



## Soil Contamination Risks and Sustainable Land Redevelopment

### A Case Study of Tolworth Court Farm

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#### ABSTRACT

This study evaluates soil contamination risks in Tolworth Court Farm, Kingston upon Thames, a semi-urban site undergoing transition for residential redevelopment. Composite random sampling was applied to six sections (A-F), and analyses included soil pH, organic matter (Walkley-Black), and heavy metals (ICP-AES). Results indicated moderately acidic soils (pH 4.56) with medium organic matter (5.02%). Cadmium concentrations averaged 1.13 mg/kg, exceeding the UK Soil Guideline Value (1.0 mg/kg), with Section A reaching 1.52 mg/kg. Cadmium was also found to be the most mobile metal (2.21%), suggesting potential risks of groundwater contamination and plant uptake. Lead, chromium, nickel, and zinc concentrations remained below regulatory thresholds but require continued monitoring. The study highlights the importance of integrating soil assessments into sustainable urban redevelopment frameworks, with targeted remediation measures such as pH adjustment, phytostabilization, and long-term monitoring to reduce exposure risks. The findings provide evidence-based guidance for policymakers and urban planners, ensuring environmental safety in post-industrial land transformation projects.

#### Keywords

- Soil contamination
- Heavy metals
- Land redevelopment
- Environmental risk assessment
- Sustainable planning

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### 1. Introduction

Soil, a fundamental component of Earth's ecosystems, faces complex challenges driven by diverse human activities. These include erosion, depletion of organic matter, biodiversity loss, and contamination by industrial and domestic pollutants, all of which threaten environmental and human health. Among these challenges, contamination represents a major risk to urban and sub-urban soils, especially where population density and industrial activity are high [1]. The projected increase in megacities from 10 in 1990 to 41 by 2030 further complicates soil management due to rising land-use pressure and waste generation [2]. As urbanisation accelerates, the need for residential land intensifies, placing additional stress on available green and semi-natural areas.

Soil suitability and quality assessments are essential when planning for redevelopment or land reuse. Its pH level affects the solubility of metals and their uptake by plants, while organic matter content can significantly impact crop yields [3]. Soil texture and mineral content, on the other hand, influence the movement of waterflow and nutrient content through soil [4].

Human activities in the industrial, commercial, and household waste disposal sectors are major contributors to soil contamination. The energy, petroleum, chemical, metal-working, and textile industries are primary sources of pollution, releasing heavy metals and organic contaminants into soils [5]. By using mineral fertilizers and pesticides, agricultural practices introduce heavy metals like Copper and Cadmium into the soil, greatly contributing to diffuse pollution [6].

Heavy metals are typically found in the top 20 cm of soil, where they can gradually build up over time [7]. This pattern of contamination is evident in most community gardens across the UK, as multiple studies [8,9] claimed that these places have higher quantities of dangerous chemicals. While the expansion of urban gardening is viewed positively, there is growing concern about the risk of heavy metal exposure from eating vegetables grown in contaminated soil. This presents a potential health issue for people involved in such activities [10]. In the UK, tools such as the Soil Guideline Values (SGVs) and Contaminated Land Exposure Assessment (CLEA) framework provide reliable methods for measuring levels of heavy metals and other harmful substances, helping to determine whether land is safe for use [11].

Most soil suitability research in urban settings focuses on issues like contamination, compaction, and soil quality in relation to urban agriculture or public green spaces rather than the specific needs for residential gardens [1]. This study's specific focus on soil properties, such as Soil Organic Matter (SOM), pH and heavy metal mobility in soil, for the suitability for plant growth and uptake, provides novel data that can influence sustainable development decisions, making it a valuable reference for future urban planning projects in similar areas [12].

Additionally, while urban soil characteristics have been studied in the context of public parks or urban agriculture, few have explored how these factors influence the design and success of residential spaces with gardens, particularly in a place like Tolworth Court Farm. By investigating this



relatively under-researched area, this study not only fills a regional gap but also contributes to the broader discussion of sustainable urban redevelopment by highlighting the importance of integrating soil health into residential planning [13]. As Tolworth Court Farm is being considered for a new housing development that includes garden spaces, ensuring the safety and quality of the soil becomes even more critical. This research contributes to those development goals by initiating a thorough investigation into the site's environmental suitability.

The objectives of this study are outlined as follows:

- To determine the pH, Soil Organic Matter (SOM) content, and the total concentrations of the existing metals of the soil.
- To compare the measured average soil metal concentrations with the established Soil Guideline Values (SGVs).

To evaluate the potential mobility of the metals within the soil and identify the possible risk of metal transfer to plants through leaching.

## 2. Method

### 2.1. Background of the study area

Tolworth Court Farm, situated within the urban area of Kingston upon Thames, reflects the ongoing interaction between urban and suburban land use. Spanning approximately 50 hectares, the site is positioned between Old Kingston Road and Jubilee Way, adjacent to the Hogsmill River, with a gas pipeline running along its northern boundary. As urban development intensifies in the area, the site presents both opportunities and environmental concerns. While plans for spacious gardens offer potential benefits, the area also faces ongoing challenges related to illegal dumping, emissions from nearby traffic, and waste disposal by local traders, all of which contribute to environmental degradation in this increasingly pressured green space.



**Figure 1.** Study area divided by sections.

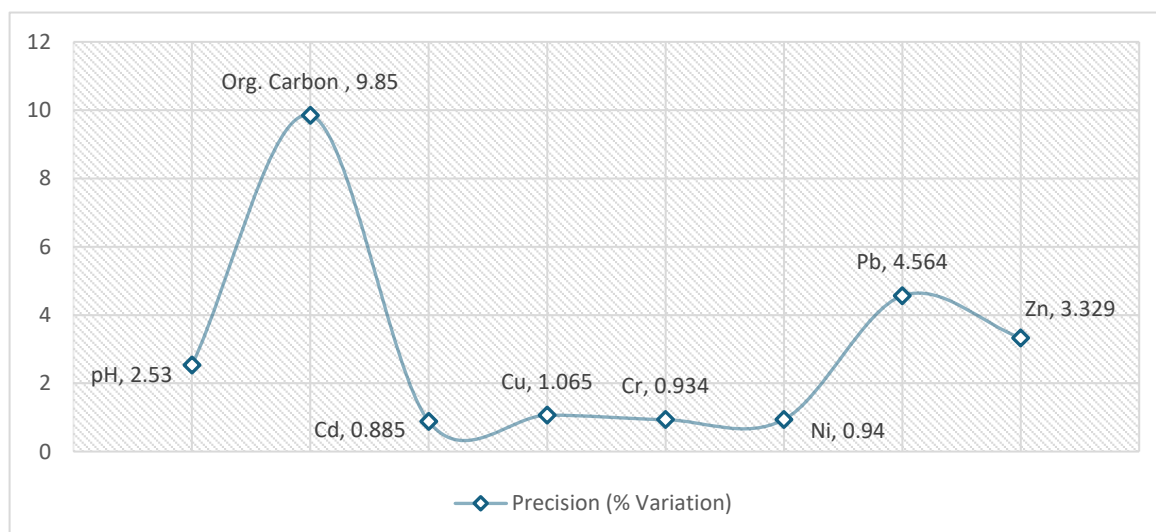
### 2.1. Data accuracy maintenance

In order to ascertain the efficacy and robustness of the data, a careful and consistent testing process was followed. This included using clean reagent blanks, repeating each test three times, and regularly checking the accuracy of equipment such as flame photometers, spectrophotometers, and

ICP-AES instruments. Each soil sample was tested in triplicate, and the average of these results was used in the final calculations. These reagent blanks which were processed in the same manner as the real samples, helped detect any contamination that might have occurred during testing. To further check the accuracy of the results, a certified reference material (CRM005) was analyzed using ICP-AES, providing a

standard for comparison. Calibration of flame photometers and spectrophotometers was done using de-ionized water and standard solutions, while ICP-AES was calibrated with several reference materials to account for differences in soil types, such as those containing carbonates, shale, or siliceous materials. Figure 2 shows the precision, expressed as percentage of variation, in replicate measurements for every measured parameter, including soil pH, organic carbon content, and concentrations of metals in the soil sample

(Cadmium, Copper, Chromium, Nickel, Lead, and Zinc). All parameters exhibit less than 10% variation, indicating a high level of precision. Whereas, Figure 3 illustrates the quality assurance metrics in terms of Mean and the Standard Deviation for every parameter that is tested. The precision consistency demonstrates the soundness of the analytical methodology and reinforces confidence in the reported Mean and Standard Deviation values.



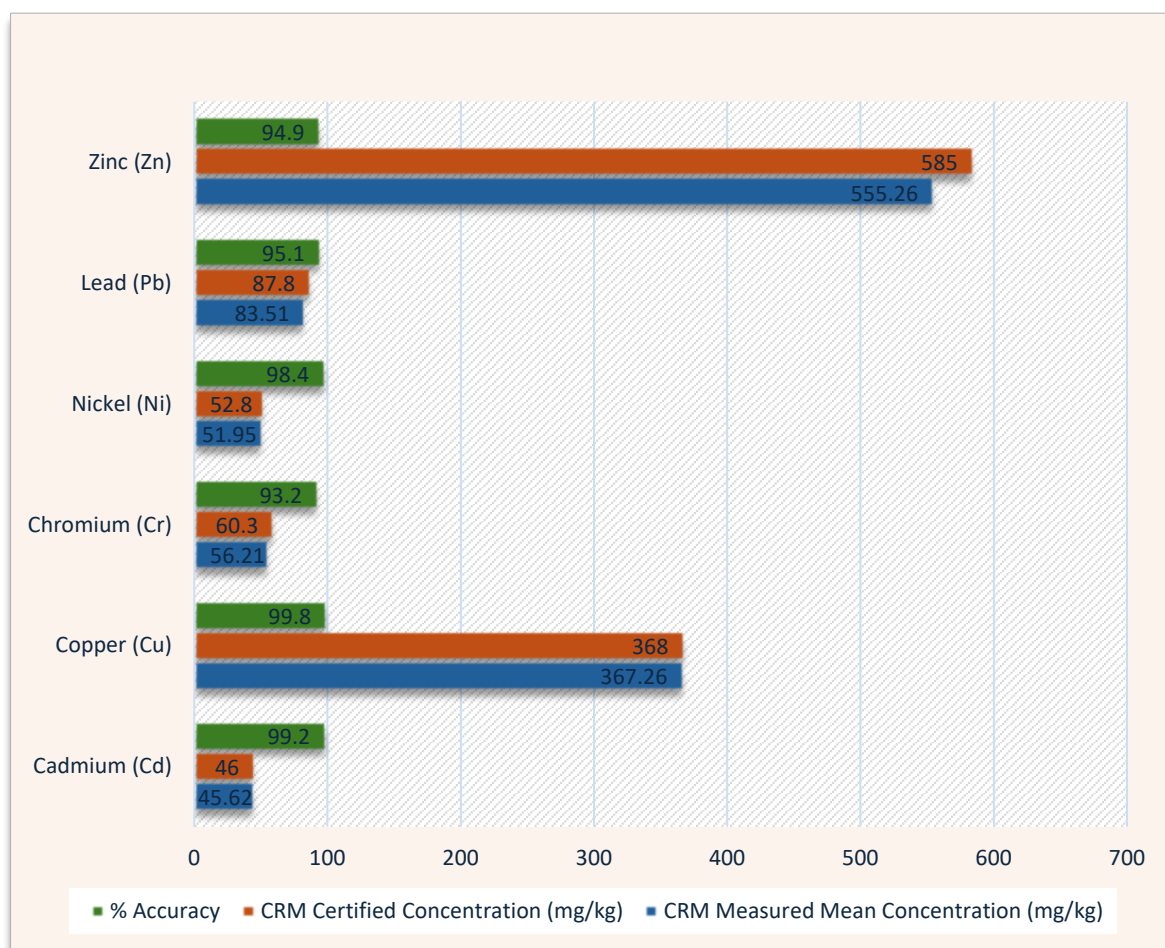
**Figure 2.** Percentage variability (precision) of the tested soil parameters.

Figure 3 shows the efficacy of the analysis by comparing the mean concentrations obtained from Certified Reference Materials (CRMs) with their certified values, expressed as percentage deviation. The accuracy of the analyzed metals ranged from 93.2% to 99.8%, indicating strong agreement with the certified values and compliance with the  $\pm 20\%$  acceptance limit.

The potency of every metal was satisfactory, demonstrating the dependability of the analytical techniques. The most accurate results were found for Copper (Cu) at 99.8%, followed by Cadmium (Cd, 99.2%), Nickel (Ni, 98.4%), and Lead (Pb, 95.1%). Zinc (Zn, 94.9%) and Chromium (Cr, 93.2%) and

also met the required threshold, confirming that all metals achieved reliable accuracy under the applied analytical conditions.

These data quality examinations give assurance regarding the data's dependability, supporting the precision of the analytical techniques employed for determining metal concentrations in the soil samples. The high level of accuracy observed across all metals underscores the meticulous calibration and quality control measures implemented during the analysis, contributing to the overall validity of the obtained results.



**Figure 3.** Data quality assurance as measured by % accuracy for total metal analysis.

### 3. Result

The measured soil pH at the site is 4.56, indicating a slightly acidic condition, which may influence both the availability of essential nutrients and the movement of heavy metals within the soil matrix. The organic matter content is recorded at 5.02%, placing it within the medium range (4–6%). This level of Soil Organic Matter (SOM) content plays a significant role in enhancing nutrient retention and uptake by plants. Typically, higher organic matter content is linked to better soil fertility and potentially greater agricultural productivity. Although pH and SOM provide valuable indicators of soil health, evaluating the site's overall suitability for residential development involving large garden spaces, requires a detailed analysis of metal concentrations and their potential mobility.

The following table presents these data, offering a more comprehensive assessment of the soil's condition and its appropriateness for future land use planning. In Table 1, the average amounts of existing heavy metals in the samples from Tolworth Court Farm's soil are compared with the

Environment Agency's Soil Guideline Values (SGVs) for residential land use. The mean Cadmium concentration across all sampled sections was 1.13 mg/kg, slightly exceeding the recommended SGV threshold of 1.0 mg/kg. Given cadmium's known toxicity and its capacity to bioaccumulate within the food chain.

This exceedance raises concerns regarding possible health risks and may reflect past industrial activity or legacy of pollution on the site. In contrast, the average Chromium concentration was 25.58 mg/kg, remaining well below the SGV of 130 mg/kg.

Similarly, the average concentrations of Nickel (19.91 mg/kg) and Lead (33.09 mg/kg) were also within their respective SGVs (50 mg/kg for nickel and 450 mg/kg for lead), indicating no immediate environmental or health risks associated with these elements at present. Although the current Chromium concentration level does not pose an immediate risk, ongoing monitoring is recommended to detect any potential future changes.

**Table 1:** Contrast between the average metal concentrations found in the soil after analysis to Soil Guide Values (SGVs).

| Metals        | Soil Guide Values for Residential-Land (mg/kg) | Average Metal Concentrations in the site under assessment (mg/kg) |
|---------------|------------------------------------------------|-------------------------------------------------------------------|
| Cadmium (Cd)  | 1,2,8 (pH 6, 7, 8)                             | 1.13                                                              |
| Copper (Cu)   | --                                             | 25.03                                                             |
| Chromium (Cr) | 130                                            | 25.58                                                             |
| Nickel (Ni)   | 50                                             | 19.91                                                             |
| Lead (Pb)     | 450                                            | 33.09                                                             |
| Zinc (Zn)     | --                                             | 82.18                                                             |

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Although the current Chromium concentration level does not pose an immediate risk, ongoing monitoring is recommended to detect any potential future changes.

The soil total metal contents (mg/kg) for the six Tolworth Court Farm sections (A through F) are shown in Table 2, along with the respective mean values. The table presents a detailed summary of heavy metal concentrations within each designated section of the site, facilitating an in-depth evaluation of the spatial distribution of Cadmium (Cd), Copper (Cu), Chromium (Cr), Nickel (Ni), Lead (Pb), and Zinc (Zn). While Cd levels in Sections D and F remained below the regulatory threshold, the remaining sections, Section B, C, and E showed Cd concentrations just above the 1 mg/kg limit. Analysis of the mean concentrations allows for a broader understanding of how these metals are distributed across the farm.

**Table 2:** Contrast between the average metal concentrations found in the soil after analysis to Soil Guide Values (SGVs).

| Metal | Section A | Section B | Section C | Section D | Section E | Section F | Mean  |
|-------|-----------|-----------|-----------|-----------|-----------|-----------|-------|
| Cd    | 1.52      | 1.13      | 1.08      | 0.98      | 1.07      | 0.99      | 1.13  |
| Cu    | 28.51     | 26.05     | 23.68     | 23.8      | 23.73     | 24.39     | 25.03 |
| Cr    | 26.38     | 27.15     | 25.28     | 24.86     | 25.01     | 24.82     | 25.58 |
| Ni    | 17.9      | 17.76     | 17.06     | 16.62     | 17.02     | 33.13     | 19.91 |
| Pb    | 40.78     | 32.84     | 31.62     | 31.51     | 30.96     | 30.79     | 33.09 |
| Zn    | 88.09     | 83.94     | 80.69     | 81.05     | 79.68     | 79.62     | 82.18 |

As seen in Table 3, the mobility order is as follows: Cadmium > Zinc > Nickel > Copper > Lead > Chromium. Their total mobility is less than 10%, which is regarded as inferior. With a mobility value of 2.21%, Cadmium demonstrated the greatest capacity for movement through the soil relative to the other metals.

Due to its enhanced mobility, Cadmium shows the propensity to infiltrate into groundwater, thereby contaminating water supplies. This high mobility of Cadmium may have been influenced by soil pH, since acidic conditions can enhance the solubility and mobility of metals. Chromium is less likely to migrate through soil, because of its lowest mobility (0.19%) [14].

Water contamination is minimized via low mobility, which lowers the chance of chromium contaminating soil and

seeping into groundwater. Zinc, lead, and nickel displayed intermediate mobility, implying a limited to moderate capacity for migration within the soil profile. Consequently, their potential to contaminate soils or leach into groundwater is considered low to moderate.

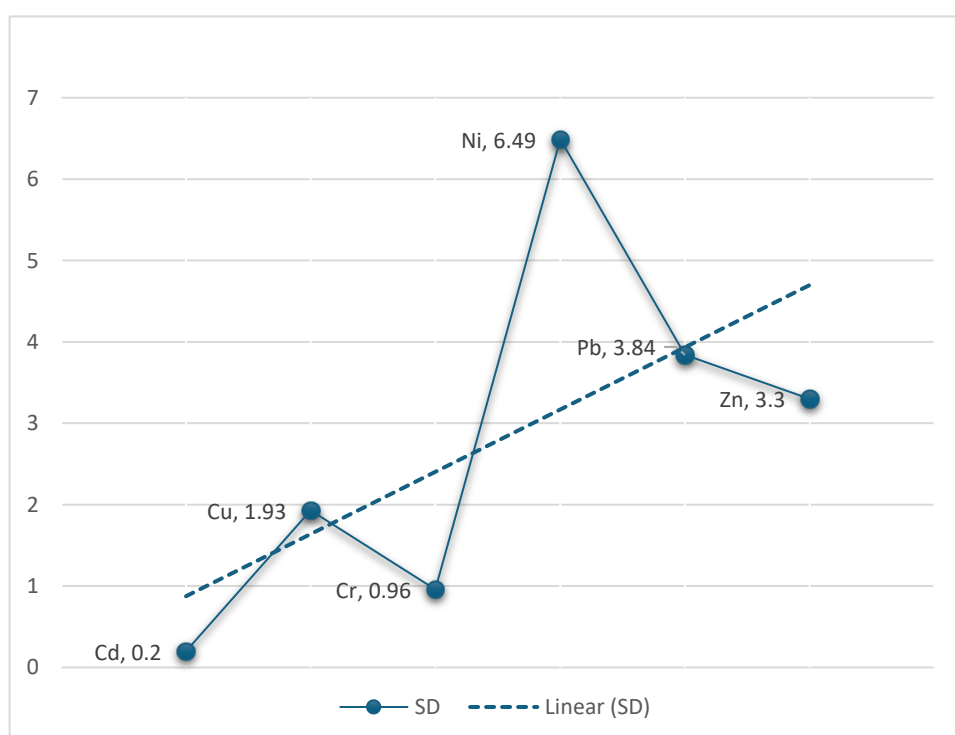
Figure 4 demonstrates the Standard Deviation (SD) for each metal throughout the sections. The standard deviation values provide insight into the extent of variability within each section. For example, Nickel (Ni) displays a higher Standard Deviation, indicating greater inconsistency in its distribution across the sampled areas. Recognising such variations is essential for evaluating potential environmental risks and for guiding effective soil remediation and management.

Furthermore, by comparing the recorded concentrations to the established Soil Guideline Values (SGVs), it becomes possible to assess whether any observed levels surpass

regulatory thresholds, potentially posing health or ecological concerns.

**Table 3:** The Number of lakes and their characteristics.

| Metal | Total concentration | NH <sub>4</sub> NO <sub>3</sub> Extractable (mg/kg) | % Mobility |
|-------|---------------------|-----------------------------------------------------|------------|
| Cd    | 1.13                | 0.025                                               | 2.21       |
| Cu    | 26.05               | 0.135                                               | 0.52       |
| Cr    | 27.15               | 0.051                                               | 0.19       |
| Ni    | 17.76               | 0.116                                               | 0.65       |
| Pb    | 32.84               | 0.096                                               | 0.29       |
| Zn    | 83.94               | 1.202                                               | 1.43       |



**Figure 4.** Standard Deviation for the metal concentrations.

#### 4. Discussion

Soil pH is a key factor influencing the ability of plants to absorb nutrients [15]. Under an acidic environment, the solubility and availability of heavy metals in the soil may increase, thereby enhancing their uptake by plants [16]. Research has indicated that the bioavailability of heavy metals generally decreases when soil pH approaches the range of 5.5 to 6.0 [17]. Additionally, a negative relationship has been observed between soil organic matter (SOM) and pH, with SOM levels often increasing as pH values decline [18].

Among the divided sections, the maximum Cadmium (Cd) concentration was found in Section A, which slightly surpassed the environmental standards-established SGV. Section A, located closest to the main road bordering the study area, also exhibited elevated levels of Chromium (Cr), Nickel (Ni), and Lead (Pb), in addition to Cadmium (Cd). Previous research [19] has linked the presence of these metals to traffic-

related sources particularly tire wear, which contributes to the accumulation of pollutants in roadside dust. The elevated Cd levels seen in Sections A, B, C, and E may be partially explained by the introduction of Cadmium into soils from other sources, such as air deposition and the usage of fertilisers based on phosphate. The elevated Cadmium concentration observed in Section A warrants further investigation to identify its source and assess any potential localized effects. Lead concentrations across the site present notable risks to both public health and the surrounding ecosystem. It is essential to explore potential sources of lead contamination and consider appropriate remediation strategies, given the well-documented toxicity of this metal. The current Zinc concentrations do not indicate an immediate threat; periodic monitoring is advisable to ensure that levels remain within safe limits. Except for Cadmium, the concentrations of other examined metals i.e., Chromium, Nickel, and Lead were found to

be below their respective regulatory thresholds in all sections.

Health risk assessment models, such as the UK CLEA framework and the USEPA Human Health Risk Assessment Model, provide a structured approach to evaluate potential exposure pathways, including ingestion, dermal contact, and inhalation. Applying these models can help quantify risks associated with the observed metal concentrations and guide targeted interventions. Remediation strategies are available to mitigate these risks. Soil amendments, such as lime, can increase pH and reduce the mobility of cadmium and zinc, while organic matter additions, like compost or biochar, can enhance metal binding capacity and improve fertility.

Phytoremediation with hyperaccumulator plants such as *Brassica juncea* (Indian mustard), *Helianthus annuus* (sunflower), and *Vetiveria Zizanioides* (Vetiver grass) can gradually extract heavy metals from the soil. Integrating these strategies with ongoing monitoring and statistical risk analysis ensures both ecological and human health protection over time. In summary, the analysis of soil samples from Tolworth Court Farm identifies heightened concentrations of Cadmium (Cd) and Lead (Pb), suggesting potential risks to both public safety and environmental preservation.

It is crucial to investigate the sources of contamination and implement appropriate land-remediation measures to mitigate these risks and ensure the land's safety for residential use. Additionally, ongoing monitoring of metal concentrations, even those within regulatory limits, is recommended to detect any future changes.

## 5. Conclusions

The Tolworth Court Farm soil quality evaluation reveals a considerable range in metal concentrations throughout the property, with Section A displaying high levels of Lead, Nickel, Chromium, and Cadmium. These increased amounts are probably caused by the site's closeness to the main road, indicating contamination by traffic. Moreover, there are higher concentrations of Copper and Zinc in Section B, which is next to Section A and has bike and pedestrian pathways.

These are most likely caused by tyre wear and the dust that it produces. Given the site's planned development into a residential area with garden areas, the elevated amounts of metals, especially Cadmium, represent potential dangers to both the human and environmental health. It is advised that these hazards be reduced by using Phyto stabilization techniques, adjusting the pH of the soil, establishing vegetative barriers to limit exposure to possible contaminants, conducting continuous monitoring, and launching public awareness programs. Raising the pH of the soil may aid in lowering the mobility and bioavailability of heavy metals, halting additional pollution. These tactics seek to lessen metal movement, protect incoming occupants, and advance the site's sustainable growth.

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