Assessment of Heavy Metals in Gangaram Tea Garden with Special Reference to Statistical Construal and Pollution Indices

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ABSTRACT

Soil pollution has become a significant threat to human society, and it is essential to evaluate its impact scientifically and plan for future research. To this end, a case study was conducted in the region of Gangaram Tea Garden in Phansidewa subdivision, West Bengal, India, analyzing experimental data on heavy metals (Cd, Fe, Pb, Ni, Mn, Cu, and Cr) present in the soils. In addition to concentration determination also contamination factor, potential ecological risk, and geo-accumulation index were estimated to determine the pollution extent of the soils, with the highest PER value being 82.3 and the lowest being 47.88, indicating low ecological risk for the environment. Statistical analysis using SPSS (Ver. 14.0) also confirms the positive correlation among the heavy metals. Generally, the risk of heavy metal contamination in the study area is comparatively low, but it is important to be aware of the potential health risks associated with heavy metals and their absorption into the soil, specifically cadmium (Cd) and chromium (Cr) to a little extent for the present research work especially due to excessive exposure to Cd or Cr containing fertilizers, pesticides, livestock mucks, domestic sewage and sludge, disposal of agricultural wastes etc. This study delivers a thorough evaluation of soil heavy metals, suggesting policy recommendations for reducing pollution and managing the environment more effectively in context of tea production and tea consumption.

Keywords: *Heavy metals, Soil contamination, Contamination factor, Potential ecological risk index*

INTRODUCTION

The Dooars region in West Bengal, India, is one of the main areas for tea production in the state. It contributes approximately 32% of the total tea yield in West Bengal. The area is known for producing black teas, including CTC (Curl, Tears, and Cut) and Orthodox teas, which are considered to be their speciality (Barman *et al*., 2020). The Terai and Dooars regions of Jalpaiguri district, along with the 2,000-meter-high mountain slopes of Darjeeling district, are the main locations for tea cultivation. However, long-term tea growing may alter the physico-chemical characteristics of the soil (Chen *et al*., 2006). A region's soil fertility quality for growing tea must be assessed if sustainable production of tea is to be achieved. According to a recent study, improper use of fertilizers containing chemicals degrades soil health and causes soil illness (Medhe *et al*., 2012). For soil management of nutrients and sustained tea production, it is crucial to regularly assess the fertility of the soil (Sahrawat *et al*., 2010).

Chandrakala *et al*. (2018) stated that controlling the soil and preserving tea productivity depend on site-specific knowledge regarding soil fertility.

Numerous factors, such as mining operations, sewage irrigation, incorrect industrial solid waste stacking, atmospheric deposition, and fertilizer and pesticide use, can lead to excessive amounts of heavy metals in the soil (Zhang *et al*., 2011).

Soil contamination by heavy metals and metalloids can stem from various sources, including emissions from rapidly expanding industrial sectors, improper waste disposal, mining waste, the use of leaded gasoline and paint, management of high-metal waste, agricultural activities such as the application of fertilizers and animal compost, sewage slurry, pesticides, residues from coal burning, industrial and domestic discharges, irrigation with wastewater, terrestrial runoff, unintentional spills, petrochemical incidents, and the accumulation of pollutants (Alloway, 2013; Wuana and Okieimen, 2011).

Heavy metals are often difficult to break down, so they can linger in the environment for a long time after being introduced. This means that soil is the main place where heavy metals from human activities build up. On the other hand, organic contaminants are usually transformed into carbon dioxide by microbial activity (Kirpichtchikova *et al*., 2006; Adriano, 2003).

Heavy metals are prevalent contaminants in soil, including arsenic (As), cadmium (Cd), chromium (Cr), mercury (Hg), lead (Pb), iron, (Fe), copper (Cu), manganese (Mn), zinc (Zn), and nickel (Ni). This form of contamination is biologically hazardous, widespread, and long-lasting in soil environments (Ma *et al*. 2013). With the rapid expansion of the economy and culture, heavy metal-contaminated soil poses a hazard to both the environment and human health (Min *et al*. 2018).

The presence of heavy metal pollution in soil poses significant dangers to human health and the environment through various channels. These include reducing food quality due to phytotoxicity, contaminated groundwater and soil, contaminating the food chain, direct contact with polluted soil, contributing to food insecurity, decreasing agricultural productivity, and land ownership issues (McLaughlin *et al*. 2000; Ling *et al*., 2007).

Ma *et al*. noted that soil contamination by heavy metals such as arsenic (As), chromium (Cr), cadmium (Cd), lead (Pb), mercury (Hg), zinc (Zn), copper (Cu), and nickel (Ni) is a prevalent and persistent issue. This type of contamination poses significant physiological risks to the soil environment. Elevated levels of manganese (Mn) can adversely affect crop growth, leading to crinkle leaf in cotton and stem stripe necrosis in potatoes. Exposure to high doses of Mn may not result in hematological complications, as indicated by periodic blood tests (Das *et al*., 2011).

Increased concentrations of heavy metals, such as lead and cadmium, can have detrimental effects on living organisms, causing metabolic irregularities, particularly in animals that consume crops grown in contaminated soil (Bakshi *et al*., 2018).

An array of concerning environmental and health issues stem from the presence of cadmium (Cd), lead (Pb), copper (Cu), and zinc (Zn) (Su *et al*., 2014).

Numerous medical diseases, such as carcinoma of the lung, urinary tract collapse, bone fragility, and metabolic disorders of calcium, may be impacted by cadmium and its derivatives (Avenant-Oldewage *and* Marx, 2000). Diabetic complications, neurological ailments, and cancers of the breast and prostate have all been linked to cadmium toxicity (Jiang *et al*., 2007).

Hemochromatosis, intestinal problems, diabetes complications, disorientation, and liver, pancreatic, and cardiovascular disease can all result from elevated iron levels (Regan, 2009). Iron is a crucial element necessary for the synthesis of DNA, as well as for the production of myoglobin, hemoglobin, and essential enzymes within the human body. Unlike other metals, the human body does not possess a natural mechanism for eliminating excess iron. However, the accumulation of excessive iron can result in iron poisoning (Domellöf *et al*., 2013).

Acute Pb poisoning may results in a dysfunction in the kidney, reproduction system, liver and brain resulting in sickness and death (Odum, 2000).

Toxic exposure to lead can cause complications and even death by causing problems with the kidney, brain, liver, and reproductive system (Goyer and Clarkson, 2001).

Ni exposition can cause various side effects, including allergic reactions to the skin, damage to the respiratory tract, neurological impairment, and destruction of the mucous membranes (Argun *et al*., 2007). Suboptimal Mn status may occur in humans with epilepsy, osteoporosis, exocrine pancreatic insufficiency, individuals undergoing hemodialysis, and in children with phenylketonuria – an inherited error of metabolism caused by a deficiency in the enzyme phenylalanine hydroxylase. Despite being essential for human survival, excessive exposure to manganese (Mn) can lead to various health issues for individuals due to their occupations or the environment (Aschner and Aschner, 2005; Wright *et al*., 2006).

Detrimental gastrointestinal disorders and gastrointestinal disorders like vomiting, severe anorexia, melena, haematemesis, and jaundice are commonly observed in cases of copper toxicity (Gamakaranage *et al*., 2011).

Hexavalent chromium (Cr VI) is a potent oxidizing agent that is corrosive, and soluble in both alkaline and mildly acidic water and is known to be toxic and potentially carcinogenic to both plants and animals (Jeyasingh and Philip, 2005).

As the health benefits of tea consumption have been established (Zhou and Li, 2008), there has been an increase in interest in the soil environmental condition of tea plantations. Prior research in tea plantations has concentrated on physicochemistry and soil fertility, as well as the impact of desirable trace metals on tea quality (Zhang *et al*., 2018; Lin *et al*., 2005).

Concern over soil heavy metal pollution's consequences on tea plants has grown as a result of its increased visibility (Han *et al*., 2006). The main causes of heavy metal contamination of soil in tea plantations include agricultural output, high fertilizer and pesticide use, and the application of manure and organic waste. Continuous use of pesticides and fertilizers raised the concentration of Ni in tea by means of root assimilation and caused varying degrees of Ni contamination in the soils of tea plantations, as Wu *et al*., (2002) demonstrated.

According to Shi *et al*., (2004), the heavy use of chemical pesticides and fertilizers over the previous ten years has caused the amounts of Cd and As in tea to nearly double. According to research by Michael *et al*., (2008), there is a linear relationship between the levels of heavy metals in tea plantation soils and tea.

For the soil study, several indices, including the well-established Geo-accumulation Index (I_{geo}) and Contamination Factor (CF), have been widely used to confidently evaluate the eco-toxicity of noxious components in topsoil (Liu *et al*., 2014; Rashed, 2010). The CF and I_{geo} of individual noxious elements in topsoil are based on their total amount and a quality reference value (Zhang *et al*. 2013). Moreover, the Potential Ecological Risk Index (PER) has been developed and is widely accepted as a robust method to assess the cumulative danger of toxic metals in soil (Huang *et al*., 2016). To maximise tea yield, assessments of the soil's fertility level in tea gardens are required in order to recommend appropriate management practices and appropriate fertilizer choices. To assess the risk of hazardous components and the extent of contamination in agricultural soils in the study location, it is important to determine the amount of pollution.

Due to the possible health concerns that contaminants provide to human beings, animals, and the surrounding environment, as well as the resulting financial ramifications, tea safety has received a lot of attention (Li *et al*., 2013). Because of their effects on human genetics and epigenetics, dietary heavy metals like chromium (Cr), cadmium (Cd), arsenic (As), lead (Pb), and selenium (Se) are believed to be associated with an increased risk of developing certain malignancies (Bower *et al*., 2005). Long-term heavy metal intake through diet can cause the metals to build up in the liver and kidneys, which can interfere with a number of biological processes and exacerbate illnesses that affect the bones, kidneys, nervous system, and cardiac system (Järup, 2003).

Many tea estates in North Bengal supply tea to both domestic and foreign markets. Due to its convenient location, the Gangaram Tea Garden can quickly deliver tea leaves and is in high demand. Studies have revealed that heavy metals may be present in tea leaves (Mukherjee *et al*., 2009) which could lower their quality and make international marketing difficult. It is essential to evaluate the presence of heavy metals in the soil in order to determine the level of contamination and how it can affect the quality and marketability of tea.

As very little information about the soil characteristics of the North Bengal region and none at all about the Gangaram Tea Garden is known in light of this, the current study aimed to collect preliminary information on the concentration level of heavy metals; Cadmium (Cd), Iron (Fe), Lead (Pb), Nickel (Ni), Manganese (Mn), Copper (Cu) and Chromium (Cr) including pollution indices and statistical data of the soils of the tea garden under investigation in the month of December, 2023. To ensure the high quality of tea leaves at Gangaram tea garden, it is crucial to conduct tests for heavy metal presence in the soil where the tea is cultivated. This assessment will help to understand any potential impact on the tea's quality, ultimately benefiting the social and economic aspects of the region. In addition to aiding in the understanding of the soil fertility state of the regions, this information will allow tea planters to implement the necessary preventive nutrient management techniques based on data analysis. This study offers authoritative information for safe tea production, early identification of ecological exposure, and pollution-free growing. The study aims to determine the concentrations of several potentially hazardous components, the link between harmful element abundances and possible sources, and the degree of contamination of harmful heavy metals in soils using pollution indices. The outcomes of this study will provide decision-makers with critical information for adhering to the Sustainable Development Goals in this ecosystem.

Study area

The study region is located in Gangaram Tea Garden; site I (26°37'39.1"N 88°17'32.8"E) and site II (26°37'35.5"N 88°17'20.5"E)) of Phansidewa subdivision, West Bengal, India as depicted in Figure 1. The study area is about 17 kilometers away from the Himalayan foothills. The area is mostly flat and consists of sedimentary deposits and rocks from nearby hills. It includes various landscapes, such as patches of sandy soil, gravel, and stones from the neighboring mountains, and is mainly covered with a dense forest of sal trees (Scientific Name: *Shorea Robusta*) (O'Malley, 1907). The environment is favourable for the flourishing of weeds, and the area's native vegetation is actually quite rich in flowers. The weed taxas are expected to be classified as warm-weather vegetation because of the region's predominance of tropical climate, although in the hills, they may be subtropical or temperate plant species. Additionally, it is anticipated that in the transition zone, the weed flora will gradually shift from a completely tropical to an exclusively temperate form as altitude increases. On average, the region receives between 225 and 275 cm of rainfall. The rainy season commences in June and continues until September. The temperature in the region during summer is not excessively high, averaging around 28°C, while in the winter it is low, approximately 16°C. The coldest month in the research area is January. With good rainfall, sandy loamy soil that prevents water from settling but also slows down its percolation, and weather that is favourable for tea plants, this location can serve as a model for analysing the current soil heavy metal contamination status in tea plantations, as its boasts one of the largest areas dedicated to tea planting. But the Gangaram Tea Estate is surrounded by numerous sources of environmental pollution and is constantly treated with chemical fertilizers and pesticides in an effort to improve the quality of the product. It is situated along a highway, with the Bagdogra Airport and railway station located nearby, along with a number of other factories and tea estates. Consequently, various petrochemicals, which are pollutants, immediately contaminate the entire environment, including the soil.

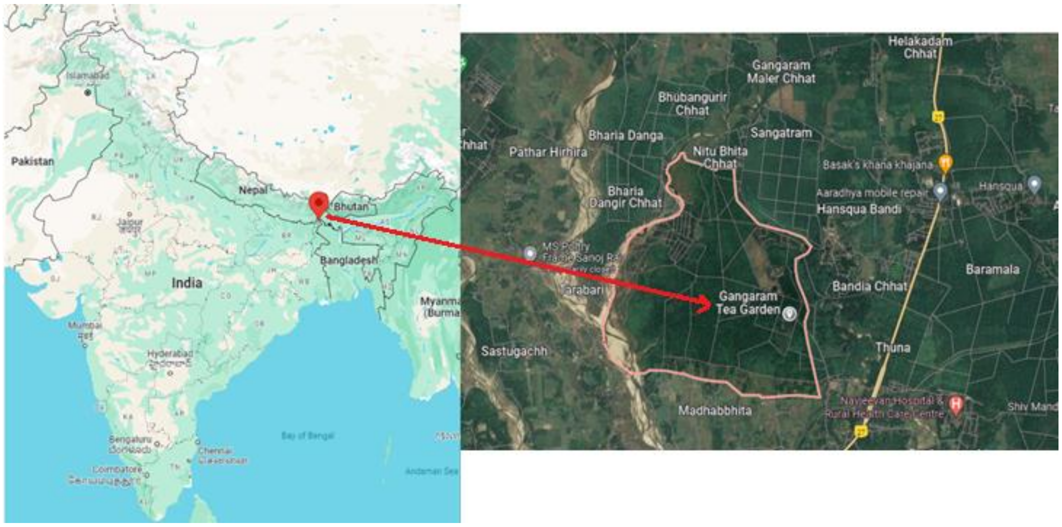

Fig. 1. Location of the study area

Source:

https://www.google.com/maps/place/Gungaram+Tea+Estate/@26.6257655,88.2882746,17z/data=!3m1!4b1!4m6!3m5!1s0x39e44fb6942d1301:0xce1a38adeb400a71!8m2!3d26.6257655!4d88.2908495!16s%2Fg%2F11f1rw8yzl?entry=ttu

MATERIALS AND METHODS

Two sampling stations were selected with care based on the projected soil condition and extent of contamination. Both the sampling points were covered by tea plants. In total, eight samples were collected; four soil samples at various depths from site I, and four soil samples at four distinct depths from site II. Using a stainless-steel manual excavator, surface soil samples were taken at a depth of 0–15 cm, 15–30 cm, 30–45 cm and 45–60 cm. They were then promptly stored in airtight, sealed plastic bags. The samples were dried in the air, shredded, and sieved using a 2 mm mesh screen in the laboratory. A solution of concentrated HNO_3 and $HClO_4$ in a 3:1 ratio was used to digest 0.5 g of composite soil samples in order to estimate the quantity of heavy metals (USEPA 2007, Method 3051A). After filtration, the solution was then diluted to 50 mL with purified water, and Pb, Cd, Cr, Fe, Cu, Ni, and Mn were examined using an atomic absorption spectrophotometer (GBC, Avanta). Since there was no previous value for levels of heavy metals recorded, an assortment of controlled bed soil samples was obtained from a free-of-contamination location 4 kilometers away from the study area, which is thought to be free of any type of contamination and was used as the background value for reference purposes.

For Statistical construal, Normal Distribution Analysis (NDA) and Pearson correlation were performed on the data using SPSS (Ver. 14.0). Confidence intervals were established at the 0.05 significance level. Finding the distribution patterns of the various soil parameters can be done statistically using normalised distribution analysis (NDA), which includes measures of mean, median, standard deviation, skewness, and kurtosis. Pearson's correlation matrix was also determined for comprehending the heavy metal interconnections features for all of the samples and sites.

To determine pollution and ecological risk assessment, the degree of enrichment, also known as the Contamination Factor (CF), was computed as follows.

CF = Cm/CB = (metal concentration in samples)/(metal background values).

The background quantity is based on the average earth metal content (Moni *et al*., 2023).

Contamination degree (CD): $\mathrm{CD} = \sum_{i=1}^{n} \mathrm{CF}$

CD is the sum of the seven CF values of experimental heavy metals found in the research area's soils for a particular site. E_r another important pollution index, symbolizes the biotic community's sensitivity to toxic substances, a single ecological index results in PER during pollution.

$E_r = CF \times T_r$ $\quad\quad$ $PER = \sum_{i=1}^{n} E_r$

In this equation, E_r represents the potential ecological risk index of a single metal, CF represents the Contamination Factor, T_r signifies the metal's toxic response factor, C_m denotes the heavy metal concentration in soil samples, and C_n signifies the background quantity of heavy metals present in soils. The geo-accumulation index was determined using the formula;

$I_{geo} = \log_2 [C_n/1.5B_n]$, where Cn is the concentration of the component in soil, B_n is the value of the geochemical background, and 1.5 is the factor used to account for possible deviations in background values due to lithological effects.

RESULTS AND DISCUSSIONS

To effectively visualize the distribution of heavy metals in the studied tea garden soils, the concentration data of the heavy metals has been represented in Table 1. The heavy metal concentrations can also be compared through Figure 2. In all the experimental sites I and II, the levels of Pb, Ni, and Cu were found to have lower values than the desirable limit except Cr for the upper layers to a small extent but not very much alarming (Srivastava *et al*., 2017). The Cr level may raise due to natural occurrence in addition to waste disposal, sewage sludge, various industrial operations, air borne issues, modern agricultural practices etc. (Stephen, 2004). Only Cd level exceeded the environmental quality threshold (Osmani *et al*., 2015). The situation with Cd contamination, in particular, was alarming, indicating relatively high pollution levels in these two places. The majority of the total concentration of Cd in soils may be caused by overall volcanic eruptions and the geological aging of parent rocks (Liu *et al*., 2017). Compost, phosphate enrichers, pesticides, cadmium based fertilizer, sewage irrigation, and other agricultural inputs are examples of anthropogenic inputs (Luo *et al*., 2009).

Fe and Mn concentrations were within the permitted limit as desired for the uncontaminated soils (Chiroma *et al*., 2014).

It has been observed that the concentrations of heavy metals in the soil decrease gradually with increasing depth. As such, the quality of soil at lower depths is significantly better.

Table 1. Distribution of heavy metals concentration in soil samples at different depths of site I and site II

Parameters (mg kg^{-1})	0-15 cm	15-30 cm	30-45 cm	45-60 cm	Desirable limit (mg kg^{-1})	
			site I			
Cd	53.42	51.01	43.26	30.12	3-6	(Osmani *et al*., 2015)
Fe	324.12	315.41	285.64	262.53	50000	(Chiroma *et al*., 2014)
Pb	113.84	99.65	75.26	67.83	250-300	(Srivastava *et al*., 2017)
Ni	36.45	34.26	38.64	23.55	75-150	(Srivastava *et al*., 2017)
Mn	232.52	229.25	212.74	186.62	2000	(Chiroma *et al*., 2014)
Cu	61.03	58.71	56.34	49.52	135-270	(Srivastava *et al*., 2017)
Cr	165.2	158.44	152.62	145.28	150	Srivastava *et al*., 2017
			site II			
Cd	73.31	71.22	53.54	40.34	3-6	(Osmani *et al*., 2015)
Fe	235.84	222.62	219.48	211.75	50000	(Chiroma *et al*., 2014)
Pb	152.22	135.65	101.31	98.26	250-300	(Srivastava *et al*., 2017)
Ni	58.03	43.12	35.56	21.78	75-150	(Srivastava *et al*., 2017)
Mn	157.64	153.48	142.85	120.55	2000	(Chiroma *et al*., 2014)
Cu	76.54	63.87	64.25	50.84	135-270	(Srivastava *et al*., 2017)
Cr	156.38	151.94	142.02	132.33	150	Srivastava *et al*., 2017

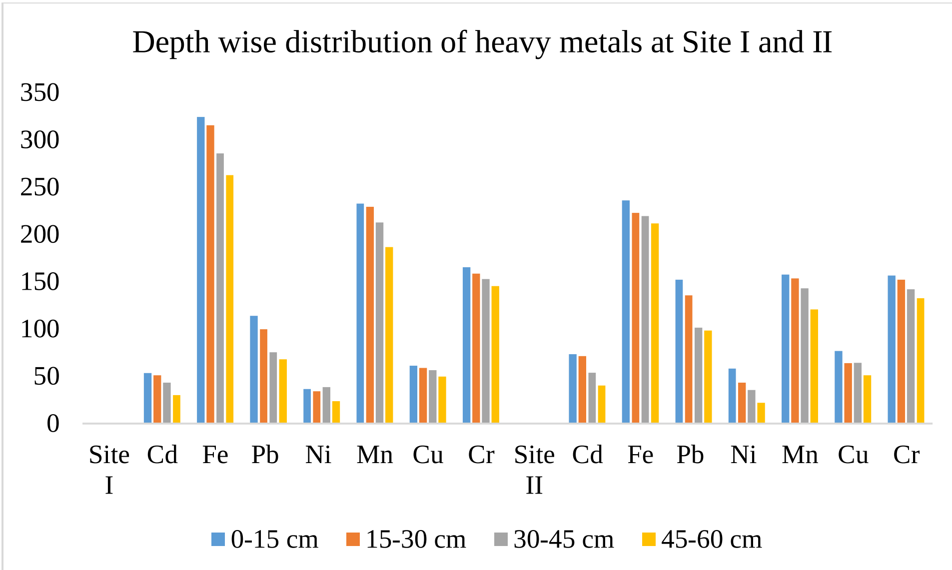

Fig. 2. Distribution of heavy metals in soils of site I and site II at different depths

Statistical construal

Table 2 presents the statistical data for element concentrations (Cd, Fe, Pb, Ni, Mn, Cu, and Cr) in experimental soils. The average amount (mg/kg) of the examined soil heavy metals decreased with each successive descending direction. The median values show a following decreasing trend as: Fe > Mn > Cr > Pb > Cu > Cd > Ni for both the sites. Kurtosis is measured to know how sharp or flat a peak is in relation to the normal distribution. A distribution with positive kurtosis is sharp, and one with negative kurtosis is flat. Skewness is a distribution's symmetry measurement. The skewness value of the normal distribution is zero, and it is symmetric. A skewness value greater than double its standard error is considered to represent a break from symmetry. The kurtosis and skewness values were compared to those of a normal distribution curve, which has a Kurtosis of 3 and a Skewness of 0. The skewness of heavy metals in this study, with less than -1 indicates concentration of the concerned elements are skewed.

Table 2. Descriptive statistics of heavy metal concentration (mg/kg) in soils collected from site I and site II

Parameters	Mean	Standard Error	Median	Standard Deviation	Kurtosis	Skewness	Range	Minimum	Maximum
Site I									
Cd	44.45	5.25	47.14	10.49	0.39	-1.12	23.30	30.12	53.42
Fe	296.93	14.12	300.53	28.23	-2.59	-0.46	61.59	262.53	324.12
Pb	89.15	10.67	87.46	21.35	-3.43	0.26	46.01	67.83	113.84
Ni	33.23	3.35	35.36	6.69	2.66	-1.58	15.09	23.55	38.64
Mn	215.28	10.49	221.00	20.98	0.29	-1.13	45.90	186.62	232.52
Cu	56.40	2.49	57.53	4.97	1.40	-1.16	11.51	49.52	61.03
Cr	155.39	4.24	155.53	8.47	-0.67	-0.09	19.92	145.28	165.2
Site II									
Cd	59.60	7.80	62.38	15.61	-2.68	-0.57	32.97	40.34	73.31
Fe	222.42	5.02	221.05	10.04	1.39	0.77	24.09	211.75	235.84
Pb	121.86	13.20	118.48	26.40	-4.07	0.32	53.96	98.26	152.22
Ni	39.62	7.56	39.34	15.12	0.31	0.10	36.25	21.78	58.03
Mn	143.63	8.30	148.17	16.60	1.06	-1.25	37.09	120.55	157.64
Cu	63.88	5.25	64.06	10.50	1.50	-0.11	25.70	50.84	76.54
Cr	145.67	5.36	146.98	10.73	-1.79	-0.51	24.05	132.33	156.38

The interconnectedness of soil parameters was scrutinized in Table 3 to ascertain potential correlations. A high degree of correlation between explanatory variables has the potential to introduce issues stemming from multicollinearity within the model. However, the correlation matrix revealed a relatively moderate level of collinearity in this instance.

Pearson's correlation matrix revealed that several soil characteristics have a positive association, being substantially linked with heavy metal concentration for all the samples and sites too. Finally, the findings confirmed that land usage and conservation disparities, as well as topographic location variation, had a significant impact on soil properties in the studied area. The significant correlations imply analogous sources and similar mechanisms of accretion of heavy metals in the soils.

Table 3. Correlation matrix of heavy metals of the soil samples

site I							
Parameters	**Cd**	**Fe**	**Pb**	**Ni**	**Mn**	**Cu**	**Cr**
Cd	1.000						
Fe	0.981	1.000					
Pb	0.911	0.971	1.000				
Ni	0.797	0.668	0.517	1.000			
Mn	1.000	0.980	0.907	0.792	1.000		
Cu	0.993	0.964	0.899	0.837	0.989	1.000	
Cr	0.960	0.978	0.973	0.691	0.954	0.967	1.000

Correlation is significant at 0.05 level

site II							
Parameters	**Cd**	**Fe**	**Pb**	**Ni**	**Mn**	**Cu**	**Cr**
Cd	1.000						
Fe	0.871	1.000					
Pb	0.935	0.908	1.000				
Ni	0.934	0.988	0.928	1.000			
Mn	0.973	0.877	0.853	0.939	1.000		
Cu	0.860	0.974	0.823	0.975	0.914	1.000	
Cr	0.993	0.922	0.943	0.970	0.978	0.912	1.000

Correlation is significant at 0.05 level

The important conclusion is that there is a clear connection between heavy metals, indicating that they have common origins. When these metrics are strongly linked, it is reflected in their high correlation and significant similarities. Furthermore, this increases the likelihood of having human-influenced origins or similar causes. Therefore, in this study, the significant correlation coefficients of heavy metals suggest that they have similar geochemical features and common sources. The substantial positive correlation found among heavy metals, which approaches unity, suggests that increasing the concentration of one metal is likely to coincide with increasing concentrations of other metals.

Extent of pollution and ecological risk assessment

The pollution indices are represented in Table 4a for site I and 4b for site II. In this study, the CF values are within the range of 1-3 indicating moderate pollution for all the samples under investigation in site I except Cd at 45-60 cm and for site II at 30-45 cm and 45-60 cm depth, with CF value <1 indicating low contamination (Ihl *et al*., 2015). The mean Contamination Factor (CF) values indicate that for site I, the order of contamination is Cr > Fe > Mn > Cu > Pb > Ni > Cd, whereas for site II, the order is Cr > Pb > Cu > Fe > Mn > Ni > Cd. The study suggests that Cd, Ni, and Cu show low to moderate contamination, while Cr exhibits moderate contamination at both sites. Additionally, CF values for Fe and Mn are moderate for site I but opposite for site II. In contrast, CF for Pb indicates low to moderate contamination for site I but moderate contamination for site II. The concentration factor (CF) values exhibited a decrease as the depth increased, accompanied by the emergence of a consistent distribution of heavy metals. This trend suggests the influence of emitted gases from vehicular exhaust near the highway, atmospheric pollution, as well as direct contamination of the upper soil layers due to environmental and anthropogenic activities.

Here, CD values for site I and II at 0-15 and 15-30 cm depths are less than 24 but a little more than 12, resulting in considerable contamination. For sites I and II at 30-45 and 45-60 cm depth, the CD values are less than 12, resulting in moderate contamination (Moni *et al*., 2023).

The metal evaluation index is calculated based on the soil's hazardous metal background reference value, providing insights into the level of external contamination. At site I, the mean E_r values followed the order: Cd (31.42) > Cu (8.6) > Pb (8.34) > Cr (5.46) > Ni (4.71) > Fe (2.47) > Mn (2.4), while at site II, the order was Cd (31.68) > Pb (11.4) > Cu (9.74) > Ni (5.62) > Cr (5.12) > Fe (1.85) > Mn (1.6). It's interesting to note that Saha *et al*. observed a similar trend. The assessment of E_r values also showed that Cd was the highest contaminant in the study soil though the mean E_r level for all the heavy metals is below 40 indicating low level of contamination based on background values (Hakanson, 1980).

The potential ecological risk index (PER) is a measure that indicates the susceptibility of different biological ecosystems to harmful pollutants. It illustrates the potential environmental hazard posed by toxic metals to the ecosystem and living organisms (Mohammadi *et al*. 2019). The soil in the study areas can be classified as posing a low ecological risk, as indicated by the fact that all the sites have PER values of less than 110, signifying a low level of ecological hazard (Hakanson, 1980). In Figure 3, the data shows that the PER values are greater for site II at depths of 1-15 cm and 15-30 cm, while for site I, the values are higher at depths of 30-45 cm and 45-60 cm.

The levels of toxic metal pollution in the soil of two sites, site I and site II, were measured using the geo-accumulation index (I_{geo}). The I_{geo} values of both the sites can be assessed through Figure 4. Cd (-0.55) and Ni (-0.38) had comparably lower mean I_{geo} scores, followed by Pb, Cu, Mn, Fe, and Cr for site I and for site II the increasing trend of I_{geo} values is Cd > Mn > Fe > Ni > Cu > Cr > Pb. Based on Muller's (1969) categories, the I_{geo} scores for Cd and Ni were classified as 'uncontaminated' at 0-15 and 15-30 cm depth and Pb at 30-45 and 45-60 cm depth for site I. For site II, Cd had the lowest I_{geo} value and was classified as 'uncontaminated'. Ni at 30-45 cm and Ni, Mn at 45-60 cm depth in site II fall under the 'uncontaminated' category. All other heavy metals are considered 'uncontaminated to moderately contaminated'. Higher values of I_{geo} may indicate excessive use of agrochemicals such as fertilizers, herbicides, and insecticides. The findings regarding CF and I_{geo} values were compared with the soil analysis conducted by Das, 2019. The results were largely consistent across the majority of cases. These values indicate a notably higher quality of soil in the present study, suggesting lower levels of pollution (Das, 2019). In their research, He *et al*. 2020, also conducted an assessment of the ecological risk factors present in soils used for tea plantation. The current study indicates a significantly higher soil quality compared to their previous research, which reported substantially higher E_r and PER values (He *et al*, 2020).

Based on the general findings of pollution and ecological risk assessment, there is a growing concern about potential soil contamination in the near future. This concern stems from the continued use of agricultural substances like fungicides, pesticides, fertilizers containing contaminants, and irrigation water. These inputs have the potential to increase the levels of heavy metals in the soil, leading to heavy metal pollution in agricultural areas (Mahmud *et al*., 2021). The levels of CF, E_r, PER, and I_{geo} in the soil suggest a connection to human activities such as emissions from vehicles, farming practices, and other human-related sources indicating that the soil composition has been impacted by human factors.

In recent years, the heightened heavy metal pollution in tea garden soils is undoubtedly linked to elevated soil background values, the use of pesticides and chemical composts holding heavy metals, and industrial endeavors. The quality of tea is essential for the growth of the tea business, the revenue of tea farmers, and the health of tea consumers. Heavy metals, in particular, are crucial evidence in the process of evaluating tea quality since they can be transported into tea infusions during the process of brewing, and then permeate to the body of an individual via tea intake, posing possible health problems. Thus, the chemical constituents of tea, especially heavy metals, have sparked widespread interest since their effects are linked to a variety of ailments

Regulations should be in place to control the quantity and quality of fertilizer used where heavy metal accumulation is mainly due to the production procedure of tea leaves. The accretion of heavy metals in topsoil may cause straight-down movement and pollution of groundwater (Hu *et al*., 2020). Several factors can influence the dynamic process of heavy metal buildup in soils (Wang *et al*., 2017). To ensure that carcinogenic and non-carcinogenic risks of heavy metals to human health are minimized, a monitoring network should be established to provide decision-makers with reliable and current soil quality data (Yuan and Lei, 2017). This network will enable long-term monitoring of dynamic changes in soil quality.

Table 4a. Contamination factor (CF), contamination degree (CD), sensitivity of the biotic community to the toxic elements (E_r), potential ecological risk index (PER) and Geo-accumulation index of the heavy metals in soil collected from site I

Parameters	CF	CD	E_r	PER	I_{geo}	I_{geo} Class	Geo-Accumulation Index
				0-15 cm			
Cd	1.26	14.72	37.75	73.96	-0.25	1	Uncontaminated
Fe	2.70		2.70		0.85	2	Uncontaminated to Moderately Contaminated
Pb	2.13		10.65		0.51	2	Uncontaminated to Moderately Contaminated
Ni	1.29		5.16		-0.22	1	Uncontaminated
Mn	2.59		2.59		0.79	2	Uncontaminated to Moderately Contaminated
Cu	1.86		9.31		0.31	2	Uncontaminated to Moderately Contaminated
Cr	2.90		5.80		0.95	2	Uncontaminated to Moderately Contaminated
				15-30 cm			
Cd	1.20	14.03	36.05	69.92	-0.32	1	Uncontaminated
Fe	2.62		2.62		0.81	2	Uncontaminated to Moderately Contaminated
Pb	1.86		9.32		0.31	2	Uncontaminated
Ni	1.21		4.85		-0.31	1	Uncontaminated
Mn	2.55		2.55		0.77	2	Uncontaminated to Moderately Contaminated
Cu	1.79		8.95		0.26	2	Uncontaminated to Moderately Contaminated
Cr	2.78		5.57		0.89	2	Uncontaminated to Moderately Contaminated

			30-45 cm				
Cd	1.02	12.94	30.57	61.78	-0.56	1	Uncontaminated
Fe	2.38		2.38		0.66	2	Uncontaminated to Moderately Contaminated
Pb	1.41		7.04		-0.09	1	Uncontaminated
Ni	1.37		5.48		-0.13	1	Uncontaminated
Mn	2.37		2.37		0.66	2	Uncontaminated to Moderately Contaminated
Cu	1.72		8.59		0.20	2	Uncontaminated to Moderately Contaminated
Cr	2.68		5.36		0.84	2	Uncontaminated to Moderately Contaminated
			45-60 cm				
Cd	0.71	11.13	21.29	47.88	-1.08	1	Uncontaminated
Fe	2.18		2.18		0.54	2	Uncontaminated to Moderately Contaminated
Pb	1.27		6.34		-0.24	1	Uncontaminated
Ni	0.83		3.34		-0.85	1	Uncontaminated
Mn	2.08		2.08		0.47	2	Uncontaminated to Moderately Contaminated
Cu	1.51		7.55		0.01	2	Uncontaminated to Moderately Contaminated
Cr	2.55		5.10		0.77	2	Uncontaminated to Moderately Contaminated

Table 4b. Contamination factor (CF), contamination degree (CD), sensitivity of the biotic community to the toxic elements (E_r), potential ecological risk index (PER) and Geo-accumulation index of the heavy metals in soil collected from site II

Parameters	CF	CD	E_r	PER	I_{geo}	I_{geo} Class	Geo-Accumulation Index
				0-15 cm			
Cd	1.30	15	38.96	82.3	-0.21	1	Uncontaminated
Fe	1.96		1.96		0.39	2	Uncontaminated to Moderately Contaminated
Pb	2.85		14.24		0.92	2	Uncontaminated to Moderately Contaminated
Ni	2.06		8.22		0.45	2	Uncontaminated to Moderately Contaminated
Mn	1.75		1.75		0.23	2	Uncontaminated to Moderately Contaminated
Cu	2.33		11.67		0.64	2	Uncontaminated to Moderately Contaminated
Cr	2.75		5.49		0.87	2	Uncontaminated to Moderately Contaminated
				15-30 cm			
Cd	1.26	13.5	37.85	75.28	-0.25	1	Uncontaminated
Fe	1.85		1.85		0.30	2	Uncontaminated to Moderately Contaminated
Pb	2.54		12.69		0.76	2	Uncontaminated to Moderately Contaminated
Ni	1.53		6.11		0.03	2	Uncontaminated
Mn	1.71		1.71		0.19	2	Uncontaminated
Cu	1.95		9.74		0.38	2	Uncontaminated to Moderately Contaminated
Cr	2.67		5.34		0.83	2	Uncontaminated to Moderately

							Contaminated
30-45 cm							
Cd	0.95	11.97	28.45	61.17	-0.66	1	Uncontaminated
Fe	1.83		1.83		0.28	2	Uncontaminated to Moderately Contaminated
Pb	1.90		9.48		0.34	2	Uncontaminated to Moderately Contaminated
Ni	1.26		5.04		-0.25	1	Uncontaminated
Mn	1.59		1.59		0.08	2	Uncontaminated to Moderately Contaminated
Cu	1.96		9.80		0.39	2	Uncontaminated to Moderately Contaminated
Cr	2.49		4.99		0.73	2	Uncontaminated to Moderately Contaminated
45-60 cm							
Cd	0.71	10.3	21.44	49.22	-1.07	1	Uncontaminated
Fe	1.76		1.76		0.23	2	Uncontaminated to Moderately Contaminated
Pb	1.84		9.19		0.29	2	Uncontaminated to Moderately Contaminated
Ni	0.77		3.09		-0.96	1	Uncontaminated
Mn	1.34		1.34		-0.16	1	Uncontaminated
Cu	1.55		7.75		0.05	2	Uncontaminated to Moderately Contaminated
Cr	2.32		4.65		0.63	2	Uncontaminated to Moderately Contaminated

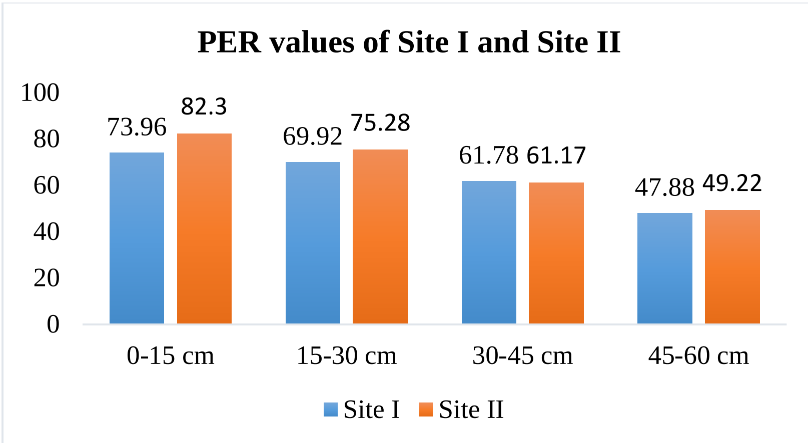

Fig. 3. Potential ecological risk index (PER) values of site I and site II

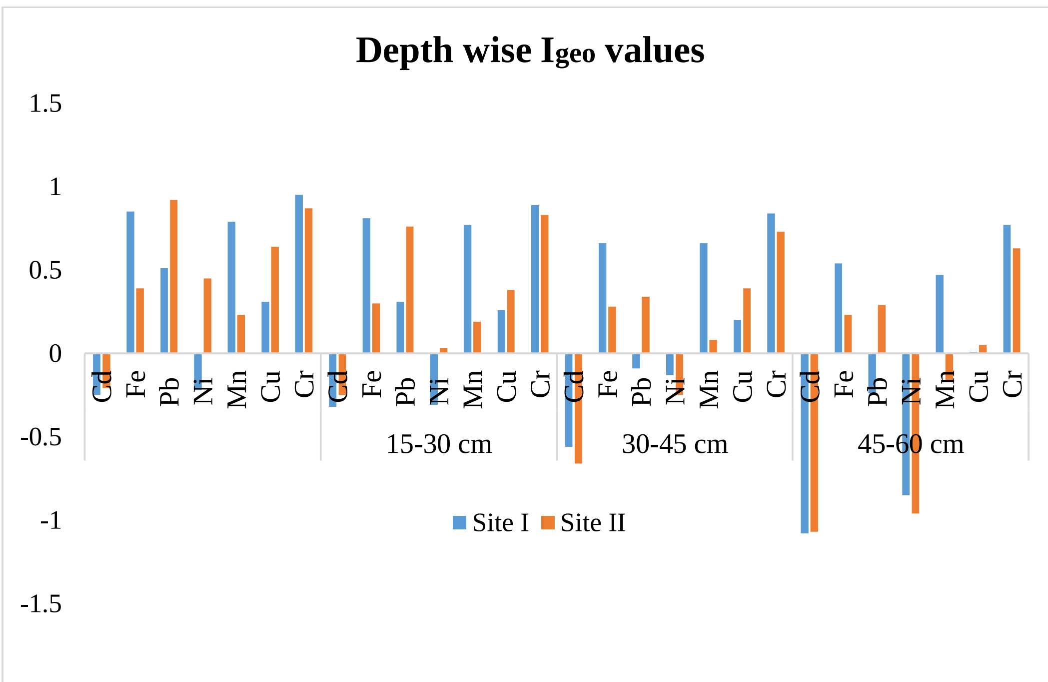

Fig. 4. Geo-accumulation index of the heavy metals in soil of site I and II

The soil plays a fundamental role in the food system and serves as the foundation for various ecological processes. Effective soil management is imperative for mitigating food insecurity and addressing climate change. Soil pollution is a significant global issue that demands prioritized remediation efforts. Phytoremediation, an environmentally friendly approach, has garnered significant recognition for its effectiveness. The results of the risk assessment indicate that the experimental soils have comparatively lower levels of contamination, due to the lack of physical or chemical disruptions. On the other hand, the use of chemical pesticides and fertilizers may have led to increased Cd contamination in soils. These findings are important for evaluating the quality of tea garden soil and developing effective farming strategies to ensure tea leaves' safety while also protecting the environment and human health.

CONCLUSION

The need to regulate soil contamination assessments and soil quality investigations remains crucial worldwide. The present study undertook an investigation and presentation of a collection of information containing a comprehensive assessment score from the tea garden soil displaying the current pollution level of heavy metals in the soil. The heavy metal concentrations, as well as the complete evaluation scores in soil, exhibited significant divergence. Heavy metal levels, mainly for the topsoil exceeded the average background values for some cases. Cd was identified as the most polluted soil in the region, posing a significant threat to the environment. Otherwise, tea garden soil quality remained low risk. Although there are no major harmful industries in close proximity to this tea garden, the garden is exposed to vehicular pollution due to its proximity to the highway. The bio-pollution of its surroundings due to vehicles is detrimental to the tea garden soil, as the harmful substances of air pollution get deposited in the soil and can ultimately become harmful to tea cultivation. While it is almost impossible to prevent this air pollution in the locational context, continuous monitoring and effective management can help measure and prevent the pollution to some extent, making it more effective for tea plantations. The information gathered will also provide valuable insights for improving soil management, decontamination, and contaminating substance prevention. Given the current circumstances, the researchers may continue to investigate the physicochemical properties and other unfavorable consequences of the experimental and nearby tea garden soil in order to ensure the quality of agricultural soil for future cultivation. To ensure the well-being and sustainability of future generations, it is crucial to take steps to protect soil resources from the harmful effects of heavy metal contamination. This is a significant challenge for the scientific community, policymakers, and advisors. Additionally, researchers face difficulties in accurately predicting and understanding the potential long-term risks associated with different soil conditions. Therefore, it is essential for scientists worldwide to work together on extensive research and establish strict guidelines for the proper disposal and use of harmful metals in agrarian soil.

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