

Estimation of potentially toxic elements in industrial agricultural soil

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Abstract

Soil contamination by potentially toxic elements is a growing environmental concern, particularly in industrial agricultural regions. This study aims to estimate the concentration of potentially toxic elements in agricultural soil from Nelamangala and Devanahalli, Bangalore, using Inductively Coupled Plasma Optical Emission Spectroscopy (ICP-OES). Soil samples were collected and analyzed for elements such as Pb, Ca. Preliminary tests, including pH and organic carbon determination, provided insights into soil characteristics. The study's findings are expected to contribute to environmental forensics and soil remediation strategies.

Keywords: Potentially toxic elements, soil contamination, ICP-OES, environmental forensics, agriculture

Introduction

Soil is primarily composed of minerals, organic substances, water, and air. On average, it contains about 45% minerals, 5% organic content, and between 20–30% each of water and air. (University of Hawai'i at Mānoa, n.d.). When soil becomes polluted, it can impact human health through direct skin contact or by inhaling harmful substances that evaporate from the soil. A more serious concern arises when these contaminants seep into groundwater sources, which may be used for drinking, even in places far from the initial pollution site. Furthermore, heavy metals present in the soil can accumulate in crops, eventually entering the food chain and contributing to various health conditions linked to environmental pollution. (contamination., n.d.)

Although heavy metals naturally occur in soil, their levels can significantly rise due to both geological processes and human activities, often reaching concentrations that are harmful to both plant and animal life. Elements like lead (Pb), cadmium (Cd), copper (Cu), iron (Fe), nickel (Ni), and zinc (Zn) are essential in trace amounts. To accurately measure these elements, Inductively Coupled Plasma Optical Emission Spectroscopy (ICP-OES) is commonly used. This technique involves atomizing the sample in a high-temperature argon plasma, which excites the metal atoms and causes them to emit light at specific wavelengths. The emitted light is then captured by detectors such as photomultiplier tubes (PMTs) or charge-coupled devices (CCDs), and the intensity is measured to determine the concentration of each element based on its characteristic emission spectrum.

Soil contamination often arises from industrial processes, the use of agricultural chemicals, or the irresponsible disposal of waste materials. Common pollutants include pesticides, lead, and various other heavy metals. The extent of contamination is generally linked to the level of industrial development and the usage intensity of chemical agents. The primary concern regarding polluted soil lies in its potential health impacts—either through direct skin contact, inhalation of vapors released by contaminants, or through the contamination of surface and groundwater sources beneath the soil.

(contamination., n.d.)

In forensic science, soil analysis involves applying soil science and related disciplines to assist in criminal investigations. Soil can serve as valuable evidence, often helping to establish a connection between a suspect and a crime scene. This analysis relies on various characteristics—such as mineral composition, chemical makeup, biological components, and physical traits. These properties play a crucial role in forensic soil identification. For instance, clay or soil particles found on a suspect's footwear may match the soil at a crime location. The investigation may also include associated materials like plant fragments, pollen, placed on preliminary screening techniques that use a series of simple yet effective method.

Material and Methods

1. Area of Study

The present study was undertaken site covers the area around the different agricultural sites of nelamangala and devanahalli of bangluru. This research will be carried out agricultural area, industrial area, industrial sites, rural in bangluru, India.

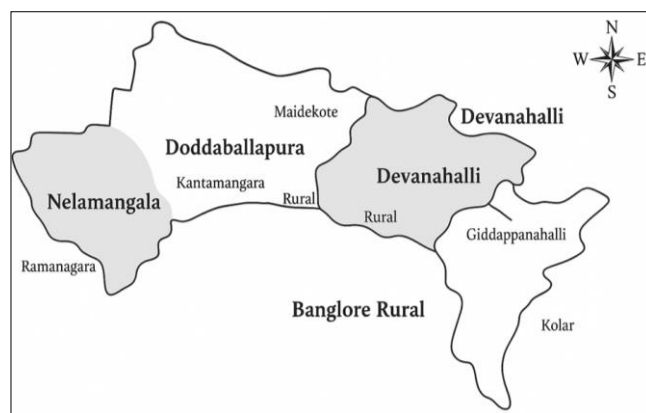


Fig 1: Map of study areas

2. Sample Collection

Soil samples were gathered from twenty different sites in Nelamangala and Devanahalli, Bengaluru, at a depth of six inches, resulting in a total of 20 samples. The distribution of

the sampling locations is presented in Fig. 1. For the composite sampling approach, the study area was initially segmented based on uniform characteristics such as topography, soil texture, drainage, topsoil depth, vegetation, or native plant species. Each homogenous zone was used to create a separate composite sample, formed by combining several subsamples to ensure an accurate representation of the site's variability. (<https://files.dnr.state.mn.us/forestry/ecssilviculture/aerialProgram/collectingCompositeSoilSamples.pdf>, n.d.) Using a shovel, a uniform soil slice was taken from the side of a hole, slightly deeper than six inches. Subsamples of around 1 kg were placed into clean zip-lock bags. Each sample was assigned a unique number and transported to the laboratory for analysis.

3. Experimental Analysis

To remove moisture content, soil samples were initially dried in an oven at 60°C for 48 hours. After this preliminary drying, a 10 g portion of each sample was placed in a Petri dish and subjected to further heating at 150°C for one hour. Once completely dried, sieved through a 2mm mesh to obtain uniform particle size. These prepared samples were then assessed for pH and organic carbon (OC) content using the Walkley and Black method.

For heavy metal analysis, 1 g of the homogenized soil sample was digested using aqua regia, consisting of a 3:1 mixture of 35% hydrochloric acid (HCl) and 70% nitric acid (HNO₃), maintained at 70°C. The digested solution was filtered through Whatman. (sabiene, 2004)

4. Data Analysis

Inductively Coupled Plasma–Optical Emission Spectroscopy (ICP-OES) was utilized to detect and quantify potentially harmful elements, specifically Lead (Pb) and Cadmium (Cd), in agricultural soil samples. This analytical technique was chosen for its exceptional sensitivity, dependable precision, and capability to simultaneously determine multiple elemental concentrations.

In this method, the processed soil extract is introduced into a high-temperature argon plasma, where the atoms and ions become energetically excited. These excited particles release light at wavelengths characteristic of each element. The brightness light emits directly to the element’s concentration within the sample. Owing to its efficiency in measuring trace-level contaminants in complex environmental matrices, ICP-OES is a preferred tool in soil pollution assessments.

Soil samples were first digested with acid following established procedures to convert the target analytes into a clear solution. These digested extracts were then injected into the ICP-OES instrument for quantitative measurement.

5. Quality Control and Assurance

Precautions were strictly followed throughout sample collection, preservation, and all experimental procedures to maintain data integrity. Only distilled water was utilized for preparing all reagents and solutions. Glassware was thoroughly cleaned by soaking in diluted acid for a minimum of 24 hours, followed by multiple rinses with distilled water before use. Each analysis was performed in triplicate to ensure the reliability and accuracy of the results. ((2020)., n.d.)

Results and Discussion

A statistical summary of the concentrations of heavy metals detected in soil samples collected at a depth of 15 cm (approximately 6 inches) is presented in Table 1 and Table 2. Cadmium (Cd) levels were found to range between 0.03 mg/kg and 0.32 mg/kg, while Lead (Pb) concentrations varied from 0.95 mg/kg to 3.87 mg/kg at the same depth. These findings indicate a slightly elevated presence of these metals in the soil across both Nelamangala (samples S1–S10) and Devanahalli (samples D1–D10) regions in rural Bengaluru.

Table 1: Instrumentally Analysed concentration of both Cadmium and Lead metals in agricultural soil

Sample	Cd (mg/kg)	Pb (mg/kg)
S1	0.18	3.64
S2	0.03	1.18
S3	0.12	3.54
S4	0.27	3.32
S5	0.32	3.67
S6	0.23	3.87
S7	0.21	2.41
S8	0.06	1.22
S9	0.07	0.95
S10	0.06	1.00
D1	0.08	2.14
D2	0.11	3.07
D3	0.05	2.36
D4	0.04	1.39
D5	0.05	1.33
D6	0.06	1.52
D7	0.07	1.68
D8	0.12	2.63
D9	0.05	2.26
D10	0.08	2.20

Table 2: Data description in statistical manner

Element	Min (mg/kg)	Max (mg/kg)	Mean (X) (mg/kg)	Standard Deviation (SD)	Median (mg/kg)
Cadmium	0.03	0.32	0.113	0.084	0.075
Lead	0.95	3.87	2.269	0.977	2.230

Cadmium (Cd)

At a depth of 15 cm, the concentration of cadmium (Cd) in soil samples ranged from 0.03 mg/kg to 0.32 mg/kg. The contamination factor (CF) for Cd varied, with a minimum value of 0.35 and an average of 0.104, indicating a low level of contamination when compared to the background reference value of 0.3 mg/kg (table-3).

Lead (Pb)

Lead (Pb) concentrations in the soil at the same depth ranged between 0.95 mg/kg and 3.87 mg/kg. The CF values for Pb ranged from 0.12, with an average CF of 2.31, which also suggests low contamination relative to the background value of 20 mg/kg (table-3).

1. Contamination Factor (CF) Assessment

The extent of soil contamination was evaluated using the Contamination Factor (CF) method introduced by Hakanson (1980), which quantitatively assesses the degree of contamination for individual heavy metals in soil. This factor is derived by dividing the average concentration of a metal detected in the soil by its respective background or natural baseline value. In the present study, soil samples (n = 20) collected from a depth of 15 cm were analyzed for

cadmium and lead content using ICP-OES. Due to the lack of locally available baseline data, internationally accepted average values were used as references—0.3 mg/kg for cadmium and 20 mg/kg for lead, as cited by Kabata-Pendias and Alloway. Based on these standards, the calculated CF values were 0.35 for cadmium and 0.12 for lead, both indicating low contamination levels (CF < 1). A detailed statistical summary of the elemental concentrations is shown in the subsequent tables.

Table 3: statistical summary of cadmium and lead concentration (15cm soil depth)

Element	Min (mg/kg)	Max (mg/kg)	Average (mg/kg)	Standard Deviation	Median
Cadmium	0.03	0.32	0.104	0.078	0.07
Lead	0.95	3.87	2.31	0.99	2.26

Table 4: Contamination Factor (CF) and pollution classification

Element	Mean Concentration (mg/kg)	Background Concentration (mg/kg)	Contamination Factor	Contamination Level
Cadmium	0.104	0.3	0.35	Low Contamination
Lead	2.31	20	0.12	Low Contamination

2. Grubbs Test

To identify any potential outliers in the dataset, Grubbs' test was applied. For a sample size of 20, the critical G value at a 95% confidence level is approximately 2.715, as referenced in Table 3. The calculated G values (G-calc) for

both cadmium and lead concentrations were compared against this threshold. Since none of the G-calc values exceeded the critical value, it was concluded that there were no significant outliers in the dataset for either metal.

Table 5: G- value of Grubbs test of both cadmium and lead

Sample	Cd (mg/kg)	G-calc Cd	Pb (mg/kg)	G-calc Pb
S1	0.18	0.799	3.64	1.403
S2	0.03	0.990	1.18	1.114
S3	0.12	0.083	3.54	1.301
S4	0.27	1.872	3.32	1.075
S5	0.32	2.468	3.67	1.434
S6	0.23	1.395	3.87	1.638
S7	0.21	1.157	2.41	0.144
S8	0.06	0.632	1.22	1.073
S9	0.07	0.513	0.95	1.350
S10	0.06	0.632	1.00	1.299
D1	0.08	0.394	2.14	0.132
D2	0.11	0.036	3.07	0.820
D3	0.05	0.751	2.36	0.093
D4	0.04	0.870	1.39	0.899
D5	0.05	0.751	1.33	0.961
D6	0.06	0.632	1.52	0.766
D7	0.07	0.513	1.68	0.603
D8	0.12	0.083	2.63	0.369
D9	0.05	0.751	2.26	0.009
D10	0.08	0.394	2.20	0.071

3. Correlation Matrix Analysis

To explore the relationship between cadmium (Cd) and lead (Pb) levels in the soil samples, a Pearson correlation analysis was carried out. The calculated correlation coefficient was 0.781, reflecting a strong positive association between the two elements. This indicates that

areas with higher cadmium concentrations tend to also have increased levels of lead. Such a correlation may suggest a common origin, possibly from human activities, or similar geochemical behavior influencing their presence in the soil. The correlation matrix is provided in Table 6.

Table 6: correlation matrix shows higher concentrations of cadmium are generally associated with higher levels of lead in the soil

	Cadmium (Cd)	Lead (Pb)
Cadmium (Cd)	1.000	0.781
Lead (Pb)	0.781	1.000

4. Boxplots and Histograms

Boxplots and histograms were created to assess the distribution and variability of cadmium (Cd) and lead (Pb)

concentrations in the 20 collected soil samples. The boxplots indicated that there were no statistical outliers in either dataset. Cadmium exhibited a slightly right-skewed distribution, with the majority of values falling below 0.15

mg/kg. Lead displayed a similar pattern, with concentrations mainly ranging between 1.0 and 3.0 mg/kg. The histogram results further supported a uniform distribution of the data,

implying a relatively consistent level of metal accumulation across the different sampling locations. Refer to Figures 2, 3, and 4 for visual representation.

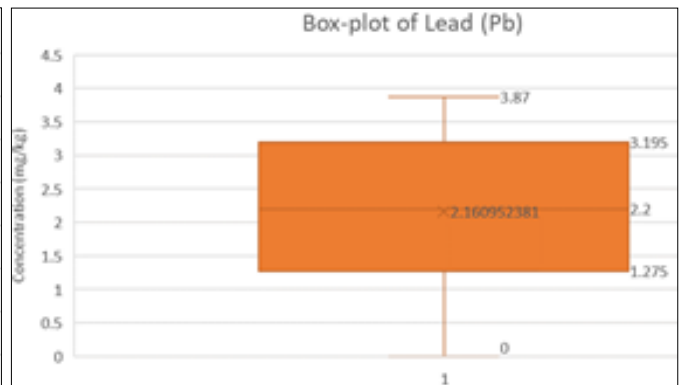
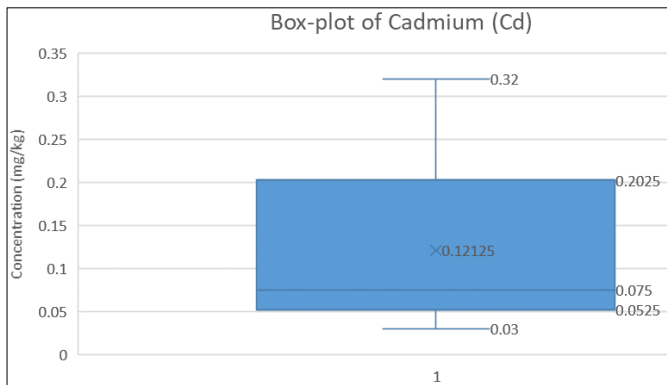


Fig 2: Boxplots representation of concentration of cadmium and Lead

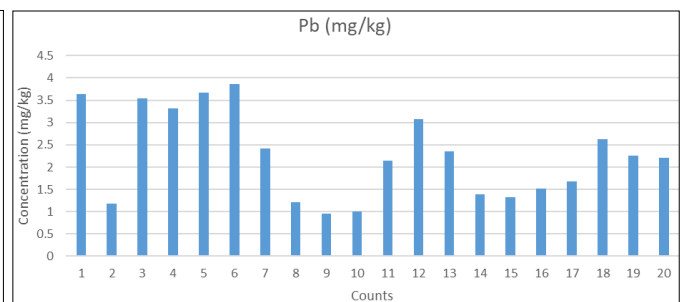
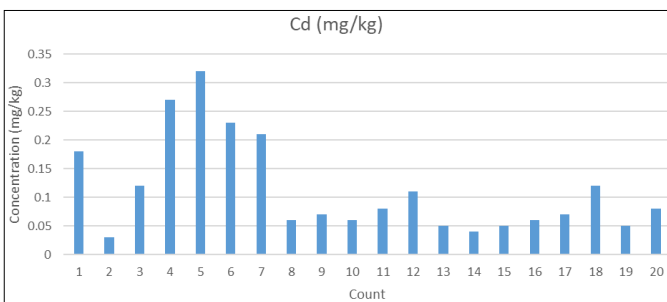


Fig 3: Histogram representation of concentration of Cadmium

Fig 4: Histogram representation of concentration of Lead (Pb)

Conclusion

This study investigated the contamination levels and statistical patterns of Cd and Pb in agricultural soils collected from a depth of 15 cm (6 inches) at 20 sampling sites within the rural regions of Nelamangala and Devanahalli in Bengaluru. Quantitative analysis of both metals was performed using Inductively Coupled Plasma–Optical Emission Spectroscopy (ICP-OES). Various statistical tools were applied to assess the data, including descriptive statistics, contamination factor (CF) evaluation, outlier detection, correlation analysis, and graphical methods for visual interpretation.

The statistical evaluation indicated that the concentrations of cadmium (Cd) and lead (Pb) may originate from similar sources or exhibit comparable geochemical characteristics within the study area. Graphical representations such as boxplots and histograms supported this observation by showing a relatively uniform data distribution, with minor skewness and no significant anomalies. In summary, the findings suggest that the soil samples from the investigated sites are not heavily contaminated with Cd and Pb. Both elements demonstrated stable spatial distribution patterns, offering a useful reference point for future environmental monitoring and risk assessments concerning heavy metal presence in agricultural zones adjacent to industrial activities.

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