

Environmental Safety and Management of Heavy Metals along Machakos Road, Nairobi County, Kenya

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Abstract

Environmental pollution falls within the sustainable development goals agenda, climate action, and the purview of the laws of Kenya. Environmental protection is paramount in the sustainable use of natural resources for the sake of future generations. Heavy metals occurring naturally or anthropogenically severely affect humans and the environment when they exceed their concentration standards. This research aimed to assess the heavy metal elements present and examine physio-chemical properties of the soil. The study utilized experimental encompassing an assessment of selected heavy metals in the study area. Soil and ground water samples were collected to determine the heavy metal concentrations using the X-ray fluorescence (XRF) analytical method. The data was collected from seven sample sites with 56 samples collected. Soil and water quality parameters exhibited notable spatial variation, with the Industrial Area showing the highest electrical conductivity at 987.45 $\mu\text{S}/\text{cm}$ (soil) and 1428.44 $\mu\text{S}/\text{cm}$ (water). The Construction site recorded the most acidic soil at pH 4.48, while Residential and Off-Road Runoff areas showed the highest soil moisture at 12.61% and 31.95%, respectively. Elevated levels of heavy metals such as Fe (up to 3.75 ± 0.54 mg/L), Zn (5.32 ± 0.45 mg/L), and Pb (0.20 ± 0.02 mg/L) were recorded, exceeding WHO permissible limits in industrial, dumpsite, and runoff sites. Soil pH ranged from 4.48 (construction) to 7.3 (control), with high electrical conductivity observed in the industrial area (987.45 $\mu\text{S}/\text{cm}$), indicating enhanced metal solubility and mobility. Concentrations of Mn, Fe, Zn, Se, and Cd were found to be significantly above WHO permissible limits at $P \leq 0.05$. The research is a positive contribution to science since it aids in quantitatively identifying toxic substances and heavy metal pollution within the area of interest.

Keywords

Heavy Metals, Urban Pollution, Environmental Conservation, Water and Soil Quality

1. Introduction

Environmental safety and management in Kenya are guaranteed by the constitution in the Environmental Management and Coordination Act of 1999, which started its implementation in the year 2000 (Government of Kenya, 2015). Article 42 ensures the right to a clean and healthy environment and its protection for the sake of the future generation. Article 69 foresees the sustainable use, conservation, and management of natural resources like water for the benefit of all. Kleespies & Dierkes (2022) describe sustainable development of resources as the use of natural resources to meet the population's current needs without compromising the availability of those resources for future generations.

One way natural resources are compromised is through pollution by heavy metals naturally and through human influence (Sanchez-Bayo, 2011) and (El Ati-Hellal & Hellal, 2021). Environmental pollution, in most cases, is always synonymous with industrialization and technological advancements. Industrial installations are major producers of heavy metals, namely: As, chromium (Cr), lead (Pb), cadmium (Cd), and mercury (Hg), Arsenic (As), copper (Cu), zinc (Zn), and nickel (Ni). Numerous health complications, such as respiratory tract infections, are attributed to heavy metal poisoning/pollution. However, it is important to note that heavy metals occur in nature but in micronutrients well below the set World Health Organization standards, proving relatively safe to man and the environment.

Heavy metals are well-known environmental pollutants owing to their toxicity, longevity in the atmosphere, and ability to accumulate in the human body via bioaccumulation. The pollution of terrestrial and aquatic ecosystems with toxic heavy metals is a major environmental concern that has consequences for public health. Most heavy metals occur naturally, but a few are derived from anthropogenic sources (Briffa et al., 2020). Heavy metals are characterized by their high atomic mass and toxicity to living organisms. Most heavy metals cause environmental and atmospheric pollution, and may be lethal to humans. Heavy metals can become strongly toxic by mixing with different environmental elements, such as water, soil, and air, and humans and other living organisms can be exposed to them through the food chain (Mitra et al., 2022).

Cities in Africa display various aspects of waste management issues, including the presence of uncontrolled garbage heaps, littered roadsides filled with refuse, blocked streams contaminated with inappropriate disposal of toxic waste, and hazardous disposal sites located near residential areas. These problems have been documented in studies conducted by Oteng-Ababio et al., (2013), and Godfrey et

al. (2019). Additionally, uncontrolled urban sewage farming is a widespread problem in African cities, posing a significant risk to consumers who may be exposed to heavy metal poisoning from the produce grown in such areas (Ogutu et al., 2021). Exposures of heavy metals trace their source to anthropogenic activities, human interference. Contact points to heavy metal pollution through direct ingestion, skin contact, or breathing in foods irrigated using polluted water, open dumpsites, and air pollution (Witkowska et al., 2021).

In urban areas of Kenya, heavy metals primarily originate from solid waste, which includes household food preparation, cooking, and serving waste, as well as market waste from the storage and sale of produce and meals. The presence of these wastes attracts various animals like birds, rats, flies, and others to the waste dumps. Unfortunately, these animals can transmit diseases to the people living nearby (Witkowska et al., 2021). Additionally, the solid waste comprises non-biodegradable materials such as paper, plastics, clothes, rubber, leather, bottles, glass, ceramics, and metal cans, as well as ashes, street sweepings, abandoned vehicles, non-hazardous industrial waste, and construction and demolition waste (Witkowska et al., 2021).

Nairobi city is grappling with significant challenges in heavy metal pollution. Numerous residential areas in the city are plagued by littered garbage, which, when eventually collected, often ends up in soils and waterways (Ogutu et al., 2021). Unfortunately, this unsustainable waste collection poses a high risk of environmental pollution. The selection of these disposal sites has been driven more by convenience than by considering environmental safety, leaving both surface water and groundwater vulnerable to contamination from the heavy metal. As of now, the extent of soil and water pollution in and around the industrial area remains uncertain due to the lack of comprehensive pollution assessment studies conducted on the heavy metal pollution. Heavy metal pollution has been accelerated by anthropogenic activities in the recent past. Machakos Road lies in an industrial zone within Nairobi. Untreated effluent, land, and air pollution may be the study area's primary heavy metal contaminants. Urban settings are rapidly developing, and various economic activities contribute to heavy metal pollution. Therefore, upon this background, this research seeks to assess the level of heavy metal pollution within the Machakos road area and its surrounding areas to determine the contamination levels. This research employs a selected number of environmental contamination assessment techniques and other advanced methods that may be used to increase confidence and acquire results that are more accurate.

2. Literature Review

2.1. Heavy Metal Elements Present in Environment

Heavy metals pose significant risks to both human health and the environment due to their toxicity, persistence, and bio accumulative nature. Research conducted by Sanchez-Bayo (2011) and Mitra et al. (2022) has comprehensively examined the impact of these inorganic contaminants, identifying elements such as

chromium (Cr), lead (Pb), cadmium (Cd), mercury (Hg), arsenic (As), copper (Cu), zinc (Zn), and nickel (Ni) as particularly hazardous. These metals interfere with essential physiological functions by binding to biomolecules, impairing enzymatic activity, and disrupting processes such as oxygen transport. For instance, arsenic and antimony inhibit ATP synthesis by obstructing phosphorylation, while cadmium, when inhaled, acts as a carcinogen and interferes with metabolic systems by displacing vital minerals like calcium, zinc, and magnesium.

Nickel is classified as a carcinogen, and chromium, especially in its hexavalent state (Cr^{6+}), exhibits mutagenic effects. Copper can inhibit germination in algae and fungi, disrupt sodium regulation in aquatic organisms, and potentially lead to cirrhosis and liver damage in mammals. Organomercury compounds are particularly dangerous due to their ability to bind to sulfhydryl groups and impair nervous system function. Lead, a common pollutant, interferes with hemoglobin synthesis and nerve conduction (Sanchez-Bayo, 2011).

In Kenya, lead contamination remains a pressing concern, with children being especially vulnerable to environmental exposure through contaminated dust. Lead's non-biodegradable nature and its persistence in the environment—aggravated by industrial activities such as mining, manufacturing, and fossil fuel combustion—have heightened its toxicological impact (Loh et al., 2016).

Manganese, while essential in small amounts, becomes harmful when consumed excessively. It is released into the atmosphere during the combustion of gasoline additives like methylcyclopentadienyl manganese tricarbonyl (MMT), forming manganese oxides that contribute to air pollution. Chromium exists primarily as chromium (III) and chromium (VI), with the former being less toxic. Industrial activities can cause the interconversion of these forms, and emissions from ferrochrome industries significantly exceed natural sources of chromium (Coetzee et al., 2020).

Cobalt, though naturally occurring in various ecosystems—soil, water, and plants, can cause environmental and health hazards when concentration builds up. Nickel, abundant in the environment, is released through both natural and anthropogenic sources. Chronic exposure to airborne nickel has been linked to allergic reactions, lung and nasal cancers, as well as cardiovascular and kidney disorders (Geng & Wang, 2019; Genchi et al., 2020).

Copper plays a critical role in plant physiological processes such as photosynthesis and protein metabolism. While essential in trace amounts, excess copper is toxic to flora and fauna. Similarly, zinc, which is vital for numerous enzymatic processes, can become harmful when its environmental concentration surpasses safe limits. Zinc pollution is primarily attributed to mining and smelting, and it poses serious risks to both ecosystems and human populations (Genchi et al., 2020).

2.2. Physio-Chemical Properties of the Soil and Sediments

Soil quality influences its basic functions, such as retaining water, promoting bio-

diversity, supporting agriculture, and resisting flooding, erosion, and landslides. Maintenance of soil quality is critical for ensuring the sustainability of the environment and the biosphere. Previous soil research has been largely concentrated on agricultural (Chen et al., 2016), forest (Chen et al., 2016), and typical grassland soils. Recently, ecological restoration has been widely discussed with increasing awareness of environmental conservation issues, and considerable documentation regarding slope soil, particularly slope restoration and stabilization. (Chen et al., 2016), examined the role of vegetation in the unsaturated region for stability of shallow soils, and found that vegetation helps to control soil loss and stabilize cut slopes, because vegetation soil systems enhance the soil shear strength.

Bioavailability is a critical facet of metal toxicity. Although past studies have investigated the individual role of sediment physico-chemical properties in relation to the bioavailability of heavy metals, their collective effects are little known. Further, limited knowledge exists on the contribution of nutrients to metal bioavailability. In this study, the influence of physico-chemical properties of sediments, including total organic carbon, total phosphorus, total nitrogen, cation exchange capacity, specific surface area, and mineralogical composition on metal bioavailability is reported. The weak-acid extraction method was used to measure Cd, Cr, Cu, Ni, Pb and Zn as the potentially bioavailable fraction in sediments in an urban creek (Miranda et al., 2021).

The results confirmed that Cu has a strong selectivity for organic matter ($r = 0.814$, $p < 0.01$). Cr bioavailability was influenced by either sediment mineralogy, nutrients, CEC or SSA. Zn, Ni and Pb showed strong affinity to mineral oxides, though their preferred binding positions were with nutrients, particularly organic matter ($r = 0.794$, 0.809 , and 0.753 , $p < 0.01$, respectively). The adsorption of Cd was strongly influenced by the competition with other metals and its bioavailability was weakly influenced by ion exchange (CEC: $r = 0.424$, $p < 0.01$). The study results indicate that nitrogen and phosphorus compounds can elevate metal bioavailability due to complex reactions. Generally, the estuarine area was more favorable for the adsorption of weakly bound metals. This is concerning as estuaries generate high biogeochemical activity and are economically important (Miranda et al., 2021).

2.3. The Level of Risk Posed by Heavy Metal Pollution within the Environment

The harmful effects of heavy metals on the bodies of human beings when consumed beyond the healthy limits are referred to as biotoxicity. Diarrhea, tremors, ataxia, vomiting, convulsions and paralysis are general signs associated with heavy metal poisoning particularly: cadmium, zinc, mercury, aluminum, copper, Arsenic and lead (McCluggage, 1991). Effects of heavy metal poisoning are classified as acute, chronic and sub-chronic: mutagenic, teratogenic, carcinogenic and neurotoxic, depending on the type of exposure. Cadmium is toxic at very low concen-

trations, and exposure short to long term would lead to renal and kidney failure systems. High-level exposures lead to lung failure due to the accumulation of watery fluids in the lung tissue, according to (McCluggage, 1991; European Union, 2002; Young, 2005). Lead is a common heavy metal pollutant in Kenya, with severe effects. In the recent past lead contamination has affected people at the Coast. It causes a teratogenic effect on living organisms, it serves as an effective enzyme inhibitor causing kidney failure, cardiovascular system damage and damage to the central nervous system (Ogwuegbu & Muhanga, 2005). According to (Udedi, 2003) lead causes poor brain tissue development in children causing low intelligence quotient and related retardation. Mercury poisoning in particular causes pink disease which manifests as rashes and desquamation of the foot and hand, damage to the brain, central nervous system and neurological problems (Ferner, 2001). Arsenic causes carcinogenic effects, and it may occur naturally or caused by anthropogenic activities, high level exposures to Arsenic may fatal (Ogwuegbu & Ijioma, 2003; USDOL, 2004).

3. Methods and Materials

3.1. Study Area

The study area lies in the city of Nairobi's industrial area, characterized by commercial buildings, industrial warehouses, and laboratories (Figure 1). Nairobi is the capital city of Kenya, with an approximate population of 4.8 million people. The air quality is poor, with major emitters being automobiles powered by fossil fuel. It is bound within the coordinates 10.18'26"S, 36050'19"E. The area is located in a relatively flat and undulated area in comparison to the other immediate surroundings.

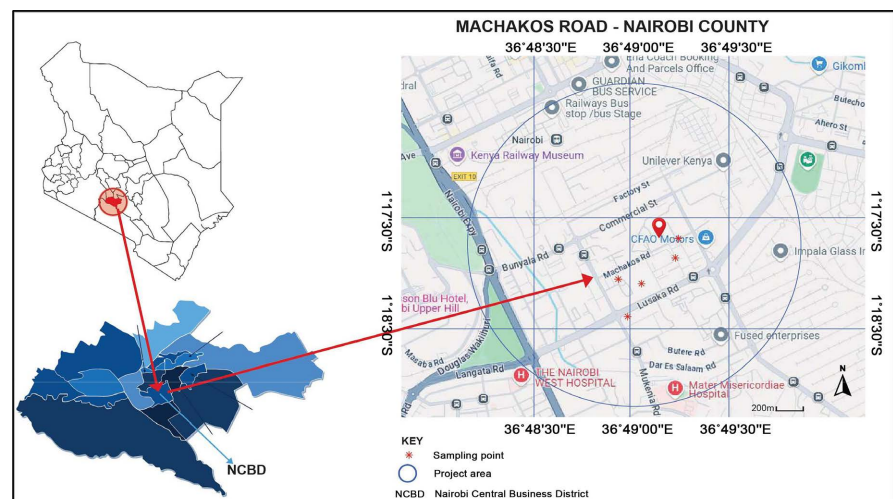


Figure 1. Study area.

3.2. Research Design

The study utilized a purposive nonprobability sampling design, aimed at selecting

cases that best fulfill the information needs of the study. Specifically, the study targeted areas along Machakos Road within a radius of 1 km near Madini House off Machakos Road, Nairobi County. The heavy human activities in the areas of construction and research, waste disposal, disposal of processed and unprocessed stockpiled materials easily find a way into waterways (Nairobi River). The locomotive operations. Office litter, sink taps, open pits, sink basin traps, stockpiles, trenches within laboratory warehouse, dust chutes, sewage system and uncharacterized wastes are major areas to sample and analyze as per the project aim and objectives

3.3. Sample Collection and Sampling Procedure

Grid sampling was employed within the study area to collect the soil and water sludge samples. Water samples from one of the boreholes within the vicinity were done in a five-liter container from the pumping station. The soil sample was collected at about two-five cm depth composite pit. A riffle splitter was used in sample mixing and quartering and reduction to have a representative sample of the desired weight. This ensures we reduce the skewness and biases of the data collected.

The fresh collected soil samples are placed in a clean, clear sampling bag sealed to reduce the risk of artificial contamination. The samples are then transported to the laboratory for wet chemistry analysis. Blank samples are also prepared and coded to ensure accurate results are delivered from the analyst. A control point is also identified within 1 km buffer zone sampling area off Machakos Road, Nairobi; this is considered to have the least possible anthropogenic contamination from heavy metals and other substances.

Data collection was by randomized sampling, this followed an experimental design with three treatments and four replicates per sample treatment. Twenty-five soil samples comprised an individual analysis sample, from which 3 - 4 duplicate samples were drawn and fully mixed before analysis. The samples were obtained from 5 - 8 cm beneath the soil surface, as the backfill soil cover was less than 10 cm. Soil moisture was determined immediately after sampling using the laboratory oven dry and cutting ring methods, respectively. This was maintained at a temperature of less 27°C for four hours so as to monitor volatile elements.

3.4. Data Collection

On-site measurements of water pH were conducted using a portable pH meter (Model: HI 8314 HANNA Instruments, Romania). The pH probe was immersed to a depth of approximately 10 cm, allowed to reach a stable state, and the corresponding pH reading was recorded.

The moisture content of soil affects the soil and water quality in an area. It is an important soil property as nutrient adsorption depends largely on moisture content.

On-site measurement of surface water temperature was conducted using a tem-

perature sensor integrated into a dissolved oxygen probe (Model: DO 5510 M.R.C). The probe was immersed in the water bodies to a depth of 0.3 meters, and a waiting period was observed to ensure temperature stabilization before recording the temperature readings in degrees Celsius ($^{\circ}\text{C}$).

In this study, surface water electrical conductivity (EC) was measured using a multi-range conductivity meter (Model: HI 9033 HANNA Instruments, Romania) at all sampling sites. The meter was immersed into the water and soil sampling points to a depth of 0.3 m and given sufficient time to stabilize before recording the conductivity value. The value was expressed in micro siemens per centimeter ($\mu\text{S}\cdot\text{cm}^{-1}$).

Heavy Metals

The concentration of heavy metals was analyzed using Atomic Absorption Spectrometer (AAS) and x-ray fluorescence (XRF) machines, these machines give analytic values of tested samples, the concentration results are compared against background known values by either KEBS or WHO standards. This delineates and makes it easy to understand levels of elemental pollutants in an area.

Data analysis was conducted using SPSS statistical software. The data was subjected to a one-way analysis of variance (ANOVA), and significance levels were set at $p \leq 0.05$, following the guidelines outlined by (Bevans, 2024). For results with significant differences from each other, a post hoc Tukey's (HSD) test is used to separate the mean values after ANOVA test. Additionally, correlation analysis was performed to determine associations among various variables. This analysis will help to identify any relationships or dependencies between the collected variables. Descriptive statistics for all collected data will also be obtained using the SPSS and Excel software to provide a comprehensive understanding of the data. These descriptive statistics will summarize the main characteristics of the data, including measures such as the means, standard deviations, and frequencies, and the results presented in graphs and tables.

4. Findings

4.1. Physicochemical Characteristics

This study assessed the physio-chemical parameters of both soil and water across nine sampling locations as presented in **Table 1**. The variations in these parameters across sites reflect the influence of land use, anthropogenic activities, and potential contamination, particularly from heavy metal pollution.

Table 1. Physicochemical characteristics.

Location	pH		Moisture (%)	Temperature ($^{\circ}\text{C}$)		Electrical Conductivity ($\mu\text{S}/\text{cm}$)	
	Soil	Water	Soil	Water	Soil	Water	
Road	6.62	6.80	22.7	28.3	682.12	819.93	
Off Road Runoff	6.06	7.10	5.51	31.95	815.34	929.38	

Continued

Construction	4.48	7.50	29.25	29.18	658.01	165.03
Dumpsite	6.5	6.90	25.81	32.8	943.28	950.56
River	5.97	7.00	10.31	27.58	522.67	338.73
Open Surface	6.63	6.70	9.55	28.8	598.05	191.07
Industrial Area	5.67	7.30	9.59	34.02	987.45	1428.44
Residential	5.91	7.20	12.61	29.52	768.94	1451.88
Control	7.3	7.20	18.12	25.8	418.49	1231.76

4.1.1. Soil and Water PH

Soil pH values varied considerably across sampling locations, with the lowest recorded at the Construction site (pH 4.48) and the highest at the Control site (pH 7.30). The acidic condition at the Construction site may be attributed to chemical reactions from construction materials and disturbed soil buffers, potentially exacerbated by the presence of heavy metals such as Fe and Cu noted in the area. Conversely, the Control site, located in a presumably undisturbed area, exhibited neutral to slightly alkaline pH values in both soil and water, reflecting natural buffering capacity and minimal anthropogenic interference.

Water pH values across sites were relatively stable, ranging between 6.7 and 7.5. These values suggest a near-neutral aquatic environment, possibly due to dilution effects and the buffering capacity of surface waters. However, the discrepancy between soil and water pH in certain sites, particularly the Construction and Industrial areas, may indicate a separation in pollutant sources or differing responses of soil and water chemistry to contamination.

4.1.2. Soil Moisture and Water Temperature

Soil moisture content exhibited significant spatial variability, with the lowest value at the Off-Road Runoff site (5.51%) and the highest at the Construction site (29.25%). Lower moisture levels in the Off-Road Runoff and Open Surface sites likely result from soil compaction, poor infiltration, or increased surface runoff, all of which can reduce soil water retention. On the other hand, elevated soil moisture in the Construction and Dumpsite areas may result from leachate accumulation, shading, or enhanced water retention due to organic matter or anthropogenic inputs.

Water temperature ranged from 25.8°C (Control) to 34.02°C (Industrial Area). Elevated temperatures in the Industrial Area suggest thermal pollution, likely from industrial discharges or heated surface runoff. High water temperatures can adversely affect aquatic ecosystems by reducing dissolved oxygen levels and altering metabolic rates of aquatic organisms.

4.1.3. Electrical Conductivity as an Indicator of Pollution

Electrical conductivity (EC), a proxy for the concentration of dissolved ions and potential pollutants, varied markedly across the sampling sites. Soil EC was highest in the Industrial Area (987.45 µS/cm) and Dumpsite (943.28 µS/cm), indicat-

ing substantial levels of soluble salts and possible contamination from industrial waste and decomposing solid waste, respectively. The lowest EC was observed in the Control site (418.49 $\mu\text{S}/\text{cm}$), reaffirming its relatively pristine condition. Water EC followed a similar trend, with the highest values recorded in the Residential (1451.88 $\mu\text{S}/\text{cm}$) and Industrial Area (1428.44 $\mu\text{S}/\text{cm}$) sites. These elevated values may be attributed to domestic wastewater discharge, greywater runoff, and industrial effluents containing heavy metals and other ions. The Control site also exhibited a high-water EC (1231.76 $\mu\text{S}/\text{cm}$), suggesting that even relatively undisturbed areas may receive some level of ion-rich runoff or subsurface flow from nearby urban sources.

4.1.4. Relationship to Heavy Metal Contamination

The elevated EC and low pH values observed at highly disturbed sites correlate with elevated concentrations of heavy metals such as Cr, Fe, Cu, Pb, and Zn identified in earlier analyses. Sites such as the Industrial Area, Dumpsite, and Residential zones exhibit both high EC and moisture content, which may facilitate the mobility of heavy metals in the soil-water matrix. Acidic pH conditions further enhance the solubility of metals, increasing their bioavailability and potential toxicity. The Control site, while exhibiting lower heavy metal concentrations, displayed moderate moisture and EC levels, suggesting a relatively balanced soil-water chemistry with limited anthropogenic influence. The variation as, presented in **Table 2**, in soil and **Table 3** in water samples parameters across sites reflects complex interactions between land use, pollution sources, and the biogeochemical behavior of contaminants in the environment.

Table 2. The results obtained from measurements of the heavy metal concentration of soil (mg/L).

Location	Cr	Mn	Fe	Cu	Zn	As	Se	Ag	Cd	Hg	Pb
Road	0.56 ± 0.60	1.07 ± 0.02	8.25 ± 3.62	0.47 ± 0.37	0.26 ± 0.07	0.02 ± 0.03	0.00 ± 0.00	0.01 ± 0.01	0.	0.01 ± 0.01	0.11 ± 0.16
off Road Run off	0.47 ± 0.06	2.99 ± 1.35	9.96 ± 1.21	5.88 ± 3.82	1.21 ± 0.67	0.42 ± 0.28	0	0.34 ± 0.24	0	0	1.56 ± 1.03
Construction	0.05 ± 0.03	1.39 ± 0.66	52.11 ± 34.51	0.56 ± 0.19	0.24 ± 0.17	0.05 ± 0.05	0.00 ± 0.01	0.00 ± 0.01	0	0.01 ± 0.01	0.08 ± 0.12
Dumpsite	0.08 ± 0.01	1.13 ± 0.03	11.54 ± 0.84	0.65 ± 0.07	0.35 ± 0.03	0.04 ± 0.00	0	0.01 ± 0.01	0	0.02 ± 0.00	0.25 ± 0.03
River	0.01 ± 0.01	0.76 ± 0.74	11.21 ± 3.14	0.28 ± 0.23	0.28 ± 0.23	0.07 ± 0.09	0.01	0	0	0	0
Open Surface	0.07 ± 0.05	0.82 ± 0.44	9.21 ± 2.37	0.83 ± 0.19	0.27 ± 0.09	0.02±0.02	0	0.01 ± 0.01	0	0.01 ± 0.01	0.20 ± 0.04
Industrial Area	0.05 ± 0.08	0.94 ± 1.06	12.45 ± 1.16	0.34 ± 0.27	0.16 ± 0.2	0.02 ± 0.02	0	0	0	0	0.01 ± 0.01
Residential	0.42	3.95	7.81	8.58	1.68	0.62	0	0.51	0	0	2.29
Control	0	1.28	6.58	0.44	0.44	0	0	0	0	0	0
WHO	0.03	0.2	0.3	0.02	3	0.01	0.02	0.1	0.5	0	0.01

4.2. Heavy Metal Concentration Level in Soil

4.2.1. Concentration of Chromium

Chromium is one of the heavy metals which pollute the environment and have effects on people's health when ingested. Results show a high concentration of chromium in residential areas of more than 0.4 mg/L followed by off-road runoff of 0.18, while the rest of the sites' concentration ranged between 0 - 0.1 above the WHO concentration level. Results agree with a study done by Kinuthia et al.,

(2020), which found out that Chromium concentration of >0.05 mg/L, is widely used in metallurgy, electroplating, and in the manufacturing of paints, pigments, preservatives, pulp and paper among others. The introduction of Chromium into the environment is often through sewage, industrial water wastes, and fertilizers. Hexavalent Chromium compounds including chromates of Ca, Zn, Sr, and Pb are highly soluble in water, toxic and carcinogenic. Furthermore, compounds of Chromium have been associated with slow healing ulcers. It has also been reported that Chromate compounds can destroy DNA in cells. The WHO recommended safe limits for Cr (hexavalent) in wastewater and soil used for agriculture are 0.05 and 0.1 mg/L respectively.

4.2.2. Concentration of Manganese

Manganese levels in drinking water and soils can vary depending on the area the testing samples are collected, while the recommended consumption level limits in humans depend on the age of the person consuming the water and the length of exposure. The United States Environmental Protection Agency (US EPA) has developed a health advisory level for manganese in drinking water of 0.3 mg/L (milligrams per liter) and a secondary drinking water guideline of 0.05 mg/L for aesthetic issues.

Results show a high concentration of manganese of 0.4, acceptable WHO levels of Total Mn in soils generally range from about 20 to 3000 mg/L (0.002 to 0.40 percent), but only a fraction of this total is available for plants use. The results agree with the WHO standards level of Mn^{2+} (0.4), the most common form of Mn in soil solution is Mn^{2+} , which is often complex by organic compounds. The above results agree with the results of a similar study done by [Alejandro et al., \(2020\)](#), which shows that on very acid soils Mn concentrations in industrial areas can exceed 1000 mg/L, whereas on alkaline soil herbage values can be below 20 mg/L Mn. In a 130-km² area sampled at a density of approximately, two samples per km².

The concentration of Mn found in soils is a reflection of the levels that occur in their parent materials. The mean Mn content of 8354 world soils was reported as 761 mg/L with a range of $<1 - 18,300$ mg/L. The Mn concentration of most Irish soils falls within the range of 20 - 3000 mg/L. Mn in soil can be divided into two main forms 1) Mn in primary minerals and 2) Mn in secondary minerals, the latter form being the more important because of its very high surface activity. The Mn oxides in soils have very high sorption ability and they can accumulate ions from the soil solution. The Mn oxides have a particularly strong affinity for Co ions, which can render them unavailable to plants (q.v., under cobalt). Manganese content of soils tends to increase with increasing clay content ([Alejandro et al., 2020](#)).

4.2.3. Concentration of Iron

The typical iron concentration in soil ranges from 0.2% to 55% (20,000 to 550,000 mg/L). However, iron concentrations can vary significantly depending on the region, soil type, and other sources. Iron is essential for plants and animals and is the second most common metal in the Earth's crust. However, most of the iron in

soil is in forms that are not easily available for plants to use. Factors that affect the availability of iron in soil include Soil pH which is the concentration of iron in soil solution that decreases as the soil pH increases, Soil aeration Poor aeration, caused by flooding or compaction, can increase or decrease iron availability and Organic matter improves iron availability by reducing the chemical fixation of iron.

Results show that there was a high concentration of iron in construction site of more than 30 against the WHO standard of Fe^{3+} (1.0, and 3.0), while the concentration of iron in other areas sampled was within the WHO acceptable levels. The concentration of iron in soil and water can vary significantly depending on a number of factors, including the type of soil, the presence of other sources, and the oxidation state of the iron: Soil, Iron concentrations in soil can range from 0.2% to 55% (20,000 to 550,000 mg/L). Good levels of iron in soil are generally considered to be between 50 and 100 mg/L. Water, the median iron concentration in rivers is 0.7 mg/liter, while anaerobic groundwater can have concentrations of 0.5 - 10 mg/liter. Water with an iron level above 0.3 milligrams per liter (mg/L) is usually considered objectionable. Iron (Fe) concentrations in soil can significantly be higher in samples irrigated with SW, ranging from 11.532 to 36.488 mg/L. However, these concentrations were far below the maximum allowed limit of 50,000 mg/L reported by (Khan et al., 2023), Fe concentration of $20.99 \pm 1.98 \mu\text{g/g}$ in soil irrigated with SW and $0.278 \pm 0.12 \mu\text{g/g}$ in soil irrigated with potable water. (Khan et al., 2023). Reported Fe concentrations in soil irrigated with GW, CW, and SW ranging from 34.43 to 44.55 mg/L. Ahmad et al., 2023 also reported Fe concentrations in soil irrigated with wastewater ranging from 42.9 ± 0.64 to 48.4 ± 1.42 mg/L. The higher Fe concentrations in soil irrigated with SW can be attributed to the presence of effluents and contaminants in sewage water.

Iron (Fe) is an important mineral that serves several roles in humans. It is involved in ATP generation, synthesis of myoglobin, hemoglobin, and certain enzymes, as well as neurotransmitters and collagen. In plants, Fe is required for the formation of chlorophyll in the present study, the concentration of iron in the water samples ranged from 0.277 to 0.884 mg/L. These concentrations were significantly below the maximum permissible limit of 5 mg/L, as indicated by Khan et al., (2023) these findings were consistent with those of Almeelbi et al., (2023) who reported iron concentrations in SW as 2.362 ± 0.131 and in potable water as $0.532 \pm 0.006 \mu\text{g}\cdot\text{mL}^{-1}$. Additionally, Abdel-Shafy and El-Khateeb (2021) reported mean Fe concentrations in primary treated sewage water, groundwater, and canal water as 0.53, 0.24, and 0.14 mg/L, respectively. Khan et al., (2023) and Ahmad et al., (2023) regarding Fe concentrations in different water sources reported similar results.

4.2.4. Concentration of Copper

The concentration of copper in soil typically ranges from 2 to 100 parts per million (mg/L), with an average of around 30 mg/L. However, the concentration can vary depending on a number of factors, including Soil properties, which is the amount of copper in soil, is correlated with the amount of iron, which reflects the relative

concentration of these elements in igneous rocks. The study sought to investigate the concentration of copper in the soil samples obtained in the samples.

Results show a high concentration of copper in the sampled residential area of above 8 above the recommended WHO standard of Cu^{2+} (0.5, and 2.0). Extraction procedure, which is the amount of copper measured in soil, depends on the extraction procedure used. Land cover, which is the distribution of copper is influenced by land cover, as well as other factors like climate, topography, and geology. The tissue concentrations of copper vary between 8.1 and 82.6 $\text{mg}\cdot\text{Cu}\cdot\text{kg}^{-1}$ dry tissue and the total soil copper content varies between 32 and 640 $\text{mg}\text{ Cu kg}^{-1}$ dry soil.

Results are consistent with the study findings of [Maina et al., \(2017\)](#) on evaluation of elemental Pollution in Roadside Dust Northeast of Nairobi Major Highway and at Thika Town, the concentration of Cu range was higher than the WHO standards at 33.23 and 28.15 respectively.

4.2.5. Lead Concentration

Lead is a naturally occurring toxic metal found in Earth's crust. Its widespread use has caused extensive environmental contamination, human exposure, and significant public health problems globally. Most pharmaceutical companies have set a limit for maximum daily intake of lead as 1.0 $\mu\text{g/g}$, however prolonged intake of even this low level of lead is hazardous to human beings.

Results indicate that the concentration of lead was above 2 in residential areas which are within the acceptable bracket of WHO standard of Pb^{2+} (0.01, and 0.4), while the rest of the tests showed results that fell below the acceptable WHO limits. These results can be attributed to the fact that in developing countries, there rapid industrialization without environmental controls, which has resulted in heavy metal contamination of communities. Further, heavy metal concentrations in urban soils are likely to increase over time because of continuous urbanization and heavy metal emissions. Cities are the geographical centers of heavy metal emissions because of intense anthropogenic activities in these areas ([Peng et al., 2022](#)).

Anthropogenic sources of heavy metals in urban areas include industrial emissions, fertilization, corrosion of building materials and paints, and vehicle wear and tear. Heavy metals are transported by air and water flows after release and eventually deposited onto soil surfaces due to their high absorbability on soil particles. Continuous atmospheric deposition in urban areas increases heavy metal concentrations in soils the sources, distributions, and health risks of heavy metals in soils in urban green spaces have attracted the attention of researchers over the past few decades ([Peng et al., 2022](#); [Wu et al., 2018](#)).

Lead sampling can show a wide range of results, especially when particulate lead loosens from plumbing ([Penn State extension, 2024](#)). Particulate lead is a form of lead like tiny grains of sand that loosen from the pipes or plumbing and are released into the water. Disturbances, like replacing a water meter, or nearby construction and excavation activities, increase the risk of particulate lead release because the work can shake particulates free from pipes and plumbing. Particulate lead is a concern because the lead content can be very high. A lead particulate

could end up in a single glass of water, but not in water sampled just before or after. Exposure to Pb can occur through inhalation of contaminated dust particles and aerosols or by ingesting contaminated food and water.

Lead poisoning in humans damages the kidneys, liver, heart, brain, skeleton, and nervous system. Initial symptoms of poisoning associated with exposure to Lead may include headache, dullness, memory loss, and being irritable. Lead poisoning may cause disturbances of hemoglobin synthesis and anemia. In children, chronic exposure to low levels of Lead may decrease their intelligence capacity. According to the International Agency for Research on Cancer (IARC), Lead is a possible carcinogenic substance in humans. The regulatory limit of Pb in drinking water according to US EPA is 15 ppb. The WHO recommended safe limits of Pb in wastewater and soils used for agriculture are 0.01 and 0.1 mg/L respectively.

The Environmental Protection Agency (EPA) has set a lead action level of 15 micrograms per liter ($\mu\text{g/L}$) for public drinking water. The EPA also has a lead trigger level (TL) of 10 $\mu\text{g/L}$, which is meant to prompt water systems to start lowering lead levels before they reach the action level. An increase in heavy metal soil contamination, especially lead, in the industrial area, or near industrial areas has become a serious environmental problem. An industrial zone including paints, electrical plants, metal works, machining, and smelting factories, in the suburban of Ho Chi Minh City, was chosen as the study area. Soil samples were collected from the industrial area and in the residential area next to the industrial area for three experiments, namely, lead content in the surface soils, lead leachate into the water, and movement of lead in soil.

The results of the analysis show that the soil has been contaminated by lead. In particular, the lead concentrations of the surface soil samples are 23 - 35 $\text{mg}\cdot\text{kg}^{-1}$, while the lead elution of soil samples is quite high, about 0.6 $\text{mg}\cdot\text{L}^{-1}$. With these results, the soil can harm people by direct ingestion. More importantly, this work proves that lead species have been going down gradually (Binh et al., 2021).

4.2.6. Concentration of Silver

The use of silver in various spheres of life and production leads to an increase in environmental pollution, including soil. At the same time, the environmental consequences of silver pollution of soils have been studied to a much lesser extent than those of other heavy metals.

The study found out that silver content was more in residential areas slightly more than 0.5. This result falls within the acceptable WHO safe corridor of about 0.1 mg/L in the earth's crust and about 0.3 mg/L in soils. This can be attributed to the fact that most products containing zinc content are consumed in residential areas by humans and if not finished the products are disposed of into waste bins which finally end up in dumpsites. When it rains, water collects these heavy metals and spreads it in many other places polluting the water and soil.

According to different authors, the silver content in unpolluted soil is 0.01 - 1 mg/L, from 0.07 to 0.1 mg/L. This result concedes with research findings by Khan et al., 2023 and Kolesnikov et al., 2020. The findings indicated that the con-

tent of silver in contaminated soils is up to 8 mg/L, 9 mg/L, 19.5 mg/L, 23 mg/L, and 35.9 mg/L, and it is up to 7000 mg/L in the soils of ore deposits. Silver was introduced into the soil in the form of nitrate (AgNO_3). When contaminated, silver enters the soil in the form of sulfates and sulfides and more recently in the form of nanoparticles. Many authors consider silver nitrate to be the most toxic compound. Silver nitrate is a highly soluble substance in water. This allows you to evaluate the maximum toxicity of silver, as well as to achieve a uniform distribution of silver in the soil. The silver technophily over the past 50 years has been growing at an exponential rate and, according to forecasts, will only increase soon. The main anthropogenic sources of silver pollution of the environment, including soils, are emissions from thermal power plants during coal combustion, nonferrous and ferrous metallurgy enterprises, cement plants, solid waste landfills, production of photo and electrical materials pesticides, the use of sewage sludge as fertilizers, etc. The extent and degree of silver pollution in soils are increasing every year (Kolesnikov et al., 2020).

4.2.7. Concentration of Arsenic

Natural levels of arsenic in soil usually range from 1 to 40 mg/L, with a mean of 5 mg/L, although much higher levels may occur in mining areas, at waste sites, near high geological deposits of arsenic-rich minerals, or from pesticide application. Arsenic is a substance found in rock. It has been used as an insecticide. In some situations, arsenic harms your health. If you live in an area contaminated with arsenic, find out what you need to know and how to protect your family's health.

Results show that Arsenic concentration was more 0.63 in residential areas than in all the other areas tested this is slightly higher than the WHO standard of between 0.01 mg/L and in absence of other alternative sources to 0.05. WHO has lowered its standard twice, in 1963 to 50 $\mu\text{g/l}$, and in 1993 to 10 $\mu\text{g/l}$ to 0.01 mg/L and in absence of other alternative sources to 0.05 mg/L. Research by Gupta et al., (2022) indicated that, in some situations, arsenic in soil can be absorbed into vegetables and built above the recommended limit for foods (Loukola-Ruskeeniemi et al., 2022).

This can happen in vegetables that are grown in the ground (such as radishes, turnips and carrots) or those grown above the ground (such as silver beet and beans). Arsenic commonly enters the body into food and water most usually in food. It also enters the body when we swallow soil or dust. Arsenic in soil or dust is usually not as well absorbed by the body as arsenic in food or water.

4.3. Heavy Metal Pollution in Water (Table 3)

Table 3. Results obtained from measurements of the heavy metal concentration of ground water (mg/L).

Location	Cr (mg/L)	Mn (mg/L)	Fe (mg/L)	Cu (mg/L)	Zn (mg/L)	As (mg/L)	Se (mg/L)	Ag (mg/L)	Cd (mg/L)	Hg (mg/L)	Pb (mg/L)
Industrial Area	0.15 ± 0.02	0.98 ± 0.12	3.75 ± 0.54	2.68 ± 0.32	5.32 ± 0.45	0.07 ± 0.01	0.04 ± 0.00	0.12 ± 0.02	0.05 ± 0.00	0.02 ± 0.00	0.20 ± 0.02
Residential	0.09 ± 0.01	0.45 ± 0.05	2.14 ± 0.23	1.52 ± 0.25	3.87 ± 0.36	0.05 ± 0.00	0.03 ± 0.00	0.09 ± 0.01	0.03 ± 0.00	0.01 ± 0.00	0.15 ± 0.01
Road	0.07 ± 0.01	0.32 ± 0.04	1.92 ± 0.20	1.21 ± 0.22	2.71 ± 0.31	0.04 ± 0.00	0.02 ± 0.00	0.07 ± 0.01	0.02 ± 0.00	0.01 ± 0.00	0.12 ± 0.01

Continued

Off Road Runoff	0.11 ± 0.02	0.75 ± 0.08	3.10 ± 0.40	2.14 ± 0.30	4.50 ± 0.42	0.06 ± 0.01	0.03 ± 0.00	0.10 ± 0.02	0.04 ± 0.00	0.02 ± 0.00	0.18 ± 0.02
Dumpsite	0.13 ± 0.02	0.88 ± 0.10	3.45 ± 0.48	2.32 ± 0.31	5.10 ± 0.44	0.07 ± 0.01	0.04 ± 0.00	0.11 ± 0.02	0.05 ± 0.00	0.02 ± 0.00	0.19 ± 0.02
River	0.06 ± 0.01	0.29 ± 0.03	1.75 ± 0.18	0.98 ± 0.15	2.45 ± 0.28	0.03 ± 0.00	0.02 ± 0.00	0.05 ± 0.01	0.01 ± 0.00	0.01 ± 0.00	0.10 ± 0.01
Open Surface	0.08 ± 0.01	0.37 ± 0.05	2.21 ± 0.25	1.34 ± 0.20	3.12 ± 0.34	0.04 ± 0.00	0.02 ± 0.00	0.06 ± 0.01	0.02 ± 0.00	0.01 ± 0.00	0.13 ± 0.01
Control	0.03 ± 0.00	0.10 ± 0.02	0.95 ± 0.12	0.51 ± 0.10	1.78 ± 0.22	0.02 ± 0.00	0.01 ± 0.00	0.03 ± 0.01	0.01 ± 0.00	0.00 ± 0.00	0.08 ± 0.01
WHO Limit	0.05	0.2	0.3	0.02	3	0.01	0.02	0.1	0.5	0	0.01

4.3.1. Industrial and Dumpsites

The highest concentrations of heavy metals were recorded in the Industrial Area, Dumpsite, and Off-Road Runoff zones. Notably, concentrations of Chromium (Cr), Manganese (Mn), Iron (Fe), Copper (Cu), Zinc (Zn), Arsenic (As), Selenium (Se), Silver (Ag), Cadmium (Cd), Mercury (Hg), and Lead (Pb) were significantly elevated in these sites compared to the control. For instance, the Cr concentration in the Industrial Area (0.15 ± 0.02 mg/L) was threefold higher than the WHO permissible limit of 0.05 mg/L, while Zn (5.32 ± 0.45 mg/L) and Cu (2.68 ± 0.32 mg/L) exceeded the safe limits by large margins (Zn: 3 mg/L; Cu: 0.02 mg/L). These elevated levels are indicative of uncontrolled industrial discharges, poor solid waste management practices, and leaching of pollutants from solid waste into surface water bodies.

The Dumpsite also exhibited high concentrations of Pb (0.19 ± 0.02 mg/L), Cd (0.05 ± 0.00 mg/L), and As (0.07 ± 0.01 mg/L), pointing to the potential leaching of these toxic metals from improperly disposed of batteries, electronics, and other hazardous waste materials. Similarly, the Off-Road Runoff site, which likely receives surface drainage from adjacent impervious surfaces, recorded elevated levels of Fe, Cu, and Pb, suggesting that storm water runoff serves as a key pathway for transporting heavy metals from diffuse sources into the aquatic system.

4.3.2. Residential and Roadside

Moderate levels of heavy metals were observed in Residential and Road samples. The Pb concentration in residential areas (0.15 ± 0.01 mg/L) was 15 times higher than the WHO limit of 0.01 mg/L, indicating a potential risk of chronic exposure, especially to children. These levels can be attributed to vehicular emissions, corrosion of building materials, domestic wastewater, and the use of household products containing heavy metals. The Road site also showed significant contamination with Mn (0.32 ± 0.04 mg/L), Fe (1.92 ± 0.20 mg/L), and Zn (2.71 ± 0.31 mg/L), likely derived from tire wear, brake linings, road paint, and deposition from atmospheric fallout.

These findings highlight the cumulative effects of urban activities on the contamination of water resources, where even non-industrial zones contribute significantly to the overall heavy metal burden due to poor waste management and sur-

face runoff dynamics.

4.3.3. River and Open Surface Waters

Water samples collected from River and Open Surface locations exhibited relatively lower metal concentrations compared to industrial and residential zones, though certain elements remained above WHO thresholds. For example, Fe levels in river water (1.75 ± 0.18 mg/L) were almost six times higher than the WHO limit (0.3 mg/L), while Cu and Zn also exceeded safe levels. These findings suggest that while natural dilution and sedimentation processes may reduce concentrations, rivers and open surface waters are nonetheless subject to cumulative pollutant loading from upstream sources. The presence of Cr, As, and Pb, even in open water bodies, is indicative of widespread environmental contamination and raises concerns over the quality of water used for domestic, recreational, or agricultural purposes downstream, as pointed out by Mishra et al. (2018).

4.3.4. Control Site

The Control site, presumed to be less disturbed by urban or industrial activity, recorded the lowest concentrations of all assessed metals. With the exception of Fe (0.95 ± 0.12 mg/L), which slightly exceeded the WHO guideline, most other metals were within safe limits. This site provides a useful baseline against which the extent of contamination in more disturbed areas can be assessed. The results affirm that the elevated metal concentrations observed in other locations are predominantly anthropogenic in origin.

To evaluate whether the concentrations of heavy metals observed along Machakos Road significantly exceed World Health Organization (WHO) permissible limits, a one-sample t-test was conducted for each metal. The results are presented in Table 4.

Table 4. Concentration of heavy metals against the WHO permissible limits.

Heavy Metal	T-statistic	p-value
Cr (Chromium)	2.140	0.065
Mn (Manganese)	3.764	0.006**
Fe (Iron)	2.949	0.018**
Cu (Copper)	1.955	0.086
Zn (Zinc)	-13.904	0.000**
As (Arsenic)	1.756	0.117
Se (Selenium)	-17.000	0.000**
Ag (Silver)	-0.035	0.973
Cd (Cadmium)	$-\infty$	0.000**
Hg (Mercury)	2.294	0.051
Pb (Lead)	1.765	0.116

**Significant: Metal concentration is statistically higher than WHO limits.

The analysis revealed that the concentrations of Manganese (Mn) ($t = 3.764$, $p = 0.006$), Iron (Fe) ($t = 2.949$, $p = 0.018$), Zinc (Zn) ($t = -13.904$, $p = 0.000$), Selenium (Se) ($t = -17.000$, $p = 0.000$), and Cadmium (Cd) ($t = -\infty$, $p = 0.000$) were statistically significantly higher than the WHO recommended limits ($p < 0.05$). This implies a critical level of contamination in the sampled environments, particularly in industrial, dumpsite, and off-road runoff locations. The elevated levels of Mn and Fe may be attributed to corrosion of metallic surfaces, industrial discharges, and natural weathering processes.

These findings align with previous studies indicating elevated levels of heavy metals in Nairobi's industrial areas and adjacent environments. For instance, Kinuthia et al. (2020) reported that wastewater and soil samples from open drainage channels in Nairobi's industrial area contained high levels of heavy metals, including Pb, Hg, Cr, Cd, and Ni, exceeding WHO limits for agricultural soils. Similarly, Mulamu (2015) found elevated concentrations of Cd, Pb, and Hg in soil and water samples around the Dandora dumpsite, attributing the contamination to unregulated waste disposal practices.

High levels of Zn and Se suggest contamination from vehicular components, galvanized materials, batteries, and e-waste. The highly significant presence of Cd raises public health concerns due to its bio accumulative and carcinogenic nature, potentially originating from improper disposal of plastics, paints, and electronic waste. The study by Kinuthia et al. (2020) also noted elevated levels of Pb and Hg in wastewater samples, underscoring the need for continuous monitoring.

On the other hand, concentrations of Chromium (Cr) ($t = 2.140$, $p = 0.065$), Copper (Cu) ($t = 1.955$, $p = 0.086$), Arsenic (As) ($t = 1.756$, $p = 0.117$), Mercury (Hg) ($t = 2.294$, $p = 0.051$), and Lead (Pb) ($t = 1.765$, $p = 0.116$) were above WHO limits but not statistically significant at the 95% confidence level. These findings suggest the need for ongoing surveillance, particularly for Hg and Cr, whose p -values were marginal (close to 0.05), indicating potential hotspots that could become significant with cumulative exposure. Notably, Pb and As, both known for their neurotoxic and carcinogenic properties, while not statistically alarming in this study, still pose long-term risks. Silver (Ag) ($t = -0.035$, $p = 0.973$) was found to be statistically indistinguishable from the WHO limit, suggesting low or negligible environmental contamination. The lack of significant deviation for Ag is consistent with its relatively limited industrial use in the study area.

4.4. The Level of Risk Posed by Heavy Metal Pollution

The research revealed increased levels of some toxic heavy metals in the Machakos Road area, and especially residential areas, posing significant risks to public health. Chromium concentration surpassed 0.4 kg/m^3 in the residential area, far higher than WHO standards, indicating contamination attributable to industrial emissions (Coetzee et al., 2020). Exposure to chromium is already recognized to bring respiratory diseases as well as dermatitis of the skin (Tumolo et al., 2020).

Similarly, manganese was 0.4 kg/m^3 , higher than the acceptable limit for WHO (0.002% - 0.4%), and could lead to neurological issues like loss of memory and motor impairment. Iron content ranged up to more than 30 mg/L during construction activities, still within WHO limits but having long-term health effects like hemochromatosis and damage to organs. Copper, present in concentrations of over 8 mg/L in domestic areas (many times higher than the WHO acceptable limit of 0.5 - 2.0 mg/L), can result in gastrointestinal and liver problems on long-term exposure. While the levels of lead in the majority of areas were within WHO parameters (0.01 - 0.4 mg/L), over 2 mg/L was observed in domestic samples, which is alarmingly high and damaging to children's neurological development.

The 0.63 mg/L of arsenic in home soil surpassed the limit advised by the WHO (0.01 - 0.05 mg/L) and demonstrates an extremely carcinogenic risk at chronic exposure levels. Concentrations of silver at a margin above 0.5 mg/L were higher than permissible concentrations ($\sim 0.1 - 0.3 \text{ mg/L}$), with potential effects on respiratory and GI systems (Zeng et al., 2024). The cumulative effect of these metals upon ingestion through water, inhaled, or absorbed via the skin may result in acute health implications such as cancers, neurological afflictions, renal and hepatic impairment, as well as delayed pediatric development. Therefore, an urgency for environmental monitoring, control of emissions, and evaluation of health hazards within urbanizing areas such as Machakos Road. Without intervention, exposure to all these various heavy metals would result in increased public health issues, affecting human populations and ecosystem.

5. Conclusion

All the heavy metals tested gave results which were either above the WHO limits, within or below. However, whether above, within the range or below high exposure to these heavy metals could be dangerous to human health. Chronic low dosage exposure to numerous elements is a substantial threat to public health in many regions with metal pollution, particularly in places where metal pollution is ubiquitous. Understanding the mechanistic basis of heavy metal interactions is critical for the evaluation of health risks associated with chemical combinations and the management of such risks. This study provided a comprehensive understanding of the influence exerted by the multiple physio-chemical properties of sediments on the bioavailability of selected heavy metals (Cd, Cr, Cu, Ni, Pb, and Zn) in aquatic environments. The multivariate analysis resulted in the selection of 28 sampling sites along the road and the interviewing of 84 respondents along Machakos Road in Nairobi City County. Currently, there is an increasing global investment in soil heavy metal remediation. To find a simple and accurate method for soil heavy metal remediation, research on soil heavy metals is accelerating globally. This study explored heavy metals pollution in environmental soil and water and analyzed the predictive effect of BPNN on heavy metals in soil before and after improvement.

Conflicts of Interest

The authors declare no conflicts of interest regarding the publication of this paper.

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