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TRACE ELEMENT ANALYSIS OF SOIL USING PARTICLE INDUCED GAMMA RAY EMISSION (PIGE) TECHNIQUE

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Abstract

Background

In particular via the discharge of trace elements which could contaminate within close proximity soil, the automobile sector is a major contributor to environmental pollution. Using particle-induced gamma-ray emission (PIGE) technology, this study is determined to ascertain the trace element concentrations and their distribution in soils adjacent to an automotive sector.

Methods

Samples of soil were taken at various depths (0 cm and 20 cm) and distances (0 m, 50 m, and 100 m) from six sites surrounding an automobile manufacturing. Following air drying, sieving, and homogenization, the samples were subjected to PIGE analysis in order to identify and measure trace elements which found lead (Pb), zinc (Zn), copper (Cu), chromium (Cr), nickel (Ni), manganese (Mn), arsenic (As), cadmium (Cd), and mercury (Hg).

Results

The analysis revealed significant concentrations of heavy metals, including Pb, Zn, Cu, and Cr.; these concentrations were highest near the industrial site (0 m) and declined as one moved farther away from the source. These elements' concentrations were significantly greater at a depth of 20 cm than at the surface (0 cm), indicating vertical contamination. According to the statistics, industrial operations are a significant cause of soil contamination in the region, with levels of Zn and Pb ranging from 110 to 260 mg/kg and 90 to 190 mg/kg, respectively.

Conclusion

According to the findings, trace element contamination in soil samples located near the factory underscores the serious environmental hazards caused by emissions from the automobile industry.

Keywords: Particle Induced Gamma Ray Emission (PIGE) technology, Trace elements, Heavy metals, Gamma rays, High energy proton radiation.

INTRODUCTION

Significant influences that disrupt the biosphere include technological advancements and overuse of agricultural additives, such as pesticides and fertilizers (Aktar MW et al.,1). In addition, the plant waste in agricultural areas decomposes to release carbon dioxide gas and humic acids under high soil pressures, which dissolves in irrigation water to generate carbonic acid (Fan Yang et al., 2). These acids leach metals from soils, adding compounds to the ground water. As it occurs, overfarming is one of the primary causes ofpollution of groundwater and soil. One of the biggest risks to soil and water resources, as well as human health, is heavy metal poisoning of the soil. (Sunil Kumar et al., 3). In a number of fields of study, including biology, geology, and environmental science, material science,and trace element analysis is essential (Terzano R et al., 4). The precise measurement of trace elements in materials offers important information about a variety of processes, from geological formation characterization to environmental contamination (María Fernanda et al., 5). Ion-atom interaction techniques have emerged as one of the most successful analytical approaches for trace element analysis because of its sensitivity, selectivity, and non-destructive nature (Chandrashekhar et al., 6). Soil pollution, which has a significant effect on all living things on Earth, is caused by human activities including mining, industrial waste, and the use of pesticides and fertilizers (ManpreetKaur et al., 7).Several trace elements can be detected in soils at concentrations ranging from tenths of parts per million to parts per billion (Bañuelos et al., 8). Since heavier elements like 33As, 48Cd, 82Pb, and 80Hg are extremely hazardous to individual health even at trace levels, it is imperative that we have analytical methods that allow us to quickly determine the metal contents of mineral wastes and that are also highly sensitive (Jessica Briffa et al., 9). Numerous analytical techniques for the quantitative elemental analysis of geological, biological, and environmental samples have been developed from this perspective (Fayyaz, Amir et al., 10). This has made it hard to decide on the most effective method for a particular analytical problem. (Sunil Kumar et al., 3).Additionally, the magnitude and seriousness of trace element contamination of soils and water due to the industrial andThe health of people, crops, and wildlife may be negatively impacted by these fabricated additions of trace elements to the soil environment (David Purves et al., 11)(Ding Z et al., 12).It is crucial for this reason to quantitatively characterize the air, water, soil, and vegetation. Elemental analysis can be used to determine the elemental or even sample's isotope makeup of materials (such as soil, drinking water, human fluids, minerals, or chemical compounds) (Kaur et al., 13) (Rahman et

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al., 14).The ion-beam analytical method known as particle-induced gamma ray emission, or PIGE, makes use of the fast gamma rays produced by the target material during nuclear processes that are initiated by the arriving ion. Examples of its use in the realm of energy-related materials include the examination of fission and, more recently, fusion reaction materials and the investigation of battery electrolytes. (Alessandro et al., 15) (CorneliuSarbu et al., 16).For environmental monitoring along with medical risk assessment, accurate trace component identification in earth is essential (MaziarMohammadi et al., 17). The Particle-Induced Gamma-Ray Emission (PIGE) method, a potent analytical tool for simultaneous multi-element analysis, was thus employed in this investigation.

METHODOLOGY

The key objective of this study is to analyze the amount of trace elements in soil samples taken at various depths and locations adjacent to an automobile factory using the PIGE technology. The soil samples underwent analysis to determine the possible levels of pollution brought on by emissions from the automotive industry as well as to analyze and measure the presence of trace elements. The comprehensive process for gathering, preparing, and analyzing samples is described here.

Sample collection

Samples of soil will be obtained in six different places throughout the automobile sector. In order to evaluate depth and spatial changes in trace element concentrations, these sites will comprise both surface and subsurface samples at different distances from the industrial site. At the location (0 m distant) – Surface (0 cm below the surface) (sample 1): Direct collection of the first batch of soil samples will take place at the industrial site. The surface, which is the region most likely to be impacted by direct emissions from the industry, will be the source of these samples.At the location (0 m away) to a depth of up to 20 cm (sample 2): A second set of samples will be taken from the same location (0 m distant) but at a depth of up to 20 cm in order to determine how trace elements might have entered the soil profile. The surface (0 cm depth) (sample 3) is 50 m away from the location. A third set of samples will be taken from the surface layer 50 meters away in order to calculate the distance that pollutants have traveled from the industrial site.At 50 meters from the site—up to 20 cm depth (sample 4): To ascertain the vertical spread of contaminants, soil will be gathered 50 meters from the site, but this time from a depth of 20 cm. At 100 meters from the site - Surface (0 cm depth) (sample 5): To assist in assess the level of pollution further away from the industrial source, the fifth set of samples will be collected from the surface at a distance of 100 meters from the site.

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To gain more information about the depth profile of pollution, the last set of samples will be collected at a 20 cm depth at a distance of 100 meters from the industrial site.

Sample preparation

The samples will be prepared for analysis after they are gathered. To ensure that the samples are stable for the following procedures, they are allowed to air dry at room temperature for 24 to 48 hours. After drying, the soils were sieved through a 2 mm mesh sieve to produce a more homogeneous sample for examination. To make sure the entire sample is uniform and typical of the original collecting site, the sieved soil will thereafter be homogenized. After that, tiny samples of the soil will be meticulously weighed and ready for PIGE analysis. The dirt will usually be compressed into a thin layer or pellet that can be exposed to high-energy proton radiation.Every sample will be tagged with the specifics of its collection, such as the depth and position (distance from the site).

Analyzing using PIGE technique

Trace elements in the soil samples were found and measured using the PIGE. By exposing soil samples to high-energy protons, typical between 2 to 5 MeV, the PIGE technique generates gamma-ray emissions from the elements contained in the sample. The high-energy protons are produced using a particle accelerator, typically a cyclotron. A high-resolution gamma spectrometer is used to detect the gamma-ray emissions produced from directing these protons onto the soil sample. The kind and concentration of elements in the soil determine the gamma rays' energy and intensity. To ensure the exactitude of the measurements, calibration standards with established concentrations of these components are employed. The peaks that correspond to particular elements are identified by analyzing the gamma-ray spectra that were acquired from the analysis. The concentration of each element in the sample is shown by the intensity of each peak.

RESULTS

Elevated quantities of heavy metals in the ground near manufacturing areas pose a major threat to human health and the environment.In order to assess the pollution levels, this study used particle-induced gamma-ray emission (PIGE) technology to analyze soil samples from an automotive industry site. Among the significant trace elements discovered and analyzed were mercury (Hg), manganese (Mn), arsenic (As), cadmium (Cd), zincs (Zn), copper (Cu), nickel (Ni), chromium (Cr), lead (Pb), and manganese (As).

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Data Analysis

Following the quantification of the trace elements, the data are examined to evaluate the pollutants' vertical and spatial distribution. Each trace element's concentration is compared at various sampling depths and locations. In particular, to ascertain whether and the manner in which pollutants have permeated the soil profile, the concentrations of the elements at the surface and at a depth of 20 cm are compared.

Table 1: Elemental Concentration Profile: PIGE Analysis

Sample ID	Distance (m)	Depth (cm)	Cr (mg/Kg)	Cu (mg/kg)	Zn (mg/kg)	Pb (mg/kg)	Ni (mg/kg)	Mn (mg/kg)	As (mg/kg)	Cd (mg/kg)	Hg (mg/kg)
S1	0	0	115	60	210	160	40	510	4	1	1
S2	0	20	145	70	260	190	50	620	5	2	1.5
S3	50	0	70	40	160	110	30	310	3	1.5	0.8
S4	50	20	103	50	190	130	40	430	5	2.5	1.2
S5	100	0	70	30	110	90	20	200	2	1	0.6
S6	100	20	90	40	130	110	25	310	3	2	1

Using the PIGE technology, the amounts of trace elements in soil samples taken close to auto factories are shown in Table 1. Samples S1–S6 were obtained at 0 and 100 meters distant and at depths of 0 to 20 cm. The ranges for lead, zinc, copper, and chromium were 90–190 mg/kg, 110–260 mg/kg, 30–70 mg/kg, and 70–145 mg/kg, respectively. The amounts of nickel, manganese, arsenic, cadmium, and mercury varied from 20 mg/kg to 50 mg/kg, 200 mg/kg to 620 mg/kg, and 1 mg/kg to 2.5 mg/kg, respectively. The environmental impact of industrial activities and the necessity of continuous monitoring and possible remediation efforts are highlighted by these results, which show notable changes depending on depth and distance.

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Table 2: Concentration of Trace Elements by Spatial Distribution

Distance (m)	Cr (mg/Kg)	Cu (mg/kg)	Zn (mg/kg)	Pb (mg/kg)	Ni (mg/kg)	Mn (mg/kg)	As (mg/kg)	Cd (mg/kg)	Hg (mg/kg)
0	115	60	210	160	40	510	4	1	1
0	145	70	260	190	50	620	5	2	1.5
50	70	40	160	110	30	310	3	1.5	0.8
50	103	50	190	130	40	430	5	2.5	1.2
100	70	30	110	90	20	200	2	1	0.6
100	90	40	130	110	25	310	3	2	1

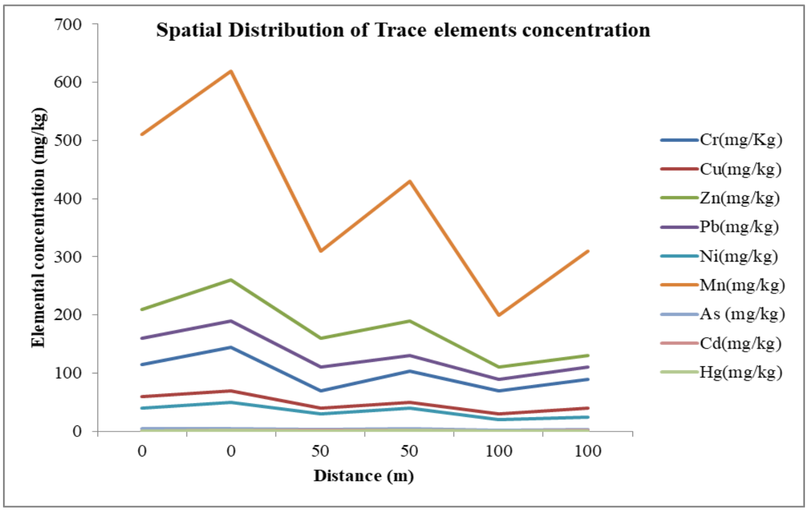

Figure 1:Concentration of Trace Elements by Spatial Distribution

The levels of trace components in soil samples collected around auto factories are spatially well dispersed, as indicated by the data in Table 2 and Figure 3. Chromium (Cr), copper (Cu), zinc (Zn), lead (Pb), nickel (Ni), manganese (Mn), arsenic (As), cadmium (Cd), and mercury (Hg) concentrations are listed according to distance (0, 50, and 100 meters). Pb ranges from 90 mg/kg to 190 mg/kg, Zn from 110 mg/kg to 260 mg/kg, Cu from 30 mg/kg to 70 mg/kg, and Cr from 70 mg/kg to 145 mg/kg. The possible effects of industrial operations on the environment are highlighted by the fluctuations observed in other elements such as Ni, Mn, As, Cd, and Hg.The concentrations of trace elements, especially lead, zinc, copper, and chromium, are higher at a distance of 0 meters from the industries than at a distance of 50 and 100 meters. This implies a major contribution of industrial activity to soil contamination.

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Table 3: Distribution of trace element concentrations by depth

Depth (cm)	Cr (mg/Kg)	Cu (mg/kg)	Zn (mg/kg)	Pb (mg/kg)	Ni (mg/kg)	Mn (mg/kg)	As (mg/kg)	Cd (mg/kg)	Hg (mg/kg)
0	115	60	210	160	40	510	4	1	1
20	145	70	260	190	50	620	5	2	1.5
0	70	40	160	110	30	310	3	1.5	0.8
20	103	50	190	130	40	430	5	2.5	1.2
0	70	30	110	90	20	200	2	1	0.6
20	90	40	130	110	25	310	3	2	1

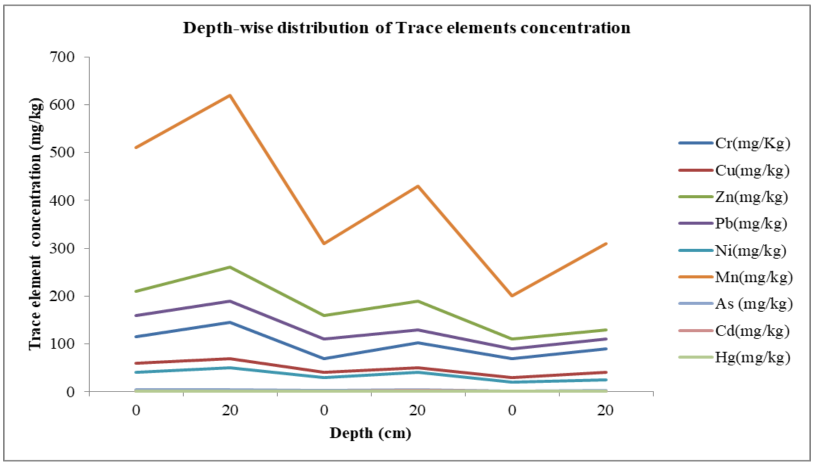

Figure 2: Distribution of trace element concentrations by depth

This table 3 and Figure 2 shows the trace element concentrations in soil samples that were took at two different depths (0 cm and 20 cm) were taken near to automobile industries and examined using the PIGE method.

Significant outcomes indicate that concentrations of certain elements, that as lead (up to 190 mg/kg) and chromium (up to 145 mg/kg), are often higher at a depth of 20 cm than they are at the surface samples at 0 cm. This pattern points to possible long-term contamination issues since trace contaminants may gradually seep deeper into the soil profile.

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Table 4: Comparative Analysis of Element concentration across samples

Sample ID	Cr (mg/Kg)	Cu (mg/kg)	Zn (mg/kg)	Pb (mg/kg)	Ni (mg/kg)	Mn (mg/kg)	As (mg/kg)	Cd (mg/kg)	Hg (mg/kg)
S1	115	60	210	160	40	510	4	1	1
S2	145	70	260	190	50	620	5	2	1.5
S3	70	40	160	110	30	310	3	1.5	0.8
S4	103	50	190	130	40	430	5	2.5	1.2
S5	70	30	110	90	20	200	2	1	0.6
S6	90	40	130	110	25	310	3	2	1

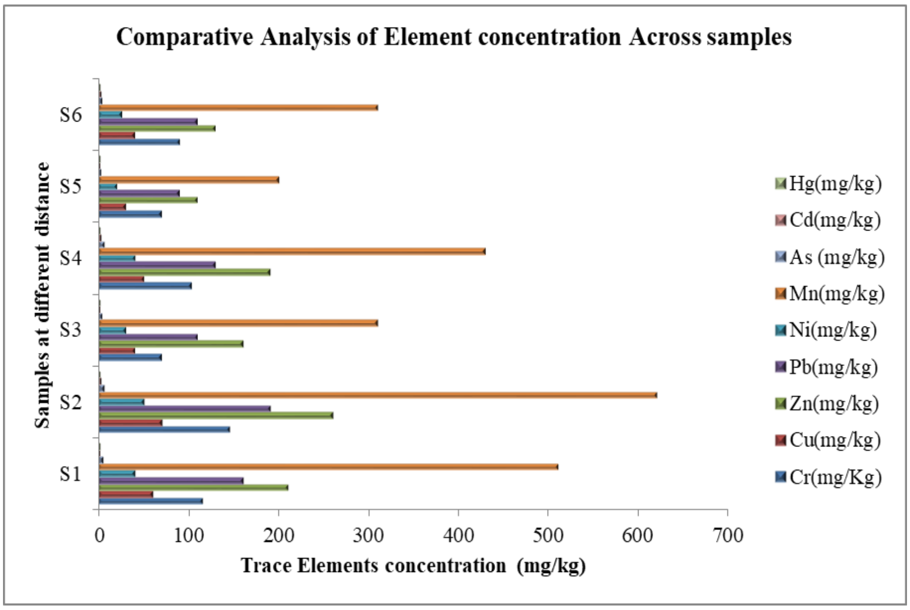

Figure 3:Comparative Analysis of Element concentration across samples

The trace element concentrations in soil samples (S1 through S6) were examined using the PIGE technique are compared in this table. Significant differences in concentrations between the samples are shown by the data. The sample S5 has the lowest quantities of most elements, whereas sample S2 has the greatest levels of chromium (145 mg/kg), copper (70 mg/kg), and zinc (260 mg/kg). Significant contamination risks are indicated by lead values ranging from 90 mg/kg in S5 to 190 mg/kg in S2. S1 has the greatest manganese levels (510 mg/kg), whereas S5 has the lowest (200 mg/kg), demonstrating the variation in soil composition.Significant differences in levels of key components in each sample are shown by the comparative analysis. The amounts in Sample S2 are

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consistently the greatest, suggesting that greater contamination is correlated with proximity to industrial operations.

DISCUSSION

The current study highlighted possible health and environmental hazards by finding increased levels of trace elements close to the automobile industry. According to **Kamal Fatmawati et al. (2007) (18)**, these findings are consistent with the study that identified untreated tannery effluent as the primary cause of element concentration contamination in the soil then sediment of Hazaribagh. The study emphasizes the significance tannery emissions are in raising dangerously high levels of heavy metals.According to **Isioma E. Arinze et al. (2015) (19)**,The following heavy elements were found in the automobile waste markets' soil: Fe, Zn, Cu, Mn, Cr, Ni, and Pb. This resides trace elements found in our study.Moreover**, M. Casetta (2024)(20)**In a highly industrialized urban area of France, this study found that Cr, Ni, and Mo are important indicators of soil contamination by industrial particles. Deposition of industrial dust impacted every zone under study, and the concentrations varied according to the quality of the soil. A major contributing component was soil exposure to wind-borne dust fallout, not just proximity to emission sources.The industrial operations at Tharsis, Ríotinto, and Huelva generate trace element-rich slag particles, which restrict environmental dispersion, according to a study by **Chopin, E. I. (2024) (21).** Slag and waste deposits have higher concentrations, while larger regions are largely unaffected. And also the states that the Environmental dangers can be decrease using targeted waste management techniques.According to a **2019 study by A. R. Justino et al.,(22)** industrial sources of iron and steel are the main causes of settled dust pollution. It presents hazards to individuals as well as the surroundings..They claimed that the targeted monitoring is required due to elevated Fe, Cr, and Mn levels associated with adjacent industrial activity. They suggested, limiting population exposure and adhering to national legislation, effective solutions are essential. In order to safeguard public health, sustainable environmental management is crucial.**MumtazOswal's (2010) (23)** research study Among the 20 elements found in soil samples taken from mining regions were the hazardous V, Cr, As, and Pb. Traces of lead had a minor impact on the surrounding surroundings, while residual mining products had higher quantities of these harmful elements. In remote places, there was no contamination. The most severe pollution, according to **Tingting Liu et al. (2024) (24)**, is As and Cd, which received a rating of 6 levels, falling into the category of incredibly potent pollutants. Near anJiaxing, Pb, Cu, and Zn are discovered at levels 3, 4, and 3.The Chinese mainland, auto manufacturer. Similarly As was present in our samples on analysis.**Pandion et al. 2023 (25),** found as soil depth increases,

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pollution reduces, possibly as a result of soil particle adsorption and diffusion.According to **Waqar Ahmad et al. (2021) (26),** metals found in soil and water present adults and children in the industrial city of Sialkot with very low non-carcinogenic and carcinogenic dangers.**PhilomeneNyiramigisha et al., 2021 (27),**to reduce elevated pollution levels, regular monitoring and awareness are required to ensure that garbage is separated before dumping.**A K Priya et al., 2023 (28),** says the efficient treatment of heavy metal contamination can also be aided by combining other remediation techniques, such as soil amendment and phytoremediation.

CONCLUSION

The study emphasizes the serious environmental issues associated with heavy metal pollution in the soils around automobile industries. Alarming levels of dangerous trace elements, like lead, chromium, and zinc, were found by analysis utilizing particle-induced gamma-ray emission (PIGE) technology, especially in samples taken at depths of 0 to 20 cm and nearer industrial areas.Significant heavy metal pollution, including Pb, Zn, Cu, Cr, Ni, Mn, As, Cd, and Hg, was found in soil samples taken nearby to an automobile manufacturing site using PIGE analysis. These elements' concentrations declined as one got more distant from the factory, suggesting that industrial activity is the main cause of pollution. Higher quantities of some elements, including Pb and Cr, were found at 20 cm depth, according to depth-wise study, which may indicate long-term contamination issues. These results emphasize the necessity of on-going observation and clean-up initiatives to lessen the risks to the environment and human health posed by industrial operations.In order to address the environmental risks caused by industrial emissions and to protect public health, these findings highlight the urgent necessity for on-going monitoring and possible remediation initiatives. All things considered, this study sheds important light concerning the way the operations of the automotive sector affect the environment and underlines the need for strong legislative actions to reduce soil pollution. And also this study suggests further research needed in different locations of automobile industry.

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Declaration of interests

- ⊕ The authors declare that they have no known competing financial interests or personal relationships that could have appeared to influence the work reported in this paper.
- ⊕ The authors declare the following financial interests/personal relationships which may be considered as potential competing interests