by rising urbanization and industrialization. The soil heavy metal levels and even the water sources nearby the waste, depends on a lot of variables, including the soil's capacity to absorb metals, the distance that exists of water sources from the wastes, and topography [33].

The amount of fresh water used by the commercial, domestic, and industrial sectors has increased due to the continuing growth of the urban population and the rising per capita water consumption, which also causes an increase in the amount of waste water produced. Inadequate waste management is the major issue of impacting environmental quality, growth, and it is linked to poor public health. Additionally, improper waste management contributed to city air pollution and water contamination.

4. Conclusion

The results of the present study revealed that high level of heavy metal concentrations was found near the wastewater channel and have a significant impact on soil samples analysed. According to the experimental findings of physicochemical characteristics, the pH ranged from 7.0 to 8.53, electrical conductivity was 180 to 710 µS/cm, and TDS was 274.2 to 429.5 mg/l. The sequence in which the mean concentrations of heavy metals dropped in the analysed wastewater samples obtained from the locations of sampling was Cu > Pb > Ni > Cr > Cd. Consequently, it is best to prevent people from eating vegetables grown using wastewater for irrigation. Additionally, it is crucial to educate local farmers about the risks associated with utilising wastewater to provide irrigation for their crops throughout the dry seasons. Farmers should look for other sources of safe water alternatively.

Finally, it can be stated that in order to prevent an excessive buildup of heavy metals in the food chain, continuous monitoring of these metals' levels in soil derived from wastewater is essential. These results suggest that the soils of the analysed study area were affected by the industrial effluent discharge need to develop proper management strategies.

Conflict of interest

The author declares that there is no conflict of interest in this manuscript.

Data availability

The author confirms that all data collected or analyzed during this study are included in this published article.

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