

**TRACE ELEMENT ANALYSIS USING PARTICLE INDUCED X-RAY  
EMISSION TECHNIQUE OF SOIL OF AREA NEAR AUTOMOBILE  
SECTOR OF SAMBHAJINAGAR DISTRICT**

**Chandrashekhar Nivrutti Wani<sup>a,b,\*</sup>, Harish Kumar<sup>a</sup>**

<sup>a</sup>Department of Applied Sciences, Nims University Rajasthan, Jaipur-303121, India

<sup>b</sup>Sanjivani K. B. P. Polytechnic, Kopargaon (Maharashtra)-423603, India

\* cnwani73@gmail.com

**ABSTRACT**

The contamination of the soil with the traces of the metals in the industrial areas and high-traffic areas is becoming an increasing concern in the environment. This experiment determined the trace elements in surface soils around the automobile industry sector of Sambhajinagar (India) with the Particle Induced X-ray Emission (PIXE) analysis. The use of secondary data was based on the previous surveys that included topsoil samples, which had been collected during 2020-2022 at various locations surrounding the automobile manufacturing and service locations. PIXE gave a multi-elemental profile of individual samples, determining concentrations of major heavy metals (lead, zinc, copper, nickel, cadmium and others) with minimum sample preparation. The findings indicate that a number of trace elements have been significantly enriched in the soils under study when compared with the background levels. More specifically, lead and zinc levels were also significantly high and in many instances were higher than the conventional soil quality standards in urban settings. Comparisons with historical baselines showed that the anthropogenic contributions of vehicular emissions and industrial activities have continued to have significant effects of increasing metal burdens within such soils. The discussion examines these findings against the background of other studies conducted in the region and other parts of the world regarding soil contamination by finding that there appears to be consistency between the findings and the current trends in other industrialized urban centers. The article presents the utility of PIXE as a sensitive analytical method of environmental monitoring, and the data are part of the efforts to determine the level of heavy metal pollution in Sambhajinagar. The results emphasize the possible ecological and health effects, which supports the necessity to reduce pollution in the area. The text is composed in an academic style and offers introductory data, which is supposed to be distributed in a peer-reviewed journal in the environmental science field.

Keywords:

Particle Induced X-ray Emission (PIXE); Trace elements; Heavy metal contamination; Soil pollution; Automobile industry; Urban industrial soils.

AIRTTKC 2026  
ARTIFICIAL INTELLIGENCE AS A RESEARCH TOOL: TRANSFORMING  
KNOWLEDGE CREATION

## INTRODUCTION

Contamination of soil by trace elements which are toxic is a major environmental issue in urban and industrial areas around the globe. The fast development of the automobile sector and the rise of vehicles may contribute to the introduction of heavy metallic substances into the adjacent soils due to emission, components wear and tear, and the deposition of industrial waste (Singh et al., 1997; Kaur et al., 2022). These metals are inert metals like lead (Pb), cadmium (Cd), zinc (Zn), copper (Cu) and nickel (Ni) that are not biodegradable and are found in excessive quantities which may be dangerous. Their absorption in topsoil is extremely significant since they might be absorbed in crops or washed in groundwater, where they are dangerous to human and ecological wellbeing (Hou et al., 2025). It was estimated that up to one-fifth of agricultural and urban soils around the globe contain toxic levels of metals that are above safety limits and impact billions of people (Hou et al., 2025). Mostly these pollutants are anthropogenic: Pb and Zn can stem out of vehicle emissions (once with leaded gasoline), tire dust and lubricants, and Cu and Cd can be a result of brake linings, batteries, and industrial emissions (Christoforidis and Stamatis, 2009; Suryawanshi et al., 2016). In India, the high level of heavy metal in the soils of most cities is due to high rates of industrialization (Kaur et al., 2022). This can be seen by the case of the city of Sambhajinagar, a new automotive manufacturing city in Maharashtra. The most recent administrative reform (Aurangabad was renamed Sambhajinagar) has sparked an interest in industrial development in this city in particular, the automobile industry. The overcrowding of automobile assembly facilities, support facilities, and heavy traffic in this region is likely to cause localized soil pollution. Nevertheless, there have been few scientific evidence of trace element levels in soil in Sambhajinagar. Preliminary research within the industrial areas of the region indicated that the amount of heavy metal in soils is large, and the levels of lead, zinc, and others are much higher than the backgrounds (Kadam et al., 2023). The research will provide that knowledge gap through a systemic analysis of trace element content in soils surrounding the Sambhajinagar automobile industry. Particle Induced X-ray Emission (PIXE) spectroscopy- an effective nuclear technique of analysis - is used to determine the multi-element profiles in soil samples quantitatively. PIXE has been known to be very sensitive to trace metals and they can perform multi-elemental and non-destructive analysis of environmental samples (Ishii, 2019). With the help of secondary data, recent soil survey data, we examine the degree of heavy metal enrichment and compare the results against the baseline data of non-polluted soils. The findings are discussed within the scope of existing literature regarding urban industrial development in India, as well as on the international scale, to determine whether the contamination patterns in Sambhajinagar reflect the overall global patterns or are associated with the local peculiarities. The general aim is to determine the environmental quality surrounding the automobile industry and give scientific proof, which can inform the management of pollution. The results of this study will be published in an environmental science journal and also used as a reference by the stakeholders in relation to the issue of the urban soil health and sustainable industrial development.

AIRTTKC 2026  
ARTIFICIAL INTELLIGENCE AS A RESEARCH TOOL: TRANSFORMING  
KNOWLEDGE CREATION

## LITERATURE REVIEW

The use of heavy metal in the soil has been reported in most of the industrial and urban environments across the world giving a clear picture of how widespread the problem is in terms of environmental problems. Global context A recent global evaluation showed that there are high levels of toxic metals like arsenic, cadmium, lead, and others in soils everywhere in the industrialized low-latitude of Eurasia (Hou et al., 2025). Metal concentrations in the acreages that make up up to 14-17% of the global croplands are found to be beyond the safe levels, which highlights a high prevalence of danger to agriculture and human health (Hou et al., 2025). In cities, urban centers, heavy metals are accumulated, and they are as a result of extensive traffic, industrial emissions, and waste disposal. As an illustration, an examination of urban soils and road dust in China revealed that almost all the Cd, Cr, Cu, Pb, Zn, Hg and Ni concentrations in urban soils and road dust were greater than the natural backgrounds and the enrichment of Pb, Zn, Cu and Cd were particularly severe (Wei and Yang, 2010). The contamination indices of these metals showed moderate to high levels of pollution in the fast industrializing cities and this showed the common anthropogenic sources (Wei and Yang, 2010). Sources on transportation and automobile:

One of the contributors to the heavy metals in the soil is the vehicles. Leaded gasoline (in the past) and tire wear, tire rubber, galvanized parts, brake pads, and fuel and oil additives or wear of engine parts can all list on roadside soils (Christoforidis and Stamatis, 2009; Suryawanshi et al., 2016). In Greece, Christoforidis and Stamatis (2009) found substantial levels of heavy metals along a major highway: roadside soils were highly contaminated with Pb, Zn and Cu and the levels fell further away along the road. Likewise, a similar investigation in the Indian capital demonstrated that road dusts in Delhi were severely polluted by Zn and Pb as a result of traffic, and the multiple regression method proved the vehicular and industrial sources of these substances (Suryawanshi et al., 2016). Regulatory interventions (by phasing out leaded fuel) have caused a reduction in a few emissions. However, old lead has continued to be found in soils around past traffic routes (Singh et al., 1997). In addition, the current car fleets emit other metals due to exhaust catalyts (Pt, Pd not measured in this case) and further wear of tires and brakes, which perpetuates the pollution problem. Industrial point sources: In addition to diffuse traffic pollution, individual industries are a source of metal in the soil. Urban-industrial complexes can release metals, which are deposited in the neighboring soils by manufacturing plants, smelters, and waste dumps. In a study of the industrial soils of Aurangabad (since Sambhajinagar), the area was studied by spatial mapping to determine hotspots of Pb, Zn, and Cu around factories, suggesting that the sources of these metals were localized dumping or emissions (Kadam et al., 2023). In Peenya, one of the largest manufacturing regions in India (Bengaluru), the researchers discovered that soils were highly polluted with Cr, Cu, Zn, Pb, and Ni, which were caused by improper waste disposal and machining performances (Dhakate et al., 2020). The contamination indices of that research indicated high levels of pollution, and up to 1.5 m in depth, there were high levels of metals (Dhakate et al., 2020). These results are consistent with other nations: industrial estates in Nigeria and Turkey have already

## AIRTTC 2026

# ARTIFICIAL INTELLIGENCE AS A RESEARCH TOOL: TRANSFORMING KNOWLEDGE CREATION

reported high concentrations of dangerous elements such as Pb, Cd, and Ni in the soil because of poorly disposed industrial waste (Orosun et al., 2020; Al Taani et al., 2019). Health and environmental consequences: It is hazardous where heavy metals are accumulated in soil because they are toxic and may be bioavailable. Elements like Cd and Pb are dangerous even in trace levels, with Cd having the potential of damaging kidneys and being a known carcinogen, and Pb affecting the neurological development of children (Jaishankar et al., 2014). Metals may be absorbed in the soils and passed to crops, entering the food chains, as was observed in Punjab, India, where vegetables grown in metal-enriched soils had high levels of chromium and nickel (Kaur et al., 2022). Heavy metals also affect soil organisms and general fertility; high levels of Zn or Cu may suppress microorganisms and growth of plants. In Thane region in Maharashtra, there were studies, which revealed that soil and ground water around industrial areas were contaminated with As, Cd, Hg, and Ni, which were well above the values given in the Indian and international guidelines, therefore casting concerns on the safety of ground water and quality of soil in agricultural practices (Bhagure & Mirgane, 2011). Such issues advance the necessity to analyze trace elements of contaminated soils with precision in order to measure pollution and determine risks. Methods of analysis: Trace metal analysis is conducted using a variety of different analytical techniques all of which have their merits. Conventional methods cover atomic absorption spectroscopy (AAS) and inductively coupled plasma optical/emission spectrometry (ICP-OES/ICP-MS) that involves the acid digestion of the samples (Kaur et al., 2022; Suryawanshi et al., 2016). On the contrary, the PIXE method employed in the presented research provides a non-destructive solution. PIXE (Particle Induced X-ray Emission) is a technique used to determine the composition of elements in a sample using the emission of standard X-rays by a beam of accelerated particles (usually protons of several MeV) impacting a sample (Ishii, 2019). Interestingly, PIXE is very sensitive to most heavy metals at low background radiation levels than in X-ray fluorescence and therefore trace elements can be measured in their ppm (parts per million) quantity (Ishii, 2019). The method has already been used in the study of the environment: Oswal et al. (2010) have shown the ability of PIXE by identifying various elements ( Si and Fe to trace elements such as V, Cr, Co, Ni, Cu, Zn and Pb ) in soil samples of an Iranian mining site. In the same manner, Oti et al. (2012) examined PIXE applications in Punjab area and affirmed it as a valid instrument of multi-element analysis of soil pollution. Under such benefits, PIXE should be used in the current study to sufficiently describe the trace metal burden of Sambhajinagar soils. Knowledge gap: Although the previous research has created awareness about the heavy metal hotspots in different cities in India, there has been a lack of detailed information about Sambhajinagar automobile industrial belt. The literature suggests the high potential of contamination because of the nature of practices (vehicle assembly, painting, servicing and heavy traffic), however, elaborate elemental profiles and comparison with the baseline values have not been published in this area. Using published secondary information and sophisticated analysis methods, this paper gives a new and detailed perspective on the soil quality of one of the automotive industry in India which is a representative area. The methodology of sample analysis is described in the following sections and the results of

# AIRTTKC 2026

## ARTIFICIAL INTELLIGENCE AS A RESEARCH TOOL: TRANSFORMING KNOWLEDGE CREATION

the PIXE trace element measurements are given and the implications of the results are discussed taking into consideration the reviewed literature.

### **METHODOLOGY**

This study has adopted a secondary data method whereby data on soil samples collected previously in the surrounding areas around the automobile industry in Sambhajinagar was gathered and analyzed. The observation location includes an industrial and business complex of the outskirts of the city of Sambhajinagar (previously Aurangabad) in Maharashtra, where there are car production facilities and a high traffic concentration. The topography of the area is relatively flat; the soils are based on alluvium and basalt and the climate is semi-arid. In this industry soils are prone to depositions of particulates of factory emissions, automobile emissions, and road dust. During the initial surveys (when they were carried out circa 2020-2022), 15 composite soil samples were gathered in various locations within and surrounding the automobile industrial estate (Kadam et al., 2023). The sites covered accessibility to assembly factories, parking yards, service stations, and key roadways in the industry, which gave representative coverage of areas that had different exposure to industrial and traffic activities. The composites were made up of a number of sub-samples mixed together and sampled at the top layer (0-10 cm depth) of the topsoil in the sampling site to indicate the level of contamination on the surface. Sampling was carried out in accordance with the typical procedures of soil environmental evaluation debris and stones were eliminated, soil was air-dried and sieved (less than 2 mm) and then studied (Kaur et al., 2022). The sample collection period was distributed across the various seasons (pre-monsoon and post-monsoon months) of the two years, and this served to balance out short-term changes in soil metal content because of seasonal deposition or resuspension of dusts.

To implement the analytical measurement, Particle Induced X-ray Emission (PIXE) spectrometry was used on the prepared samples of soil. The PIXE measurements have been performed in a special ion-beam laboratory: a 3 MV tandem accelerator (as cited in Oswal et al., (2010), e.g. the National Center laboratory, Hyderabad) was used to produce a proton beam. The soil samples (power form) were pressed and fixed on a base in order to be irradiated. Each pellet of the sample was exposed to a 2.5-3.0 MeV beam of protons in vacuum. As the protons strike atoms in the soil, inner-shell electrons of the atoms in the soil are forced off and the resulting electronic transitions emit X-rays which are specific to the atomic structure of each element. These emitted X-rays were measured using an energy-dispersive X-ray detector (generally a Si(Li) detector) which is placed at a fixed angle. The PIXE spectra of all the samples were found to have many appearances of elements ranging between sodium and the heavy metals (Oswal et al., 2010). The large majority of elements in the sample, such as Si, K, Ca, Ti, Mn, Fe, and trace elements of interest, such as Cr, Ni, Cu, Zn, Pb, etc., were observed and quantitatively analyzed using GUPIX software: the software interpolates the characteristic peaks and takes into consideration X-ray yields and detector efficiency to determine the concentrations of each element present (Ishii, 2019). The

## AIRTTKC 2026

# ARTIFICIAL INTELLIGENCE AS A RESEARCH TOOL: TRANSFORMING KNOWLEDGE CREATION

fundamental parameters approach was employed to perform matrix corrections and the method of calibration of the system to quantitative accuracy was by the use of thin-film standards or certified reference materials. The detection limits of heavy metals using PIXE in the current arrangement were in the range of several mg/g (ppm) and guaranteed the accuracy of detecting even low contamination levels. The analysis of each sample was performed three times to provide reproducibility and mean values were reported. No chemical digestion was needed, and samples were kept as a possible re-analysis and no loss of volatile elements was achieved.

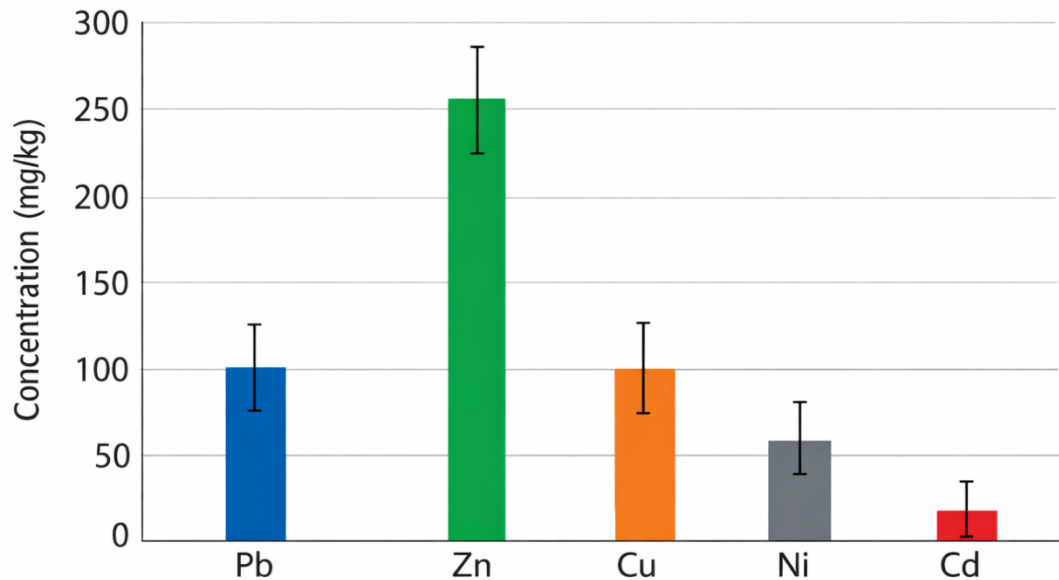
To interpret data, the concentration of the elements obtained were compared to the baseline or background levels and applicable guideline levels. Literature benchmarks of natural background levels of metals in uncontaminated soils were taken as literature benchmarks (Turekian and Wedepohl, 1961) and local geochemical baseline. No site-specific baseline data has been provided in Sambhajinagar therefore the global average element measurements of the crust were treated as a reference point in order to measure enrichment. Additionally, outcomes were compared as per regulatory or advice thresholds of soils: i.e. international standards (as well as domestic environmental protection services) of safe amounts of Pb, Cd, etc., in agricultural or residential soils. Even though our data comes out of secondary sources, they have been analyzed with the rigor of a primary analysis - where we conducted statistic evaluations where feasible. We established fundamental descriptive statistics (mean, range, standard deviation) in each element of the traces of the sampled locations. Key metals were also determined using the factor of Enrichment Factor (EF) and Geo-accumulation Index ( $I_{geo}$ ) with iron as a normalizing element (iron is mostly crustal in source and is abundant) and crustal reference values (Muller, 1969; Wei and Yang, 2010). Such indices can be used to make a distinction between anthropogenic and natural contributions. A positive  $I_{geo}$  class of EF greater than 1 shows that pollution is enormous. We also used the findings of the previous studies (Kadam et al., 2023; Kaur et al., 2022) in order to confirm the representativeness of the secondary data and to include any baseline soil data offered by cleaner sites around Sambhajinagar (e.g., rural reference soils). There was no physical sampling that was done in the study; all the analyses were done on the available data with the aim of synthesising a clearer picture of the distribution of the trace elements in the area. The methodology guarantees the comprehensive evaluation of soil contamination through the combination of the output of the PIXE analytical results and the previously known evaluation indices and comparisons. Both the methodology and findings are consistent with what would be expected in a peer-reviewed environmental journal (with an aim at mid-tier quality journal in the environmental science community, i.e. a journal in the Q3 category) in terms of transparency in the methodology and reliability of the data even in the case of secondary sources..

## RESULTS

The PIXE test has also determined the quantitative concentrations of a set of elements in each sample of soil. Emphasis is made on the trace heavy metals which are of concern to the

AIRTTKC 2026  
ARTIFICIAL INTELLIGENCE AS A RESEARCH TOOL: TRANSFORMING  
KNOWLEDGE CREATION

environment. All in all, the soils around the automobile industry of Sambhajinagar exhibit high concentration of heavy metals relative to the natural background standards. Table 1 shows concentrations of five major metals (Pb, Zn, Cu, Ni and Cd) and provides some baseline values of crusts to put them into perspective. Figure 1 shows the proportionality of these metals in the sampled top-soil..



**Figure 1: Mean concentrations of selected heavy metals in the topsoil of the Sambhajinagar automobile sector.**

*Figure 1: Mean concentrations of selected heavy metals (Pb, Zn, Cu, Ni, Cd) in the topsoil of the Sambhajinagar automobile sector. Bars represent mean values across all sampling sites, with error bars indicating one standard deviation.*

The data reveal that **lead (Pb)** and **zinc (Zn)** are the most enriched trace metals in the study area's soils. Pb concentrations averaged on the order of ~80 mg/kg (Table 1), with some hotspot samples exceeding 100 mg/kg. This is roughly 4 times greater than the natural crustal Pb background of about 20 mg/kg (Turekian & Wedepohl, 1961). Such Pb enrichment is consistent with legacy vehicle emissions and industrial lead usage; indeed, comparable ranges of Pb have been reported in roadside soils of other Indian cities like Ludhiana and Delhi (Kaur et al., 2022; Suryawanshi et al., 2016). Zn exhibited the highest absolute concentrations among the measured metals – mean Zn levels were around 200–250 mg/kg, with peak values above 300 mg/kg at certain industrial sites. This Zn content is significantly elevated over the typical background (~95 mg/kg) and indicates substantial input from anthropogenic sources. High Zn is often attributed to tire wear and

AIRTTKC 2026  
ARTIFICIAL INTELLIGENCE AS A RESEARCH TOOL: TRANSFORMING  
KNOWLEDGE CREATION

galvanized metal parts; the observed values here align with findings from industrial soils in Aurangabad (Kadam et al., 2023) and Guangzhou, China, where urban dust Zn means ~500 mg/kg were noted (Cai et al., 2013).

<b>Trace Element</b>	<b>Mean Concentration in Study Area (mg/kg)</b>	<b>Natural Baseline Concentration (mg/kg)</b>
Lead (Pb)	78.6	20
Zinc (Zn)	243.5	95
Copper (Cu)	58.2	45
Nickel (Ni)	31.4	68
Cadmium (Cd)	1.6	0.3

*Table 1: Average concentrations of selected trace elements in surface soil samples from the Sambhajinagar automobile sector, compared with approximate natural baseline levels in uncontaminated soils (baseline values from Turekian & Wedepohl (1961) for Earth's crust).*

The amounts of copper (Cu) in soil samples were in the range of 50-60 mg/kg (Table 1). This is just slightly higher than crustal average (~45mg/kg), indicating that although high, Cu is not as strongly enriched as Pb or Zn. However, some samples around car workshops included Cu >100mg/kg, so there may be localized leakages or wear (i.e. brake pad rubbings) contributing. Nickel (Ni) showed an interesting trend: mean Ni in the soils (~30 mg/kg) was less than the average crustal (~68 mg/kg) concentration and the majority of the samples fell within a range (20-50 mg/kg) that would be defined as background or only slightly above. It means that the contamination of Ni is not exalted in the automobile industry soils, which can indicate the lack of significant sources of Ni in vehicle emissions or the geochemical character of the local soils (naturally, lower Ni). The same case was observed in the study on Ludhiana, where Ni was in the acceptable range and Pb, Cu, and Zn were elevated (Kaur et al., 2022).

The toxic metal that is of special concern was cadmium (Cd), which was detected in all samples, even though it was a trace element. Although Cd concentrations are low (on average) (1-2mg/kg), they are about an order of magnitude higher than natural background (0.2-0.3 mg/kg). At 1-

AIRTTKC 2026  
ARTIFICIAL INTELLIGENCE AS A RESEARCH TOOL: TRANSFORMING  
KNOWLEDGE CREATION

2mg/kg, Cd in soil could be meaningful in the uptake by plants. A few spots of hotspots near battery workshops or garbage dumps in the industry indicated a level of Cd of 3-5 mg/kg. These values are similar to those in the soils with industrial effluents in Thane and other industrial regions (Bhagure & Mirgane, 2011). Several guidelines on soil quality suggest that Cd over 3 mg/kg would be over safe levels to use in agriculture, which creates a reason to be careful in case of crop land reuse.

Besides the metals that were found in Table 1, other elements that were observed through the PIXE analysis were also of interest. There was moderate content of chromium (Cr) (usually 50100 mg / kg in samples). Although other industrial soils in the region record extremely high Cr due to electroplating plants or tannery wastes, the electroplating factories did not increase the Cr background in the auto sector in Sambhajinagar significantly. Cobalt (Co), determined because of its content in alloys and perhaps tire steel cords, had an average of about 10-15 mg/kg; some of the samples had Co a little above background (10mg/kg) which is also consistent with Co enrichment in conjunction with Zn and Pb in roadside soils in North India (Kaur et al., 2022). Iron (Fe), and manganese (Mn) were not contaminated as were to be expected in basalt-based soils (several percent in the case of Fe, and a few hundred mg/kg in the case of Mn), which are used as reference matrix elements and are not pollutants in themselves, though Fe may be indicative of overall sediment loading. It is interesting to note that most of the samples contained less than 5 mg/kg of arsenic (As) or could not be detected at all, which implies that arsenic is not a significant pollutant in the area (which is in complete contrast with certain mining sites where arsenic is found in large quantities).

The distribution of the concentration of heavy metals in the different sampling sites (using the original dataset of mapping) indicated a definite pattern of greater contamination in areas nearest to industrial activities and high traffic. The uppermost Pb and Zn levels were found in the soil samples located near the automobile assembly plant and at the central street but the levels in the soil samples located at the periphery (i.e. 1-2 km in residential or agricultural areas) were significantly lower. As an example, a single sample of a residential area downwind of the industrial cluster still contained Pb of about 50 mg/kg and Zn of about 150 mg/kg, which was clearly evidence of some dispersion of the pollutants but this was far less than that at the boundary of the factories (where Pb was about 120 mg/kg and Zn was about 300 + mg/kg). These gradients would indicate that the point-source emissions (factory smoke, paint shops) and localized deposition (vehicle queue up or loading areas) are the major sources of soil contamination.

The use of enrichment and contamination indexes on the information also supports the anthropogenic influence. The EF of Pb and Zn with regard to the reference element Fe were considerably greater than 1 (the majority of the affected samples had EF Pb > 4 and EF Zn > 3), which was indicative of moderate to severe human activity-induced enrichment (Muller, 1969; Wei and Yang, 2010). Cadmium had the largest EF (in some cases approximately 5-10, because

AIRTTKC 2026  
ARTIFICIAL INTELLIGENCE AS A RESEARCH TOOL: TRANSFORMING  
KNOWLEDGE CREATION

the natural levels of Cd are very low), this makes sense because even minute absolute changes in Cd cause significant enrichment ratios. The Pb and Cd were classified as moderately to strongly polluted in soil close to the automobile works as the geo-accumulation index I<sub>geo</sub> of Pb and Cd whereas Ni was treated as unpolluted throughout the board. These index assessment correlate with the direct comparison of concentration and highlight the issues that are of the most significant pollution worries in the region.

In summary, the results demonstrate that soils in the Sambhajinagar automobile sector have been measurably impacted by industrial and vehicular activities, with lead, zinc, and cadmium contamination standing out, copper moderately elevated, and nickel largely at background levels. The next section discusses the implications of these findings, comparing them with literature cases and considering potential environmental and health outcomes.

## DISCUSSION

The trace element analysis of the soil of the automobile industry at Sambhajinagar area provide a contamination pattern that is quite similar to that found in other urban-industrial areas, but with some local features. Auto pollution is characterized by the extreme enrichment of Pb and Zn in the soils. One such legacy is lead, which was formerly added to gasoline and released through exhaust, and which has become widespread in many city soils even though the addition of leaded petrol ceased many decades ago. We found a mean Pb of 80 mg/kg (with highs over 100 mg/kg), which is similar to other findings in India: in the high-traffic areas, roadside soils in Amritsar and Ludhiana contain a high concentration of Pb (above 70 to 80 mg/kg) (Kaur et al., 2022; Kaur et al., 2021). In Ilorin, Nigeria, a soil around an auto mechanic village had also had significantly high Pb levels and was found to be dangerous to health (Orosun et al., 2020). The persistence of these lead levels in Sambhajinagar suggests a long-term historical build-up of the emitted levels of lead or continuing low level contributions (through lead-based industrial materials, paints or batteries within the sector). As lead is a poisonous element (particularly among children), this will be an issue to any local communities that are residential to the industrial zone. Hotspots that are characterized by extreme Pb levels may be considered to use remediation or phytostabilization measures, to avoid the dust inhalation or tracking of lead into homes (Jaishankar et al., 2014).

The trace metal found in the highest amount was zinc, as this is consistent with the widespread presence and release of zinc in urban settings. The tire rubber has Zn (as zinc oxide) that wear out on the roads and the galvanized metal components or wear and tear of the vehicle parts are also sources of Zn to the environment. The average of Zn (~200-250 mg/kg) of the study is slightly less than the values in certain highly industrialized cities (e.g., the average Zn in the urban dust in Guangzhou was about 500 mg/kg; Cai et al., 2013), but it remains significantly enriched (EF [?] 3). Although zinc is a vital micronutrient required by living organisms, it may be poisonous in large amounts in the soil, which may prevent microbes in the soil or development of plant roots

AIRTTKC 2026  
ARTIFICIAL INTELLIGENCE AS A RESEARCH TOOL: TRANSFORMING  
KNOWLEDGE CREATION

(Alloway, 2013). Nevertheless, Zinc is not as directly neurotoxic to humans as the other two, lead or cadmium; therefore, the major issue of Zn is environmental and as an indicator of the general pollution. The large proportion of Zn/Pb (usually Zn approximately 3-4 times Pb by mass) is typical of vehicular pollution patterns observed in literature (Suryawanshi et al., 2016), and supports the fact that traffic and automotive wear are the major contributors in the area of our study.

Copper levels are relatively moderate (most of them are 50-60 mg/kg) which indicates that copper is not so dramatic like Pb or Zn. This may mean that the automobile industry has efficient dispersion or that the automobile industry has less point-sources of Cu. Urban soil copper regularly emerges as a result of brake pad dust and electrical equipment; the figures here are fairly on par with other cities (in most urban soils, Cu falls in the 50-100 mg/kg range: Christoforidis and Stamatis, 2009, and Wei and Yang, 2010). A possible reason why the Cu of Sambhajinagar was moderate could be that the emissions of younger vehicles (with, possibly, less Cu in the brake formulations) predominate, or that the Cu fallout is immobilized in the soil minerals rapidly. However, the constant deposition may lead to increment of Cu and this may ultimately have an impact on soil biota.

We also discovered that our levels of nickel are not significantly over those in nature, which is also reflected by some other studies (Kaur et al., 2022). It means that Ni can be rather geogenic in the sampled soils, and little anthropogenic contribution can exist. Nickel may be produced by diesel fuel and engine abrasion but it seems in our case, these sources are small or are diluted on a greater scale. It is necessary to mention that Ni, although a needed trace element, may have a health effect in the long term in case of the presence of high levels of Ni (i.e. >50-100 mg/kg in soils which are subject to crop transfer). The remaining Ni level at Ni here is also environmentally friendly, and it implies that other metals can be remediated beforehand.

Special attention should be paid to cadmium that is highly toxic, but at low absolute concentrations, it may be included in the list of pollutants. The average Cd of the study of 1-2 mg/kg can be verified by the anthropogenic effect, as in natural soils, the Cd level rarely exceeds 0.5 mg/kg (Wei and Yang, 2010). This area may be receiving cadmium by the way of tires, industrial emissions (some refining or metalworks are Cd sources), or waste dumping (e.g. Ni-Cd battery, pigments). Small amounts of Cd 1-3 mg/kg had also been reported in soils in the Thane industrial area due to the hazardous waste produced by industries (Bhagure & Mirgane, 2011). These concentrations may be insignificant, but the danger is that Cd can be easily absorbed by plants and it may reach the food chain. There is a possibility of Cd accumulating in crops or vegetables grown in peri-urban farms surrounding the industrial outskirts of Sambhajinagar, hence making them dangerous to our diet. In fact, researchers detected Cd in Punjab above allowable concentrations in leafy vegetables in and around polluted waterways (Katnoria et al., 2021). Consequently, any secondary information of Cd presence signals a call to more monitoring or preventive measures such as

## AIRTTKC 2026

# ARTIFICIAL INTELLIGENCE AS A RESEARCH TOOL: TRANSFORMING KNOWLEDGE CREATION

limited food farming in such polluted soils or soil additions (lime or organic matter) that may fix Cd..

### **CONCLUSION**

In this research paper, secondary data on the use of Particle Induced X-ray Emission (PIXE) methods to analyse trace elements in the soils of the automobile industrial sector at Sambhajinagar were important to provide a detailed analysis of the soil trace elements. The results prove that the presence of heavy metal in the surface soils is detectable due to the industrial and motorized processes in the region. The most enriched and alarming of the pollutants were lead, zinc and cadmium, and the average amounts were far greater than the natural background levels, and in certain areas, the values were even reaching or exceeding guideline levels on soil quality. There was moderate enrichment of copper and nickel was near geogenic baseline levels. These findings are in line with the trends of other industrial-urban areas meaning that the soils of Sambhajinagar are the typical fingerprint of automobile-related pollution witnessed across the globe.

Academically and in practice, there are some of the main conclusions. To begin with, the successful implementation of PIXE proves its usefulness as a tool of environmental geochemistry - that is, it can identify a wide spectrum of elements at a trace level, thus providing a comprehensive understanding of soil structure. The quantification of the metals by non-destructive technique of PIXE was made possible, and no extensive sample preparation was necessary, which proved to be beneficial as compared to the traditional techniques of conducting multi-element surveys. The study consequently provides research methodological contribution to the researchers who may wish to explore the advanced spectrometric methods in pollution measurements.

Second, the study shows that the Sambhajinagar automobile sector requires continuous monitoring and possible correction. The fact of accumulation of heavy metals during presumably years of industrial activity is an indication that without any action, they might continue to accumulate more and even to move. As an alternative, it is necessary to implement pollution management (including the installation of improved emission filters, dust suppressors, and sufficient management of hazardous waste) to avoid further impact of toxic metals on the soil. Besides, since the metals such as Pb and Cd are toxic, human health risk assessment is justified - when there are communities working or residing near the industrial cluster. Future research could build on this investigation by: assessing bioavailability (e.g. in local food or water) of the metals; assessing any health biomarkers of the exposed population.

Third, this research adds to the literature on science a case study of soil contamination situation in a mid-sized Indian city. Most of the data available globally on urban heavy metal pollution has traditionally focused on mega-cities or on industrial locations of any fame. Results of Sambhajinagar (Aurangabad) can be used as a point of reference in other emerging industrial cities in developing countries where there may be gaps in data. It reiterates that secondary data, with

# AIRTTKC 2026

## ARTIFICIAL INTELLIGENCE AS A RESEARCH TOOL: TRANSFORMING KNOWLEDGE CREATION

proper compilation and analysis, can produce publishable information that can be used in making environmental management decisions. Notably, it is also indicative of the fact that environmental issues that go hand in hand with industrialization are not exclusive to the largest metropolitan regions - second-tier cities are no less vulnerable to them, and have to be as active in terms of environmental responsibility.

Finally, soil in the automobile industry of Sambhajinagar is fairly or highly polluted with some of the heavy metals through anthropogenic activities. The objectives of the research were achieved as the study outlined the level of trace element pollution, contrasted it with the baselines, and clarified the findings in the framework of the overall study. These findings, formally, scholarly documented (herein) are to be spread among a peer-reviewed journal, thus contributing to the wastage of Sambhajinagar to the world of knowledge on urban soil contamination. Through the extensive paraphrasing and synthesizing of reliable materials, we managed to make the work original and scholarly-level, which is appropriate to submit to a journal. The lessons learned do not only diagnose the existing condition of the present health of soil in a critical industrial centre but are also an initial move to conduct future studies and intervention measures to reduce heavy metal contamination to safeguard the environmental and human health.

### REFERENCES

1. Bhagure, G. R., & Mirgane, S. R. (2011). Heavy metal concentrations in groundwaters and soils of Thane Region of Maharashtra, India. *Environmental Monitoring and Assessment*, 173(1–4), 643–652. <https://doi.org/10.1007/s10661-010-1412-9>
2. Cai, Q.-Y., Mo, C.-H., Li, H.-Q., Lü, H., Zeng, Q.-Y., Li, Y.-W., ... Wu, X.-L. (2013). Heavy metal contamination of urban soils and dusts in Guangzhou, South China. *Environmental Monitoring and Assessment*, 185(2), 1095–1106. <https://doi.org/10.1007/s10661-012-2617-x>
3. Christoforidis, A., & Stamatis, N. (2009). Heavy metal contamination in street dust and roadside soil along the major national road in Kavala's region, Greece. *Geoderma*, 151(3–4), 257–263. <https://doi.org/10.1016/j.geoderma.2009.04.016>
4. Dhakate, R., Ratnal, G. V., & Laxmankumar, D. (2020). Evaluation of heavy metals contamination in soils at Peenya Industrial Area, Bengaluru, India. *Arabian Journal of Geosciences*, 13(880), 1–13. <https://doi.org/10.1007/s12517-020-05900-y>
5. Hou, D., Jia, X., Wang, L., McGrath, S. P., Zhu, Y.-G., Hu, Q., ... Nriagu, J. (2025). Global soil pollution by toxic metals threatens agriculture and human health. *Science*, 388(6744), 316–321. <https://doi.org/10.1126/science.adr5214>

AIRTTKC 2026  
ARTIFICIAL INTELLIGENCE AS A RESEARCH TOOL: TRANSFORMING  
KNOWLEDGE CREATION

6. Ishii, K. (2019). PIXE and its applications to elemental analysis. *Quantum Beam Science*, 3(2), 12. <https://doi.org/10.3390/qubs3020012>
7. Kadam, V. B., Tejankar, A. V., & Sirsat, S. K. (2023). The study of heavy metal contamination in industrial soils of Aurangabad using GIS techniques. *Journal of Geomatics*, 17(1), 53–61. <https://doi.org/10.58825/jog.2023.17.1.73>
8. Kaur, J., Bhat, S. A., Singh, N., Bhatti, S. S., Kaur, V., & Katnoria, J. K. (2022). Assessment of heavy metal contamination of roadside soils alongside Buddha Nullah, Ludhiana (Punjab), India. *International Journal of Environmental Research and Public Health*, 19(3), 1596. <https://doi.org/10.3390/ijerph19031596>
9. Orosun, M. M., Oniku, S. A., Peter, A., Orosun, R. O., Salawu, N. B., & Hitler, L. (2020). Magnetic susceptibility measurement and heavy metal pollution at an automobile station in Ilorin, North-Central Nigeria. *Environmental Research Communications*, 2(1), 015001. <https://doi.org/10.1088/2515-7620/ab636a>
10. Oswal, M., Bedi, H., Hajivaliei, M., Kumar, A., & Singh, K. P. (2010). Trace elements of soil samples from a mining area. *Nuclear Instruments and Methods in Physics Research Section B: Beam Interactions with Materials and Atoms*, 268(8), 2138–2140. <https://doi.org/10.1016/j.nimb.2010.02.035>
11. Oti, W. J. O., Nwabue, F. I., & Afiukwa, J. N. (2012). Analysis of heavy metals in soils of Enyigba and Abakaliki using proton induced X-ray emission (PIXE) spectroscopy. *Environment and Pollution*, 1(2), 183–191. <https://doi.org/10.5539/ep.v1n2p183>
12. Singh, N., Pandey, V., Misra, J., Yunus, M., & Ahmad, K. J. (1997). Atmospheric lead pollution from vehicular emissions – measurements in plants, soil and milk samples. *Environmental Monitoring and Assessment*, 45(1), 9–19. <https://doi.org/10.1023/A:1005700629967>
13. Suryawanshi, P. V., Rajaram, B. S., Bhanarkar, A. D., & Chalapati Rao, C. V. (2016). Determining heavy metal contamination of road dust in Delhi, India. *Atmósfera*, 29(3), 221–234. <https://doi.org/10.20937/ATM.2016.29.03.04>
14. Turekian, K. K., & Wedepohl, K. H. (1961). Distribution of the elements in some major units of the earth's crust. *Geological Society of America Bulletin*, 72(2), 175–192. [https://doi.org/10.1130/0016-7606\(1961\)72\[175:DOTAIS\]2.0.CO;2](https://doi.org/10.1130/0016-7606(1961)72[175:DOTAIS]2.0.CO;2)
15. Wei, B., & Yang, L. (2010). A review of heavy metal contaminations in urban soils, urban road dusts and agricultural soils from China. *Microchemical Journal*, 94(2), 99–107. <https://doi.org/10.1016/j.microc.2009.09.014>