

Determination of Heavy Metal Levels in Soil Samples from Selected Areas in Nairobi County

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ABSTRACT

Heavy metals play a dual role in soil ecosystems, being essential for biological and biochemical processes crucial for crop development, with elements such as zinc, copper, and iron serving as vital micronutrients for plant growth. Zinc, for instance, is fundamental for enzyme function, protein synthesis, and immune response. However, the presence of these elements in excessive concentrations, often a direct consequence of human activities, can lead to significant toxicity, thereby posing a substantial threat to both environmental integrity and ecosystem health. This inherent tension between essentiality and toxicity underscores the complex challenge of environmental management, which must focus on maintaining concentrations within a beneficial-to-safe range rather than pursuing outright elimination. This approach is critical for establishing appropriate environmental thresholds and addressing the multifaceted nature of pollution. Soil contamination by heavy metals represents a major environmental concern due to their inherent persistence in the environment and their propensity to accumulate within the food chain. Primary sources of such contamination include industrial operations, improper waste disposal practices, agricultural runoff, and vehicular emissions. This study specifically analyzed heavy metal concentrations in soil samples collected from petrol stations and a designated control site within Nairobi County. The investigation focused on quantifying levels of lead, cadmium, chromium, and nickel using atomic absorption spectroscopy. The findings revealed distinct contamination trends directly linked to fuel-related activities, providing valuable information for the development of effective environmental management strategies and targeted remediation efforts.

Keywords: Heavy metals, Soil contamination, Petrol stations, Nairobi County, Lead, Cadmium, Chromium, Nickel, Atomic Absorption Spectroscopy, Environmental management, Remediation.

INTRODUCTION

The pervasive issue of soil contamination, particularly by heavy metals, constitutes a critical environmental concern. Elements such as lead (Pb), cadmium (Cd), arsenic (As), and mercury (Hg) are widely recognized for their toxic effects on living organisms and their tendency to accumulate within various ecosystems. The impetus behind this research stems from an urgent necessity to comprehend and mitigate the potential health and environmental risks associated with anthropogenic activities, especially those concentrated around petrol stations, which are known to be significant point sources of environmental contamination.

While heavy metals naturally occur in the environment, typically at trace concentrations, they rarely exhibit toxicity under natural conditions. However, human activities, including industrial emissions, the combustion of fossil fuels, and inadequate waste disposal, have dramatically increased their environmental concentrations. This anthropogenic input disrupts the natural geochemical balance, accelerating the accumulation of these metals beyond safe thresholds and consequently posing substantial risks to human health, plant and animal life, and broader ecosystems. A critical aspect of this contamination is the non-biodegradable nature of heavy metals, which allows them to persist in soils for decades, potentially accumulating to toxic levels. Furthermore, the mobility, availability, and retention of these contaminants within the soil matrix are significantly influenced by various physicochemical parameters of the soil, such as pH, electrical conductivity, and moisture content.

Statement of Problem

In recent years, the environmental ramifications of human activities have become an escalating concern,

particularly within rapidly urbanizing regions like Nairobi County. One of the most pressing environmental challenges is the contamination of soil by heavy metals. These toxic elements, including lead (Pb), cadmium (Cd), chromium (Cr), and nickel (Ni), are known for their prolonged persistence in the environment and their capacity to accumulate in the food chain, thereby presenting severe risks to both ecosystems and human health. Chronic exposure to heavy metals has been definitively linked to a spectrum of adverse health outcomes, including neurological disorders, kidney damage, and various forms of cancer. The problem is particularly acute in urban and industrial areas where activities such as fuel handling, industrial emissions, vehicular traffic, and improper waste disposal contribute to elevated levels of heavy metals in the soil. Petrol stations are of specific concern, as fuel spills and leaks can lead to localized, yet substantial, contamination of the surrounding environment. This direct causal link between urban infrastructure, such as petrol stations, and environmental degradation highlights that development, while essential, carries inherent environmental costs. Therefore, future urban planning and infrastructure development must integrate robust environmental impact assessments and preventative measures from the outset, moving beyond merely reactive remediation to embrace proactive design.

Despite the well-documented risks, there remains a notable absence of localized data concerning the extent of soil contamination by heavy metals in many areas of Nairobi County. This data gap is not merely an academic void; it represents a significant barrier to the formulation and implementation of effective environmental policies and public health interventions. Without specific, localized empirical data, policymakers face considerable challenges in accurately assessing risks, prioritizing remediation efforts, or designing targeted regulations. Consequently, understanding the distribution and concentration of heavy metals across diverse environments, especially areas with varying degrees of human activity, is paramount for assessing public health risks and informing environmental management policies. This study, by providing such foundational data, plays a crucial role in enabling evidence-based environmental governance in urban settings, directly linking scientific research to practical policy implementation. This project aims to analyze and compare the concentrations of selected heavy metals in soil samples collected from three distinct sites within Nairobi County. Two of these sampling points are situated near active petrol stations, areas anticipated to be significantly impacted by intense anthropogenic activities. The third sampling point is located in an area characterized by minimal human activity, intended to serve as a baseline or control site. By systematically comparing heavy metal levels across these diverse sites, this study seeks to establish a clear relationship between human activities, particularly those associated with fuel usage, and the accumulation of heavy metals in soil. The anticipated findings will contribute to a more profound understanding of pollution hotspots and support the development of effective strategies for soil remediation and broader environmental protection in urban areas.

General Objective

To determine the heavy metal levels in soil samples obtained from three selected sites in Nairobi County.

Specific Objectives

The specific objectives in the proposed study were to:

1. To assess the pH, electrical conductivity, and moisture content in soil samples collected from three selected sites in Nairobi County.
2. To determine the concentration of heavy metals in soil samples obtained near two petrol stations in Nairobi County.
3. To determine the concentration of heavy metals in soil samples collected from an area with minimal human activity in Nairobi County.
4. To compare the levels of heavy metals in soil samples from the three sampling points to evaluate the influence of anthropogenic activities.

MATERIALS AND METHODS

To achieve the objectives of this study, a systematic approach involving sample collection, preparation, and analysis was employed. The methodologies were designed to ensure precision and accuracy in the determination of heavy metal concentrations and physicochemical parameters in soil samples.

Study Area

The study was conducted within Kware ward, located in Embakasi Sub County, Nairobi County. This ward encompasses a catchment area of approximately 1.6 Km². Soil samples were strategically collected from three distinct sites identified as representative of potential soil contamination from petrol stations within Kware ward.

Table 1 Characteristics of Sampling Sites in Kware Ward, Nairobi County

Sampling site	Local name	Coordinates	Human activities
1	Kware stage	Latitude 0°33'32.74"S Longitude 37°3'9.12"E	Petrol station(15 years)
2	Kware rubis	Latitude 0°33'49.46"S Longitude 37°3'24.29"E	Petrol station(4 years)
3	Kware salon	Latitude 0°33'46.72"E Longitude 37°3'8.00"E	No human activities from the petrol station

The inclusion of site coordinates allows for precise geographical referencing, which is essential for reproducibility and for understanding the spatial distribution of contaminants. The clear delineation of human activities, particularly the operational age of the petrol stations, provides critical contextual variables for interpreting the analytical results, especially when assessing the impact of anthropogenic activities on heavy metal accumulation.

Instruments and Apparatus

The following instruments and apparatus were utilized during the study: 9 watch glasses, reagent bottles, an analytical weighing balance, 100ml and 250ml beakers, a 250ml conical flask, a hot plate, a desiccator, a spatula, an Atomic Absorption Spectrometer (AAS), and a conductivity meter.

Chemicals and Reagents

The chemicals and reagents employed for the laboratory work included hydrated copper (II) sulphate, hydrated zinc (II) sulphate, lead (II) nitrate, cadmium sulphate, hydrated chromium (II) chloride, concentrated hydrochloric acid, concentrated nitric acid, and distilled water.

Description of the Sampling Sites

The sampling sites were selected after careful consideration. Petrol stations are emerging to be a common site in our day day activities and thus it would be important to see how they impact to the living organisms around them. Two petrol stations were therefore selected in Kware ward and an area far away from petrol station also selected as the third sampling sites. This was important so as to compare the three sites and therefore give accurate results of this human activity. One of the petrol stations has been in operation for more than 15 years according to the residents whereas the other one is approximately 4 years old.

Sampling Sites Selection and Sample Collection

Soil samples were collected from five distinct points within each of the two selected petrol stations, and from one point in the designated control site, located away from petrol stations. At each sampling point, approximately 100 g of soil was dug using a hoe and scooped with a spade from a depth of 0-15 cm. These individual samples were then thoroughly mixed in sterilized aluminum foil to create a composite sample for each site. From each

composite sample, triplicate subsamples of 100 g were taken. Each subsample was wrapped in aluminum foil, labeled to indicate the collection site and date, and then transferred into a labeled self-sealing polythene bag. The

packaged samples were transported on the same day to the Department of Chemistry laboratory at the University of Nairobi for immediate analysis of pH, electrical conductivity, moisture content, organic carbon, and metal ion levels, as well as for further storage. All soil samples were analyzed within one day of collection.

Soil Physicochemical Parameters Determination.

Determination of physiochemical parameters involved assessing various properties including pH, electrical conductivity, moisture contents and organic carbon. These analyses help in evaluating the suitability of substances for specific purposes. Determination of physiochemical parameters utilizes tools like pH meters and conductivity meters.

Soil pH Determination

For pH determination, 2 grams of each soil sample were weighed and dissolved in 15 ml of distilled water. This procedure was performed in duplicates for each of the three sampling sites. The soil-water mixture was then carefully stirred using a magnetic stirrer to ensure homogeneity. A pH meter, which had been calibrated prior to use, was then inserted into the stirred solution, and the pH readings were recorded.

Soil Electrical Conductivity Determination

To determine the electrical conductivity (EC) of the soil samples, 2 grams of each soil sample were dissolved in 10 ml of distilled water and stirred to facilitate dissolution. The conductivity meter was calibrated by measuring the conductivity of a standard potassium chloride (KCl) solution and adjusting the instrument to match its known value. Following calibration, the electrical conductivity was measured for each of the three soil samples in duplicates, and the readings were recorded in micro Siemens per centimeter ($\mu\text{S}/\text{cm}$).

Soil Moisture Content Determination

The moisture content of the soil samples was determined gravimetrically. Initially, 2 grams of soil were weighed into a pre-weighed weighing tin with its lid. The tin containing the soil sample was then placed in an oven and dried to a constant weight at a temperature range of 105 °C to 110 °C for 24 hours. After drying, the tin with its contents was removed from the oven, the lid was replaced, and it was transferred to a desiccator to cool to room temperature. The weight of the tin and its dried contents was then measured, allowing for the calculation of the moisture content using the formula: $\times 100$.

Soil Organic Carbon Determination

An empty crucible was weighed and recorded before adding the sample. 2g of the sample was weighed and placed in the crucible. The contents of the crucible then put in the oven to dry and later removed to cool. The difference of the mass before putting the sample in the oven and after gave the moisture content. The muffle furnace was then set to the desired temperature and the sample was ignited for the 2 hours. Once cool, the crucible was then weighed again and the dry weight gave the organic content.

Heavy Metal Ion Levels Determination

Heavy metal analysis is an important process that is used to determine the levels of toxic heavy metals present in substances like water, soil and food, by employing techniques, such as atomic absorption spectroscopy, identification and quantification of heavy metals present in a sample accurately are obtained.

Soil Samples Digestion for Heavy Metal Analysis

Prior to heavy metal analysis, solid soil samples underwent a digestion process to convert them into a homogeneous solution. For each sample, 1g of soil was accurately weighed using an analytical balance and transferred into a 250ml conical flask. Subsequently, 25ml of aqua regia (a 3:1 mixture of concentrated hydrochloric acid and nitric acid) was added to the soil. The contents of the conical flask were then heated on a hot plate under a fume hood to facilitate the evaporation of nitrogenous compounds. This digestion procedure

was performed in duplicates for each soil sample, and a blank sample, containing only 25ml of aqua regia, was prepared and treated identically. After evaporation to near dryness, the solutions were allowed to cool. Filtration was then performed using Whatman filter paper. The resulting filtrate was transferred to a 50ml volumetric flask and topped up to the mark with distilled water. The digested solutions were then stored in reagent bottles, ready for analysis using the Atomic Absorption Spectrometer

Figure 1 A photo showing digestion of the soil samples



Preparation of Heavy Metal Stock and Standard Solutions

Stock solutions and standard solutions for heavy metal analysis were prepared with meticulous precision. Initial stock solutions of 1000 ppm (parts per million) were prepared by accurately weighing specific masses of the respective metal salts: Heptahydrate zinc (II) sulphate, copper sulphate pentahydrate, lead nitrate, cadmium

chloride, and hydrated chromium chloride. Each weighed salt was then dissolved in 1000 ml of de-ionized water to achieve the desired 1000 ppm concentration. Subsequently, working standard solutions were prepared by serially diluting these 1000 ppm stock solutions to concentrations of 100 ppm, 50 ppm, 10 ppm, 5 ppm, 1 ppm, 0.5 ppm, and 0.01 ppm.

Figure 2 A photo showing analysis for heavy metals using AAS



Soil Samples Analysis using Atomic Absorption Spectroscopy (AAS)

Following the digestion of the soil samples, the analysis for selected heavy metals—Zinc (Zn), Copper (Cu), Lead (Pb), Cadmium (Cd), and Chromium (Cr)—was performed using an Atomic Absorption Spectrometer (AAS) Shimadzu 6300.[1, 1] For each heavy metal under investigation, five calibration standard curves were prepared to ensure accurate quantification. Each metal was analyzed using a specific hollow cathode lamp

designed for that element. Samples were aspirated into the AAS flame, where the elements were atomized (converted into ground state free atoms in the vapor state). A light beam, characteristic of the element being analyzed, was directed through the flame into a monochromator and then onto a detector, which measured the amount of light absorbed by the atomized element in the flame. The principle of AAS relies on the fact that atoms of different elements absorb characteristic wavelengths of light; for example, a lamp containing lead emits

light that is specifically absorbed by lead atoms in the sample. The greater the number of atoms in the vapor, the more radiation is absorbed, with the amount of light absorbed being proportional to the number of atoms present. This method is relatively free from spectral or radiation interference due to the use of a source lamp composed of the specific element being analyzed. The optimum conditions and limits of detection for the heavy metals determined using AAS are presented in Table 2.

Table 2: Optimum Conditions and Limits of Detection for Heavy Metals Determined Using AAS

Elements	Wavelength. (nm)	Flame/gases	Limit detection (mg/L)
Zn	213	Air/acetylene	0.01
Cu	324.7	Air/acetylene	0.01
Pb	217	Air/acetylene	0.01
Cd	228.6	Air/acetylene	0.01
Cr	359	Air/acetylene	0.01

After analysis, the concentration of each element in the soil samples was determined by interpolating the absorbance readings against calibration graphs, which were constructed by plotting the absorbance values of the prepared standards against their known concentrations.

Data Analysis

The quantitative data obtained from the study were subjected to statistical analysis using a one-way Analysis of Variance (ANOVA). This statistical method was employed to ascertain whether there existed a significant difference in the mean values of the heavy metals across the different sampling sites. The P-value and the F-critical value derived from the ANOVA were utilized to compare the mean heavy metal levels obtained from the three areas under investigation.

RESULTS AND DISCUSSION

This chapter presents and discusses the results obtained from the analysis of soil samples, including the physicochemical parameters and heavy metal concentrations. The calibration curves, which were essential for determining the concentrations of the metals, were plotted using the absorbance values and corresponding concentrations of the standards.

Introduction

In this chapter, the results obtained are presented and discussed. The calibration curves were plotted using the values of absorbance and concentrations of the metals.

pH Values

The physicochemical characteristics of soil, such as pH, electrical conductivity, and moisture content, are crucial indicators that often correlate with the retention and mobility mechanisms of heavy metals within the soil matrix. The pH values of the soil samples from the different sampling sites are presented in Table 3.

Table 3: Soil pH Values Across Sampling Sites

Sampling sites	pH $\pm$ SD
Petrol station -Kware stage	7.79 $\pm$ 0.02
Petrol station-Rubis energy	8.30 $\pm$ 0.04
Away from petrol station-Kware Salon	5.70 $\pm$ 0.03

The pH values indicate that the soil samples from the petrol station sites (Kware stage and Rubis energy) were alkaline, with mean pH values of 7.79 $\pm$ 0.02 and 8.30 $\pm$ 0.04 respectively. In contrast, the control site (Kware Salon) exhibited acidic conditions with a mean pH of 5.70 $\pm$ 0.03. Soil pH significantly influences the mobility and bioavailability of heavy metals; acidic conditions generally increase the solubility and mobility of metals like lead, cadmium, and nickel, thereby increasing the risk of groundwater contamination and plant uptake. While the alkaline conditions observed at the petrol stations might suggest some immobilization of certain metals, the overall high concentrations of heavy metals at these sites, as discussed later, still indicate significant accumulation.

Electrical Conductivity

The electrical conductivity (EC) of the soil samples, which reflects the concentration of dissolved salts and other soluble substances, is shown in Table 4.

Table 4: Soil Electrical Conductivity ($\mu\text{S}/\text{cm} \pm \text{SD}$) Across Sampling Sites

Sampling sites	Electrical Conductivity ($\mu\text{S}/\text{cm} \pm \text{SD}$)
Petrol station -Kware stage	175 $\pm$ 3
Petrol station-Rubis energy	80 $\pm$ 2
Away from petrol station-Kware Salon	15 $\pm$ 5

Kware Stage petrol station exhibited the highest EC value (175 $\mu\text{S}/\text{cm} \pm 3$), suggesting elevated levels of dissolved ions, including heavy metals and other soluble substances. This elevated conductivity is consistent with the potential presence of petroleum hydrocarbons and other chemicals that can alter soil chemistry, increasing the concentration of dissolved solutes from fuel spills, vehicle emissions, and lubricants. Rubis Energy's lower EC (80 $\mu\text{S}/\text{cm} \pm 2$) implies a comparatively reduced level of contamination by such substances, while the control site (Kware Salon) showed the lowest EC (15 $\mu\text{S}/\text{cm} \pm 5$), confirming minimal anthropogenic influence on its salinity. High salt concentrations can influence metal solubility and transport, potentially enhancing the leaching of metals into groundwater or increasing their availability for plant uptake.

Moisture Content

Table 5: Soil Moisture Content (%) Across Sampling Sites

Sampling sites	Value of moisture content in percentage (%)
Petrol station -Kware stage	5.40
Petrol station-Rubis energy	10.78
Away from petrol station-Kware Salon	13.99

The petrol station sites generally exhibited lower moisture content (Kware Stage: 5.40%; Rubis Energy: 10.78%) compared to the control site (Kware Salon: 13.99%). This observation aligns with existing literature suggesting that soils contaminated with heavy metals often exhibit reduced water retention capacity. Heavy metals, particularly lead, can alter soil structure by disrupting the aggregation of soil particles, which in turn reduces porosity and water-holding capacity. This finding further supports the negative impact of heavy metal pollution on overall soil health and its hydrological properties.

Levels of Heavy Metal

The concentrations of the analyzed heavy metals (Lead, Copper, Zinc, Cadmium, and Chromium) in the soil samples from the three sampling sites are detailed in Table 6. This table provides the core quantitative findings of the study, directly addressing the objectives by presenting the empirical data necessary to assess contamination levels and the influence of anthropogenic activities.

Table 6: Concentrations of Heavy Metals (mg/kg) in Soil Samples Across Sampling Sites

Sampling sites	Lead (mg/kg)	Copper (mg/kg)	Zinc (mg/kg)	Cadmium (mg/kg)	Chromium (mg/kg)
Petrol station -Kware stage	7.1629 ± 0.78	0.3823±0.07	10.7242±1.02	0.1273±0.04	16.7245±2.03
Petrol station-Rubis energy	5.8950±0.63	0.2535±0.05	5.2774±0.89	0.0182±0.03	5.0424±00.98
Away from petrol station-Kware Salon	2.0912±0.54	0.6217 ±0.09	7.43702±0.75	0.002±0.007	1.7827±00.65

DISCUSSION

The results clearly indicate that soil samples collected from the vicinity of petrol stations exhibited relatively higher concentrations of most heavy metals compared to the control site. This observation strongly suggests a direct anthropogenic influence on the heavy metal content of the urban soils studied. The Kware stage petrol station consistently showed the highest concentrations of lead, cadmium, zinc, and chromium. This finding is particularly noteworthy when considering the operational age of the petrol stations. Kware stage has been in operation for approximately 15 years, while Rubis energy petrol station has been active for about 4 years. The consistently higher levels of these heavy metals at the older Kware stage site compared to the newer Rubis energy site suggest a cumulative effect of contamination over time. This indicates that heavy metal pollution is not merely an acute event resulting from individual spills but rather a chronic process of accumulation in the soil.

This observation implies that older urban infrastructure sites may necessitate more intensive and urgent remediation efforts than newer ones, and it underscores the critical importance of implementing robust preventative measures at newer stations to mitigate future accumulation. Such a trend highlights the need for long-term environmental monitoring strategies that factor in the age and operational history of potential contamination sources.

Lead (Pb): Lead concentrations were significantly higher at Kware stage (7.1629 mg/kg) and Rubis energy (5.8950 mg/kg) compared to the control site (2.0912 mg/kg). This aligns with lead's historical use as a gasoline additive and its continued presence as an environmental contaminant stemming from vehicular emissions, tire and brake wear, and fuel spills. Lead poses substantial health risks, including neurological disorders, kidney damage, and developmental issues in children, while also negatively impacting soil fertility and aquatic life.

Cadmium (Cd): Cadmium levels were notably elevated at Kware stage (0.1273 mg/kg) and Rubis energy (0.0182 mg/kg) when contrasted with the control site (0.002 mg/kg). Cadmium is a recognized heavy metal poison with no known essential biological function and can be introduced into the environment as a contaminant in gasoline or from the metal components within petrol station infrastructure. Chronic exposure to cadmium can lead to severe health problems, including kidney damage and respiratory issues if inhaled.

Chromium (Cr): Chromium concentrations were highest at Kware stage (16.7245 mg/kg) and Rubis energy (5.0424 mg/kg) compared to the control site (1.7827 mg/kg). While trivalent chromium (Cr III) is an essential nutrient, hexavalent chromium (Cr VI) is highly toxic, mutagenic, and carcinogenic. Its presence in soil can be linked to petroleum products and their combustion. The high solubility of hexavalent chromium makes it particularly hazardous, as it can easily move through soil and groundwater, posing significant environmental and health risks.

Zinc (Zn): Zinc levels were elevated at Kware stage (10.7242 mg/kg) and Rubis energy (5.2774 mg/kg) compared to the control site (7.43702 mg/kg). Although zinc is an essential micronutrient for plants, it becomes phytotoxic at elevated concentrations, interfering with root development, nutrient uptake, and photosynthesis, and disrupting soil microbial activity. Zinc is also a common component of vehicle tires, contributing to roadside and urban soil contamination through wear and tear.

Copper (Cu): An unexpected finding was that copper levels were highest at the control site (0.6217 mg/kg) compared to both petrol stations (Kware stage: 0.3823 mg/kg; Rubis energy: 0.2535 mg/kg). This deviation from the general trend observed for other heavy metals suggests that the "control" site may not be entirely pristine for all pollutants. It is plausible that copper contamination in this specific area originates from different, non-fuel-related anthropogenic sources. For instance, the literature review notes that trace metals from copper-based pesticides are significant sources of contamination in agricultural soils. This highlights the inherent complexity of environmental studies, where multiple pollution sources can exist simultaneously, and underscores the need for more comprehensive baseline characterization of "control" sites. Such a finding suggests a valuable avenue for future research to precisely identify the specific origin of copper in this particular area.

The permissible Limit Level ranges in Soil (mg/kg)/Toxicological by WHO include; Chromium (Cr) 50 – 200. It exists mainly as Cr(III) and Cr(VI); Cr(VI) is far more toxic, carcinogenic, and mobile than Cr(III). Cadmium (Cd) 0.5 – 3 Highly toxic; accumulates in crops and enters the food chain; long biological half-life in humans. Zinc (Zn) 100 – 300 Essential micronutrient for plants and animals; toxic in excess, causing growth inhibition and soil–plant imbalance. Copper (Cu) 30 – 100. Essential trace element but toxic at high concentrations; excess leads to soil toxicity and crop yield reduction. Lead (Pb) 50–300. Persistent, neurotoxic, especially harmful to children; accumulates in soil with minimal natural attenuation.

Overall, the findings confirm that soil samples collected from around petrol stations generally exhibit higher heavy metal concentrations, providing clear evidence of anthropogenic influence.

CONCLUSION AND RECOMMENDATION

Conclusion

The proposed project aims to contribute to the growing body of knowledge on heavy metal contamination in soil by comparing areas affected by petrol stations to those in untouched environments. Through meticulous sampling, analysis, and interpretation, the study seeks to highlight the environmental and health implications of soil contamination, laying a foundation for informed decision-making and potential mitigation strategies.

The findings reveal that heavy metal levels near petrol stations are higher than in areas farther away. However, these levels remain below the WHO's permissible limits, indicating that while contamination exists, it is still within acceptable and controllable levels. Notably, the area around Kware stage was identified as the most polluted, while the soil quality in areas away from petrol stations is relatively higher, reflecting lower concentrations of heavy metals. Ultimately, the insights gained from this research contribute to the broader discourse on environmental sustainability and public health, underscoring the importance of monitoring and managing pollution near petrol stations.

This study contributes to the understanding of heavy metal contamination in soils by comparing petrol station-affected areas with undisturbed environments, revealing that while heavy metal levels near petrol stations exceed those in control sites, they remain below WHO permissible limits, indicating contamination exists but is currently within manageable thresholds. The most polluted site, Kware Stage, contrasts with less contaminated

areas farther from petrol stations, demonstrating a clear anthropogenic influence on soil quality. By systematically analyzing these findings, the research underscores the need for ongoing monitoring and targeted mitigation strategies near fuel stations, offering actionable insights to support environmental sustainability and public health protection

Recommendation

Given the identified elevated heavy metal levels near petrol stations in this study, the following measures are recommended to mitigate potential risks to environmental and human health:

1. **Frequent Assessment:** The levels of heavy metal contaminants in these areas should be frequently assessed to ensure that their concentrations remain within permissible ranges.
2. **Public Awareness and Sensitization:** Comprehensive sensitization and awareness campaigns should be developed and implemented for individuals living and working around petrol stations, as they are at a higher risk of exposure to heavy metals.
3. **Infrastructure Improvement:** The infrastructure surrounding petrol stations should be improved to prevent leakages and spills, thereby reducing the direct release of contaminants into the soil.
4. **Health Surveillance Programs:** Health surveillance programs should be established for people residing in the vicinity of petrol stations to monitor for any early signs of heavy metal poisoning.
5. **Cost-effective soil remediation:** Where contamination is confirmed, employ sustainable in-situ clean-up methods. Phytoremediation planting metal accumulating species like vetiver grass or certain ferns can extract Pb, Cu, Zn, Cd and Cr from soil over time. Soil stabilization e.g. adding lime, biochar or phosphates can immobilize metals and reduce leaching.

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