AKENTEN APPIAH-MENKA UNIVERSITY OF SKILLS TRAINING AND ENTREPRENEURIAL DEVELOPMENT

CONTAMINATION CHARACTERISTICS AND HUMAN HEALTH RISK ASSESSMENT OF POTENTIALLY TOXIC ELEMENTS IN DUST FROM SEVEN DIFFERENT LAND USE TYPES

CHRISTIAN BARWUAH

MASTER OF PHILOSOPHY CHEMISTRY EDUCATION

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CHRISTIAN BARWUAH

8211440003

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DECLARATION

STUDENT DECLARATION

I BARWUAH CHRISTIAN declare that this thesis, except quotations and references in published works which have all been identified and duly acknowledged, is entirely my original work, and it has not been submitted, either in part or whole, for another degree elsewhere.

SIGNATURE ………………………………………………….

DATE ……………………………………………………………

SUPERVISOR'S DECLARATION

I/We at this moment declare that the preparation and presentation of this work were supervised by the guidelines for supervision of the thesis as laid down by the Akenten Appiah Menka University of Skills Training and Entrepreneurial Development.

Supervisor: DR. OPOKU GYAMFI

SIGNATUERE ……………………………………...

DATE ………………………………………………….

Supervisor: PROF. KOFI SARPONG

SIGNATUERE …………………………………………………

DATE …………………………………………………………….

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DEDICATION

To my lovely mother, Abenaa Agyeiwah, my dear wife, Addai Naomi Christopherina, and children, Ohenewaa, Barima, Brempong, and Okesie for their support.

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ABSTRACT

The contamination characteristics, risks, and sources of the potentially toxic elements in dust from seven different land use types were investigated. One hundred and seven (107) dust samples were collected from seven different land use areas and analyzed for lead, arsenic, zinc, copper, iron, manganese, chromium, vanadium, titanium, nickel, and cadmium using a field portable X-Ray fluorescence analyzer. The mean concentration (mg kg^{-1}) ranges of toxic elements in the dust at different land uses were: Pb (3.5 – 42.1), As (3.0 – 4.6), Zn (43.2 – 272.9), Cu (12.1 – 54.6), Fe (12792.1 – 28202.3), Mn (101.9 – 321.4), Cr (44.4 – 127.4), V (53.8 – 123.7), Ti (1918.8 – 3746.9), Ni (16.0 – 18.9), and Cd (5.2 – 5.9). Except for cadmium, the potentially harmful element levels in the dust were generally found to be below the background, World Health Organization (WHO), and Dutch target (VROM) guideline limits across all land use zones. According to the results of the geo-accumulation indicator, the dust in Sekyere South was unpolluted to moderately polluted with lead, arsenic, zinc, copper, manganese, iron, chromium, and titanium, moderately polluted with vanadium, and severely polluted with cadmium. The enrichment factor calculation revealed that zinc was moderately enriched, vanadium was significantly enriched, and cadmium was greatly enriched, while the others showed deficient to little enrichment. According to the modified degree of contamination findings, the site has a moderate degree of contamination with cadmium accounting for 57% of the contamination. The contamination of the site is in the following order: auto mechanic shop > residential > school > lorry park > market > road > playground. Only cadmium posed a very high potential ecological risk in the dust, according to the potential ecological risk rating. The principal component analysis yielded three distinct components of elements. Component one (Ti, V, Cr, and Fe) could be the outcome of natural sources. Component two (Mn, Cu, Zn, As, and Pb) could have come from both human (traffic emissions) and natural sources, whilst component three (Cd and Ni) could have come from waste incineration, agrochemical application, and paints.

Children were exposed to higher levels of risk than adults. The study found that all of the potentially harmful elements evaluated were at tolerable levels and are not likely to pose any health risk. The study found a significant cadmium pollution load in the areas, hence proper pollution management methods must be implemented. The findings will assist local governments in developing legislation to protect the environment and human health.

CHAPTER ONE

1.0 INTRODUCTION

1.1 Background

Humans have engaged in various activities to promote economic expansion, industrialization, and urbanization. In one way or another, these activities have been polluting his surroundings, especially with potentially toxic elements (Anyanwu et al., 2018; Masindi & Muedi, 2018; Nkansah et al., 2017). As a result, concern over the environmental deterioration brought on by these activities has grown. The operations include grinding, smelting, tanning, farming, welding, automobile emissions, and producing finished and intermediate goods such as batteries, paints, car tires, and mercury cosmetics (Wuana & Okieimen, 2011). Since human beings first began to pursue economic expansion, industrialization, and urbanization, the levels of organic and inorganic metal contaminants in the soil, air, water, and animal tissues have increased over the years (Ali et al., 2019). Manufacturing of goods containing potentially toxic elements, such as insecticides, paints, pharmaceuticals, and cosmetics, as well as industrial processes like milling, welding, tanning, soldering, and smelting, produce dust particles. The dust particles as a result of their size and chemical composition become harmful to the respiratory system, the body cells and the vital organs in the body if inhaled (Wuana & Okieimen, 2011). When these contaminant particles finally make it to the surface, their concentrations in the soil, water, and tissues of animals and plants increase (Ali et al., 2019).

Exposure of potentially toxic elements persists and even rises in some regions of the world, especially in less developed nations (Anyanwu et al., 2018; Nkansah et al., 2017), even though the harmful health impacts of potentially toxic elements have long been known (Balali-Mood et al., 2021; Järup, 2003; Masindi & Muedi, 2018). Metal elements that are essential for the development of animal and plant tissues include zinc, iron, chromium, cobalt, manganese, and copper (Pajarillo et al., 2021). They support particular biochemical activities like catalysis, electron transfer, oxygen transfer, storage, and oxidation in staying in good working order. These advantageous results, meanwhile, are only noticeable at low concentrations (Jaishankar et al., 2014). Mercury, cadmium, arsenic, selenium, and lead are non-essential and are hazardous to living things even at low doses (Tchounwou et al., 2012). The majority of elements have been found to affect cells in a variety of ways, and they also have synergistic effects (Singh et al., 2017).

Drinking water, food, cigarette smoke, industrial operations, and home sources are the main causes of lead exposure (Engwa et al., 2019). Lead is used in plumbing pipes, storage batteries, pewter pitchers, toys, faucets, paints, cosmetics, insecticides, gasoline additives, and soldering (Jaishankar et al., 2014). Lead is particularly easily absorbed through the skin when it is in an organic matrix, but it can also be absorbed through the respiratory system if inhaled and through the digestive tract if consumed (Balali-Mood et al., 2021). Due to its bioaccumulative nature, lead is a dangerous toxin, especially when exposed over an extended period. In the body, lead deposits in the bones, liver, and kidneys (Dejkovski, 2016). Exposure to lead can result in birth defects, mental retardation, autism, psychosis, allergies, paralysis, weight loss, dyslexia, hyperactivity, muscular weakness, kidney damage, brain damage, and coma, and may even result in death (Engwa et al., 2019). Acute exposure to lead can cause headaches, loss of appetite, abdominal pain, fatigue, sleeplessness, hallucinations, vertigo, renal dysfunction, and arthritis (Balali-Mood et al., 2021; Engwa et al., 2019; Tchounwou et al., 2012).

Cadmium is mostly employed in the making of paints, pigments, alloys, coatings, batteries, and plastics (Turner, 2019). Consuming contaminated foods and beverages, particularly cereals, grains, fruits, and leafy vegetables, can result in human exposure to cadmium (Balali-Mood et al., 2021). The detrimental health effects of cadmium exposure, manifest as kidney impairment but may also include bone problems and fractures (Anyanwu et al., 2018).

Chromium is a metal that can be found in coal and oil well drilling, chromium steel, pigment oxidants, fertilizers, catalysts, and tanneries used for metal (Education & Toxicity, 2013; Engwa et al., 2019; Sharma et al., 2021; Wuana & Okieimen, 2011). Humans can experience severe cardiovascular, respiratory, hematological, gastrointestinal, renal, hepatic, and neurological symptoms as well as possible fatal outcomes when exposed to excessively high doses of chromium (VI) compounds (Engwa et al., 2019).

A widely dispersed metalloid, arsenic can be found in rocks, soil, water, and the atmosphere (Katherine A. James, 2016). Humans and other environmental species can be harmed by the inorganic forms of arsenic. Arsenic enters the environment through a variety of channels, including industrial sources like smelting and the microelectronics industry (Engwa et al., 2019). Low-level arsenic exposure can result in nausea, vomiting, decreased erythrocyte, and leukocyte production, blood vessel damage, irregular pulse, and prickling sensations in the hands and legs (Balali-Mood et al., 2021). Skin lesions, lung disease, neurological issues, peripheral vascular disease, diabetes mellitus, hypertension, and cardiovascular disease can all develop as a result of prolonged exposure (Engwa et al., 2019; Tchounwou et al., 2012).

Due to some of the human activities that are increasingly generating potential toxic elements in our environment, as well as the consequences of these potential toxic elements, it is essential to constantly monitor and understand the level of potential toxic elements to which humans are exposed in the environment (Guidotti et al., 2009; Sharma et al., 2021).

1.2. Problem Statement

Excessive buildup of potentially toxic elements in our environment can cause a variety of issues, such as soil contamination, contamination of surface and groundwater, the extinction of aquatic life, and even serious health risks for humans due to its adverse effects on the nervous, blood-forming, renal, and reproductive systems (Jan et al., 2015). It has been determined that the toxicity of elements like Cd, Hg, and Pd can disrupt the endocrine system and change how the human central nervous and respiratory systems function (Briggs, 2003; Mmaduakor et al., 2022).

Auto technicians and other automotive artisans are crucial to the upkeep of automobiles in Sekyere South which drive the free flow of goods and services. Their shops are sited randomly and are located in every setting including homes, marketplaces, schools, and even hospitals. According to research by Marahatta, (2018), the operations of craftspeople in the automotive sector produce a wide range of waste. Their daily activities including getting rid of used motor oil, car battery acid water, welding carbide, and metal trash generate a lot of waste. The chemical waste from automobiles is composed of a variety of substances, including petroleum hydrocarbons, chlorinated biphenyls, and potentially toxic elements. Engine oil disposal, engine and gearbox overhaul, battery charging, welding and soldering, and auto body work all result in the discharge of potentially hazardous elements into the environment (Coast, 2020). Spraying, painting, and combustion processes are among more sources (Johnbosco et al., 2020). The locals apply fertilizers, insecticides, and weedicides indiscriminately to increase agricultural productivity and remove weeds and pests from crops in their backyard. It is generally known that phosphate fertilizers frequently contain cadmium, which has the potential to contaminate crops and agricultural land. Fertilizers can also contain up to 400 ppm Pb, which may represent a significant source of soil pollution (Johnbosco et al., 2020; Wuana & Okieimen, 2011).

A rise in waste generation without suitable and adequate disposal systems has been brought on by population growth, urbanization, industrialization, and the rapid growth of structures as a result of poor planning (Anyanwu et al., 2018). According to the Ghana Statistical Service, (2021), the widest method of solid waste disposal is dumping in the open space which accounts for 51.8 percent with 7.6 percent of households dumping their solid waste indiscriminately. For liquid waste disposal, throwing waste onto the street/outside (38.1%) and onto the compound (37.5%) are the two most common methods used by households in the district. In recent years, the neighbuorhood has seen an upsurge in vehicular traffic (Sekyere South District, 2020). Numerous studies (Balali-Mood et al., 2021; Engwa et al., 2019; Tchounwou et al., 2012a) have shown that traffic emissions, such as vehicle exhaust fumes, tire wear particles, weathered street surface particles, and brake lining wear particles, are anthropogenic sources of potentially toxic elements in urban soils and dust. In Sekyere South, unpaved inner-city roads dominate, making the surrounding homes and roadside vegetation frequently dusty. People are frequently seen eating raw fruit and food that has been left out on arid roadsides. Additionally, children are exposed to polluted dust while playing in the soil on housefronts and roadside edges (Anyanwu et al., 2018).

The environment in Sekyere South may be polluted or contaminated as a result of the rise in anthropogenic activities (traffic emissions, agricultural activities, industrial activities, waste generation, etc.). However, very few study projects have been undertaken addressing the issue in the Sekyere South.

1.3 General Objective

This study aims to assess the contamination characteristics and human health risk of potentially toxic elements in dust samples from different land use areas in Sekyere South.

1.4 Specific Objectives

1. To determine the presence and concentration of potentially toxic elements in dust from different land use areas in Sekyere South.
2. To evaluate the spatial distribution and do source apportionment of the potentially toxic elements
3. To determine the extent of potentially toxic elements contamination using pollution indices.
4. To evaluate the ecological risk index that the presence of potentially toxic elements in dust poses.
5. To evaluate the carcinogenic and non-carcinogenic health risks posed by the potentially toxic elements.

1.5 Justification / Significance of the Study

Particle inhalation, skin contact, and ingestion are the three main ways by which humans are exposed to potentially toxic elements (Kabir & Rashid, 2022). While some potentially hazardous elements, such as zinc and copper, are useful to humans biologically, others, such as arsenic, cadmium, lead, and mercury, are not (Balali-Mood et al., 2021; Jaishankar et al., 2014; Kabir & Rashid, 2022). Even biologically beneficial potentially toxic elements can have negative effects if consumed in excess, while others, like arsenic, can have negative effects even in small doses. Arsenic, cadmium, and nickel exposure can cause cancer in people (Cui et al., 2021). About 40 million individuals in more than 70 countries suffer from keratosis and cancer-related illnesses as a result of arsenic poisoning of soils and water that contaminates food and water (Ng et al., 2019).

The presence of potentially toxic elements in the environment does not always signify a problem with the ecosystem (Mitra et al., 2022). However, it is a concern when the levels found approach or surpass the concentrations that can harm organisms, including people, (Wuana & Okieimen, 2011). Natural occurrences of lead, zinc, and other potentially toxic elements can be found in ore minerals and rocks. These elements are present in soils, waterways, sediments, and living things at a normal background concentration. However, concentrations above background levels result in pollution in the vulnerable medium (Jaishankar et al., 2014; Kabir & Rashid, 2022). Therefore, it is crucial to identify and understand the concentration that pertains to the environment. Plants in the environment can readily absorb potentially toxic elements since they are mobile (Alengebawy et al., 2021). Several potentially toxic elements tend to build up in the body and have long biological half-lives. For instance, it is believed that cadmium in humans has a half-life of at least two decades. Thus, accumulation will continue throughout one's lifetime with continued exposure (Balali-mood et al., 2021; Dome et al., 2015). One of the reported negative effects of potentially toxic elements poisoning is the development of neurological problems, the destruction of the Central Nervous System, and cancer in numerous body organs (Balali-Mood et al., 2021).

Cadmium is extremely harmful to humans, animals, and even plants. In humans, it can irritate the lungs and digestive tract and cause vomiting and convulsion (Balali-Mood et al., 2021). Lead exposure during pregnancy may cause premature birth, low birth weight, and the delivery of mentally impaired children in mothers (Balali-mood et al., 2021; Wani et al., 2015). Children are more susceptible to the effects of lead than adults are, and lead exposure can result in a low intelligent quotient, stunted growth, hearing issues, etc. (Dome et al., 2015; Mihankhah et al., 2020). Among other effects, exposure to copper and zinc can result in nausea, vomiting, and stomach pain (Mitra et al., 2022). Mercury can result in a variety of conditions, including ulcers, neurological disorders, Minamata illness, nausea, and diarrhea (Ali et al., 2019a; Balali-Mood et al., 2021; McNutt, 2013).

The information and data gathered from this study will show the amounts of potentially toxic elements buildup in the dust at the Sekyere South, which will be utilized to help the government decide what kinds of measures to pursue to improve the quality of the environment. Residents can use the findings of this assessment of the health risks of potentially toxic elements to take preventative action. The data gathered will also serve as a baseline for more research in the area.

As such, this study focuses on exposure to dust particles in the Sekyere South terrestrial environment to track the concentrations of Potential toxic elements. Sekyere South has experienced rapid population growth in recent times, also heavy traffic, an increase in hastily-stated small-scale industries, an increase in waste production without an adequate disposal system, the growth of structures without sufficient planning, and other issues. Li et al., (2022) claim that the increase in population, industrialization, and new technological advancements in recent years has contributed to the accumulation of potentially toxic elements in our environment (Adriano, 1988; Li et al., 2022). Potential toxic elements pose significant risks to human health because of their toxicity, tendency to accumulate, persistence in the environment, and potential for environmental transformation into more dangerous species (Ayangbenro & Babalola, 2017; Jan et al., 2015; Manzoor, 2020). As a result, this phenomenon is quite concerning (Ayenimo et al., 2005).

1.6 Hypothesis

To meet the objectives stated, the study will examine the following hypotheses:

H1: The potentially toxic element levels in the study area do not significantly differ from background values and the Maximum Permissible Concentrations, which are frequently used as regulatory guideline limits based on which informed decisions about the site's quality are made.

H2: The potentially toxic element concentrations from the various land use areas do not differ statistically from one another.

H3: The amounts of potentially toxic elements to which individuals are exposed do not pose a risk to locals' health.

H4: Risk and hazard indices derived from the results would be within or below the USEPA soil and dust threshold levels.

CHAPTER TWO

2.0 LITERATURE REVIEW

2.1 Potentially Toxic Elements Contamination of Dust Samples

Dust is defined as solid particles with sizes ranging from less than 1 µm to at least 100 µm that may be or become airborne depending on their origin, physical features, and environmental conditions (Darren Carvell, 2019). Urban dust has been investigated for its potential to contain toxic elements, and it is frequently used as one of the global markers of environmental contamination (Kaonga et al., 2021). Most of the research has connected mobile (car exhausts and abrasion of vehicle body parts like tires) and stationary sources (power plants, industries, incinerators, and home heating) with potentially toxic elements in urban dust (Kaonga et al., 2021).

According to Benhaddya et al., (2016), dust particles differ in size and have a wide surface area, making them a great vehicle for transporting and depositing potentially toxic elements in the environment. Dust storms, known to accumulate and deposit pollutants in cities, have also impacted urban ecosystems (Awadh, 2023). According to a study by Che et al., (2022), transportation emissions were not the main source of metal contaminants in urban environments; industrial processes and coal combustion were to blame. There are many different sizes of dust particles, according to Kaonga et al., (2021), who utilized fluorescence microscopy to show that dust particles from areas with high traffic circulation were finer than those from other places. Additionally, Liu et al.'s (Aguilera et al., 2022) research connected urban dust pollution from potentially harmful elements to population density. The need to develop systems that would reduce the levels of these heavy metals in urban dust is because urbanization is causing population densities in most cities to continue to rise (Saha et al., 2022).

According to the reviewed literature, Hg, As, Cd, Cu, Cr, Ni, Mn, Fe, Pb, Sb, and Zn are the potentially toxic elements that have been investigated the most in urban dust (Benhaddya et al., 2016). Although there are questions about the sources, risk factors, and toxicity levels of the heavy metals, a study by Ferreira Batista and De Miguel, (2005), discovered higher levels of lead and arsenic in dust particles in the streets of Luanda, Angola.

Similar findings were reported by Benhaddya et al., (2016), who discovered unusually high amounts of potentially toxic elements (Cu, Mn, Ni, Pb, and Zn) in urban dust from Hassi Messaoud in Algeria. Furthermore, a study of potentially toxic elements in urban dust in the northern Mexican cities of Torreon, Chihuahua, and Monterrey found extremely high concentrations of potentially toxic elements, particularly in residential areas close to metal smelting and refining sites, endangering the health of those who live there (Kaonga et al., 2021). All of these findings indicate that pollution from potentially harmful elements in urban environments is becoming an issue and a hazard to the urban human population (Kaonga et al., 2021).

2.2 Sources and Distribution of Potentially Toxic Elements in Dust Samples

Numerous studies have shown that anthropogenic pollution sources for potentially harmful elements in urban soils and dust include traffic emission (vehicle exhaust particles, tire wear particles, brake lining wear particles) (Atiemo et al., 2011; Victoria et al., 2014), industrial emissions from power plants, coal combustion, metallurgical industry, auto mechanic shop, chemical plant, (Ma & Singhirunnusorn, 2012), domestic emission, weathering of building and pavement surface, atmospheric deposition (Kadhum, 2020), and others. For instance, transportation pollution is a major source of Pb, Zn, and Cu. One of the primary sources of potentially toxic elements in the urban environment is dust samples (Karanasiou et al., 2014); (Kabir & Rashid, 2022), which come from eroding pavement on buildings and roads, industrial smoke, and vehicle exhaust. Potentially toxic elements may be absorbed by soil very well, which causes accumulation over time (Kumari & Mishra, 2021). Through unintentional oral ingestion, cutaneous contact, and inhalation, potentially toxic elements in soil and roadway dust will endanger the health of populations (Han et al., 2017; Liu et al., 2021; Ma & Singhirunnusorn, 2012b).

The production of chemicals, metal smelting, welding, metallurgy, electroplating, and accumulator manufacturing are only a few of the industrial processes that contribute to the release of various toxic elements into the environment in urban areas (Reichenbach et al., 2019). The manufacturing of fertilizer, pigments, dyes, and textiles, as well as the recycling and processing of electronic trash (e-waste), are just a few of the additional businesses that contribute to the release of potentially harmful elements in a variety of forms and concentrations into urban areas (Briffa et al., 2020; Reichenbach et al., 2019). The catchment regions of e-waste processing companies have regularly been observed to include dust contaminated with potentially harmful elements such as Cu, Pb, Cd, Cr, and Zn (Moni et al., 2023).

The widespread use of pesticides and fertilizers in agricultural practices also contributes to the contamination of soils with potentially harmful elements (Han et al., 2023; Moni et al., 2023). One of the major sources of contamination with potentially hazardous elements is the widespread use of chemical-based fertilizers in agricultural activities to improve the fertility of the soil for the improvement of crop yields (Reichenbach et al., 2019). These fertilizers contain considerable levels of As, Cr, Cd, Pb, Zn, Ni, Fe, Mo, and Mn, which are essential for improving plant development and health, but their excessive concentrations have hazardous impacts on both soil and aquatic resources (Han et al., 2023).

Numerous studies have shown that the main contributors to the pollution of urban road dust with potentially hazardous elements are motor vehicle emissions (Moskovchenko et al., 2022). The primary sources of potentially harmful substances released from automobiles are the burning of fossil fuels (engine exhausts), lubricating oil, brake lining wear, tire wear, and corrosion of various motor vehicle components (Odediran et al., 2021). The sources of potentially hazardous elements that are most frequently mentioned include arsenic, which is easily produced through coal burning. Fly ash, produced when coal is burned, can be released into the atmosphere and deposit whatever potentially toxic element(s) it contains on the dust (Briffa et al., 2020). Chrome is a substance found naturally in rocks, animals, plants, soil, volcanic gases, and dust (Delaware Health and Social Service, 2015). The industrial oxidation of mined chromium deposits, as well as possible fossil fuel, wood, and paper combustion, as well as industrial processes like ore refining, processing (chemical and refractory), manufacturing (cement, automobile brake linings, and catalytic converters), and tanning (leather), are some of its most prevalent anthropogenic sources (Hanfi & Yarmoshenko, 2020). Additionally, Cr is released during the production of tools, the wear of stainless steel, and the wear of vehicle parts (Aguilera et al., 2021). Chromium is then utilized in motor components and the motor's body, and it is also produced during the burning of coal (Z. Li et al., 2020).

The naturally occurring metal cadmium occurs in conjunction with other elements and is quite rare (Genchi, Sinicropi, et al., 2020). Fossil fuel combustion and municipal waste incineration are the main causes of Cd in the air (Alengebawy et al., 2021). Cd is employed in the creation of specialty alloys and solders, metal plating, nickel-cadmium rechargeable batteries, electronic waste, pigments in yellow or brown paints (used to color plastics, glass, and polishes), and pigments in cadmium-based paints (Kubier et al., 2019). Cd is an important element found in lubricating oil and tires, both of which can leak Cd into the environment (Kubier et al., 2019). The environment contains a lot of copper, an important trace element. It is a naturally occurring element and a constituent of several minerals (Time, 2023). Cu may come from road vehicle exhaust emissions from both gasoline and diesel-powered cars, oil pump wear, and brake pad wear (Fussell et al., 2022; Time, 2023). In addition to being found in construction materials, cu is emitted during industrial processes including metal processing and smelting (Wuana & Okieimen, 2011).

The combustion of coal also easily produces the metals iron and manganese, which are produced by the smelting industry, by the wear on brake systems, and by the general wear on cars (Pajarillo et al., 2021). Nickel is easily produced through the combustion of coal and is used in the body and parts of automobiles (Aguilera et al., 2021). In urban regions with heavy industry, lead is a common metal. Brick kilns, heavy traffic, and the usage of leaded gasoline are all linked to high Pb concentrations in dust samples (Rahimi, 2020). It is released by fuel/oil leaks from moving vehicles with oil lubricants as well as from tire, brake, and other component wear and tear (Odediran et al., 2021). Trace metals like Pb are produced in substantial quantities through the recycling of e-waste (Hanfi & Yarmoshenko, 2020).

A vital trace element that is abundantly present in the environment is zinc (Hussain et al., 2022). Traffic emissions, such as engine emissions, mechanical abrasion of cars, and tire and brake wear, have a significant impact on the contamination in dust samples (Mazen Khaled Nazal, 2020). To speed up the vulcanization of rubber, Zn is added to tire tread rubber mostly as zinc oxide (ZnO) and in smaller amounts as a variety of organo-zinc compounds (Hussain et al., 2022). Vanadium is typically thought of as a sign of burning fuel oil or petroleum. Vanadium can also be made through smelting (Aguilera et al., 2021).

2.3 Exposure and Human Health Effects of Potentially Toxic Elements

Common exposure routes to potentially hazardous elements in dust include ingestion, inhalation, and skin contact (Moni et al., 2023; Neisi et al., 2016). Ingestion happens through the digestive system, inhalation happens through the respiratory system, and dermal involves skin absorption (Moni et al., 2023). The liquid, gas, solid-state, or, chemical form in which potentially harmful materials are found indicates the degree of exposure along a particular pathway (Jaishankar et al., 2014). The main method of exposure to airborne hazardous elements and polluted dust particles dispersed in the environment is through inhalation (USEPA, 2017). The volume, force, and degree of inspiration, as well as the exposed person's age and sex, as well as the organ involved (oral or nasal), all have an impact on the possible effects of inhaling potentially harmful substances (USEPA, 2017). Arsenic, cadmium, lead, nickel, and other toxic metals are common airborne contaminants that can enter the body through breathing (Jaishankar et al., 2014). The dermal absorption factor of each metal and the exposed surface area determine how much potentially harmful substances are absorbed through the skin (Mitra et al., 2022). Therefore, even if the amount may vary from one exposure pathway to another, all exposure paths permit a sizable amount of potentially dangerous substances to enter the body of the exposed individual (Balali-Mood et al., 2021).

Increased concentrations of potentially harmful elements have a significant negative impact on how well the body performs physiological functions like metabolism and nerve transmission (Mitra et al., 2022). They can also harm internal organs and systems, lead to cancer, and even cause death. Zinc, copper, cadmium, chromium, nickel, mercury, and lead are examples of potentially harmful elements that are known to be stable and cannot be metabolized or digested by the body (Engwa et al., 2019). These potentially dangerous elements tend to build up in the bones, tissues, and organs of the body, and after a significant buildup, their negative consequences start to manifest (Witkowska et al., 2021). The recommended limit is the only range where the human body will tolerate potentially harmful elements (Mihankhah et al., 2020). After exposure to a larger concentration of potentially harmful elements, both acute and chronic symptoms are occasionally noticed. The type of toxicity most relevant to environmental toxicants is typically chronic toxicity, which is linked to prolonged exposure to potentially toxic substances (Javaid et al., 2022). Potentially harmful substances are released into the environment in low quantities and take a long time for their effects to manifest in the exposed population, hence the majority of researchers are interested in this kind (Ali et al., 2019b). According to investigations, the forms in which potentially harmful elements occur in the environment determine how toxic the elements are to biological systems. Organic, inorganic, and metallic forms of potentially hazardous elements exist. For instance, it is well known that the inorganic forms of mercury, arsenic, and lead are less dangerous than their organic counterparts (Balali-Mood et al., 2021).

2.3.1 Toxic Effect of Lead Exposure

The lungs, kidneys, heart, brain, and reproductive organs are among the body organs that are impacted by high lead exposure (Lead, 2022). Acute abdominal discomfort, agitation, cyanosis (bluish staining of the gums), headache, saturnine gout (severe pain, redness, and tenderness in joints), and heart toxicity can all result from lead overdose (Collin et al., 2022). Lead exposure over an extended period can result in neurological conditions such as lethargy, convulsions, paralysis, and hematological disturbances (Balali-Mood et al., 2021). Epidemiological studies have shown that children who are exposed to lead throughout their early development have a lower intelligence quotient (Collin et al., 2022). Other research revealed that children who are persistently exposed to lead experience a 1–5 point decline in intelligence quotient for every increase of 10 g/dL in blood lead levels (Lead, 2022). Lead exposure is also linked to the onset of schizophrenia, a condition in which sufferers acquire severe and persistent mental illnesses (Jaishankar et al., 2014). According to Anyanwu et al., (2018), elevated lead levels in blood can interfere with calcium-mediated signal transduction, resulting in diminished nerve transmission and loss of cutaneous sensitivity. While lead exposure in men can have negative effects on sperm quality and sperm count, lead intoxications in pregnant women can result in spontaneous abortion and premature birth (Mishra et al., 2019). Lead and its compounds have been labeled human carcinogens by the US EPA and IARC, which means that those who have been exposed to them over an extended period run the risk of developing cancer (Mishra et al., 2019).

2.3.2 Toxic Effect of Arsenic Exposure

Arsenic has a lengthy history of use as a metalloid material and as a pharmaceutical (Marzo & La Mendola, 2021). It is infamously referred to as "the poison of kings" and "the king of poisons” (Empire, 2016). The small intestine is where most arsenic is absorbed initially (Engwa et al., 2019). Inhalation and skin contact are two additional ways to be exposed (Dome et al., 2015). Arsenic exposure is frequently caused by ingesting contaminated food, drink, or dust as well as by breathing in arsenic particles in the air (Ryder et al., 2020). Lung, kidney, and bladder cancer risks are all increased due to exposure to inorganic arsenic, which is also classified as a group 1 human carcinogen (C. Huang et al., 2022). Ingestion of inorganic arsenic may result in a decrease in the synthesis of white and red blood cells, which might harm the blood vessels and result in irregular heart rhythms (Briffa et al., 2020). Ingesting excessive amounts of arsenic can cause visible symptoms such as nausea, vomiting, diarrhea, stomach pain, and intestinal irritations (Balali-Mood et al., 2021). It can also sometimes damage nerves, which is accompanied by a burning sensation in the hands and feet. Arsenic exposure through skin contact can result in skin rashes, lesions, edema, and occasionally skin redness (Witkowska et al., 2021). According to the information at hand, long-term exposure to inorganic arsenic may cause neurological damage in children, which may result in impaired motor and cognitive functioning (low IQ) (Theisler, 2022). It has been documented that exposure to all types of arsenic, whether acute or chronic, can result in human death, particularly in occupational workers who are exposed to high quantities of arsenic (Witkowska et al., 2021). The central nervous system, cardiovascular system, and vascular system of humans are known to be severely harmed by the organic form of arsenic, which is highly poisonous (Theisler, 2022). When both adults and children consumed tube well water laced with arsenic, the frequency of enormous arsenic poisoning and death in human history was documented in Bangladesh in 1970 (Ahmad et al., 2018).

2.3.3 Toxic Effects of Zinc Exposure

Although zinc metal is a necessary element for humans, sometimes taking too much of it might have negative health effects (Hussain et al., 2022). Metal fume fever can be brought on by short-term occupational exposure to excessive levels of zinc metal and zinc compounds like zinc oxide. Metal fume fever is characterized by symptoms like headache, dry cough, chills, shortness of breath, fever, generalized body aches, persistent chest pain, and joint pain (Szűcs-Somlyó et al., 2023). As described by Hussain et al., (2022), these symptoms are always reversible and may go away four days after an acute dose or when exposure stops. Long-term exposure to zinc metal and zinc chloride in zinc dust or fumes might result in respiratory issues like lung inflammation and damage, diminished lung vitality, drowsiness, respiratory tract irritation, and throat burning (Hussain et al., 2022). Respiratory distress syndrome, lung collapse, and lung thickening and scarring have all been linked to prolonged exposure to high concentrations of zinc salts, particularly zinc chloride (Mahboob et al., 2017). The intermediate symptoms of zinc poisoning, including vomiting, abdominal pain, nausea, anemia, vertigo, epigastric pain, and occasionally diarrhea, have been observed in workers exposed to high doses of oral zinc and zinc sulfate as well as zinc fumes or dust (Plum et al., 2010).

2.3.4 Toxic Effect of Copper Exposure

Due to its role in human biological processes, metallic copper is a necessary component for optimal health (Jomova et al., 2022). When this element's physiological concentration surpasses the advised concentration limit, it is reportedly detrimental to human health (Jomova et al., 2022). Long-term exposure to copper fumes or dust can cause lung fibrosis, coughing, headaches, eye and nose irritations, nausea, dizziness, and occasionally diarrhea in susceptible individuals (Benhaddya et al., 2016). When exposed to airborne copper concentrations between 0.64 and 1.05 mg/m^3, occupational workers may have hematological consequences such as decreased hemoglobin concentration and poor red blood cell count (Wuana & Okieimen, 2011). There have been reports of endocrine and digestive system problems in workers who grind and sieve dust that contains copper (Mazen Khaled Nazal, 2020). Chronic copper poisoning is also associated with red cheeks, hypophyseal adenoma, anorexia, arterial hypertension, and sexual dysfunction (Mitra et al., 2022). Metal fume fever is caused by exposure to copper dust or fumes at concentrations of 0.075 to 0.012 mg/m^3, according to studies (Reichenbach et al., 2019). Long-term copper exposure is also linked to other dangerous health problems, such as black tarry stools (melena), Wilison's disease, and coma.

Exposure to copper sulfate has been associated with anemia, pancreatic damage, and liver damage (Balali-mood et al., 2021).

2.3.5 Toxic Effects of Iron Exposure

Iron compounds with low acute toxicity include iron sulfate, iron sulfate heptahydrate, and iron sulfate monohydrate (Sharma et al., 2021). Other kinds of iron, however, might cause major health issues. There are four phases to iron toxicity. Gastrointestinal symptoms such as vomiting, diarrhea, and gastrointestinal bleeding characterize the first stage, which starts six hours after an iron overdose (Patel & Marwaha, 2020). After an overdose, there is a latent phase of apparent medical recovery that lasts between six and twenty-four hours before the second stage progresses. The third stage starts between 12 and 96 hours following the onset of clinical symptoms; it is marked by hypotension, shocks, lethargy, hepatic necrosis, tachycardia, and metabolic acidosis, and it occasionally results in death (Mazen Khaled Nazal, 2020). Normally, the fourth and final stage happens between two and six weeks after an iron overdose. The onset of strictures and the growth of gastrointestinal ulcerations characterize this stage (Mitra et al., 2022). Due to the high iron content of meat, countries with a meat-eating population are more likely to develop cancer (Engwa et al., 2019). Workers who are heavily exposed to asbestos are at significant risk of developing asbestosis, a condition known to cause lung cancer since asbestos contains roughly 30% iron (Patel & Marwaha, 2020). Free radicals, which are thought to be the cause of cancer linked to asbestos, are known to be produced by iron. Free radicals produced by iron can cause DNA damage and oxidation, which can result in cancer (Engwa et al., 2019).

2.3.6 Toxic Effects of Manganese Exposure

Despite being a necessary metal for the body, manganese only recently gained attention due to the introduction of the gasoline additive methylcyclopentadienyl manganese tricarbonyl (MMT), which was recognized to be hazardous (O'Neal & Zheng, 2015). MMT has allegedly been related to the emergence of a Parkinson's disease-like illness characterized by tremors, gait abnormalities, postural instability, and cognitive disorders, and is stated to be an occupational manganese hazard (Kulshreshtha et al., 2021). Neurotoxicity may develop from prolonged exposure to high manganese levels (Jomova et al., 2022). The neurological condition known as manganism, which is caused by manganese, is characterized by rigidity, action tremor, a mask-like expression, gait difficulties, bradykinesia, micrographia, memory and cognitive failure, and mood problem (Kulshreshtha et al., 2021). Manganism shares several characteristics with Parkinson's disease in terms of symptoms (O'Neal & Zheng, 2015).

2.3.7 Toxic Effects of Chromium Exposure

Chromium (Cr), a naturally occurring potentially toxic element used in industrial operations, may be found in saltwater and the crust of the planet (Balali-mood et al., 2021). The most prevalent stable forms of Cr are trivalent and hexavalent, which range in oxidation state from 2 to +6 (Balali-Mood et al., 2021). While Cr (III) is necessary for trace amounts for normal lipid and protein metabolism as well as acting as a cofactor for insulin action, Cr (VI) is linked to several illnesses and pathologies (Ao et al., 2022). Hexavalent chromium has been categorized as a category I occupational carcinogen according to the International Agency for Research on Cancer (IARC) study from 2018 (Balali-mood et al., 2021). For non-occupational human populations, skin contact with chromium-containing goods or consumption of chromium-containing food and water are the main routes of exposure (Ao et al., 2022). Additionally, the metallurgical, refractory, and chemical industries discharge a significant quantity of Cr into the air, groundwater, soil, and marine life, posing health risks to all living things (Mihankhah et al., 2020). Cr can bioaccumulate in the body and lead to several illnesses. This includes anything from skin, kidney, neurological, and gastrointestinal illnesses to the emergence of numerous malignancies, including those of the thyroid, lungs, throat, bladder, kidneys, testicles, and bones (Balali-Mood et al., 2021).

Short-term contact with chromium may result in skin burns, eye inflammation, skin irritation, and in extremely extreme cases, eye damage. Metal fume fever and throat and nasal irritation can result from exposure to chromium through inhalation of chromium dust or fumes (Ao et al., 2022). Metal fume fever's immediate symptoms include headache, coughing, fever, and chills. Workers who are exposed to hexavalent chromium compounds over an extended period may develop chronic respiratory conditions including pneumonia, bronchitis, nasal septum ulceration, and decreased lung function (Delaware Health and Social Service, 2015). Ingestion of high concentrations of Cr (VI) might expose people over short periods to unfavorable gastrointestinal issues including stomach and intestinal ulcers, mouth ulcers, vomiting, bloody diarrhea, and abdominal pain (Z. Li et al., 2020). When exposed to chromium-containing products through skin contact, hypersensitive chromium industry workers have reportedly acquired erythema and skin rashes (Mihankhah et al., 2020). Lung cancer has been identified in long-term exposed employees, and there have been numerous reports of worker deaths brought on by the disease (Balali-mood et al., 2021).

2.3.8 Toxic Effects of Nickel Exposure

The detrimental effects of nickel and its compounds on both occupational and non-occupational workers have been thoroughly investigated (Genchi, Carocci, et al., 2020).

According to a study by Genchi et al., (2020), exposure to nickel dust and fumes through the skin has a greater impact on occupational workers. Nickel is known to produce allergic skin reactions, and people who are more sensitive to nickel are more likely to experience them (Buxton et al., 2023). A variety of cancers have been linked to exposure to nickel and its compounds, which are categorized as human carcinogens (Balali-Mood et al., 2021). Numerous malignancies, including lung, pharyngeal, and Sino nasal sarcoma, have been recorded in occupational workers exposed to more than 10 mg/m3 of nickel (Mitra et al., 2022). Chromosome damage, mitochondrial malfunction, induced mutagenesis, and suppression of DNA repair are other effects of nickel (Rahimzadeh et al., 2017). Acute exposure to high levels of nickel and its compounds is known to cause a variety of symptoms, including body weakness, headaches, nausea, vomiting, irritability, insomnia, cyanosis (bluish discoloration of the hands or feet), persistent coughing, skin and eye irritation, visual issues, shortness of breath (dyspnea), and vertigo (Genchi, Sinicropi, et al., 2020). Occupational workers who are exposed to high quantities of nickel have experienced long-term exposure effects of nickel poisoning such as asthma, lung inflammation, septum perforation, kidney injury, loss of smell, and inflammation of the nasal sinus (sinusitis) (Jan et al., 2015). Nickel is known to cause oxidative stress by causing lipid peroxidation and has been associated with the malfunctioning of hormonal systems (Genchi, Sinicropi, et al., 2020). Malformed bodily organs are one of the problems seen in infants, and it has been reported that pregnant workers in nickel manufacturing and smelting industries have spontaneous abortions (Balali-Mood et al., 2021).

2.3.9 Toxic Effect of Cadmium Exposure

Food and water contamination is the main source of cadmium exposure for humans (Genchi, Sinicropi, et al., 2020). Inhaling cigarette smoke is a common way to become exposed. Cadmium accumulates in plants and animals for about 25–30 years, which is the cause of its toxicity (Kubier et al., 2019). One of the best ways to eliminate cadmium from food is by microbial fermentation (Rahimzadeh et al., 2017). Phosphate fertilizers and garbage incineration are two other significant environmental sources of cadmium (Tchounwou et al., 2012b). Smokers and non-smokers of cigarettes have very different blood cadmium levels (Witkowska et al., 2021). Alzheimer's disease can be brought on by lead and cadmium toxicity in the human body, which can reach the brain (Genchi, Sinicropi, et al., 2020). Urinary cadmium levels have been used as indicators for cadmium levels in people because, following exposure, cadmium can build up in the kidneys in humans (Rahimzadeh et al., 2017). Workers in the battery manufacturing, pigment manufacturing, and electroplating industries may be exposed to cadmium during work (OMS, 2010). Because even modest amounts of prolonged accumulation in the human body are hazardous and cancer-causing. Sewage sludge, which can produce cadmium in about the same amount as fertilizer use, is another significant source of cadmium in the soil (Genchi, Sinicropi, et al., 2020). The most common adverse health consequence of cadmium poisoning in people is nephropathy, which often manifests as tubular or renal failure (OMS, 2010). Chronic cadmium nephropathy impairs phosphate and calcium metabolism, resulting in kidney stones, bone demineralization, and bone fractures (Ali et al., 2019b). People who had long-term exposure to cadmium experienced bone deterioration, which led to the Itai-Itai sickness that was first noted in Japan in the 1950s (Mazen Khaled Nazal, 2020). It is well known that cadmium causes prostate cancer in males and has been designated by the IARC as a human and animal carcinogen (Balali-Mood et al., 2021). Long-term exposure to airborne cadmium may impair lung function, increase the risk of developing lung cancer, and worsen respiratory conditions such as emphysema and bronchiectasis (S. Huang et al., 2019). According to the epidemiological study, men who are exposed to cadmium for an extended period may experience infertility, low sperm count, germ cell death, bleeding, and testicular edema (Alengebawy et al., 2021). Additionally, cadmium exposure during pregnancy may result in preterm birth, low birth weight, and a 50% reduction in progesterone in the mother (S. Huang et al., 2019).

2.4 Sampling Methods for Steet Dust

Urban dust sampling can be done in several ways. Some of them have been documented, such as the use of a plastic dustpan and brush (Mihankhah et al., 2020), a plastic hand broom and dustpan (Kaonga et al., 2021), brushing 1 m^2 of the previously delimited asphalt surface (Yu et al., 2016), an ABA1-120-02A portable aspirator (Saghatelyan et al., 2014), brush and plastic hand shovel (Kaonga et al., 2021), a vacuum cleaner (Q. Han et al., 2023), and a portable high-pressure washer device with a piston fitted into a rigid, sealed rubber dome (Moja & Mnisi, 2013). For dry dust samples, several techniques are typically utilized. Wet dust samplers (WDS) come in helpful when it's wintry and wet, according to Lundberg et al., (2022). The wet dust sampler works on the theory of flushing highly pressurized water over a predetermined surface area and then transferring the dust-laden water into a container for further analysis (Kaonga et al., 2021). Colinet, (2010) outlines certain dust-sampling tools that have detectors that give the real-time concentration of dust in a given region in addition to these techniques that are used for the actual sampling of the dust for the analysis of potentially harmful elements. These include a personal dust monitor (PDM), which enables instant measurement of respirable dust, and a gravimetric dust sampler, which provides time-weighted-average respirable dust concentration. The potential threat of urban dust to human health can be estimated by combining these dust collection techniques with the findings of analyses of potentially harmful elements (Kaonga et al., 2021).

2.5 Determination Methods of Potentially Toxic Elements in Dust Samples

The determination of potentially toxic elements in urban dust has been done using different methods across the globe (Kaonga et al., 2021). The commonly used methods include Atomic Absorption Spectrometry (AAS), Inductively Coupled Plasma-Dynamic Reaction Cell-Mass Spectrometry (ICP-DRC-MS), Inductively Coupled Plasma-Mass Spectrometry (ICP-MS), Inductively Coupled Plasma-Atomic Emission Optical Spectrometry (ICP-OES), Atomic Fluorescent Spectrometry (AFS), X-Ray Fluorescence Spectroscopy (XRF), Flame Atomic Absorption Spectroscopy (FAAS), Anodic Stripping Voltammetry (ASV) and Cold Vapor Generation-Atomic Fluorescence Spectrometry (CV-AFS, XGF-1011A) (Darko, Dodd, Nkansah, Aduse-Poku, et al., 2017). The availability of the instrument, the cost of the analysis, the sensitivity and limits of detection, and the characteristics of the material being examined are the main factors that influence the choice of the analytical method in the majority of cases (Nkansah et al., 2017a). To ascertain the levels of heavy metals in the dust samples, an X-ray fluorescence spectrometer (XRF) was employed in this investigation. The benefits of X-ray spectrometry were listed by Mathias J., (2019). The analysis is effective across a variety of organic and inorganic compounds, analyses stainless steel passivation, is effective at identifying surface contaminants and is an expedient testing procedure in that an analysis may be completed in three (3) minutes.

2.5.1 Principles of X-Ray Fluorescence (XRF) Spectroscopy

X-ray fluorescence spectroscopy is a non-destructive analytical method for measuring the intensity of secondary X-rays or distinctive fluorescence generated by atoms of each element present in a sample after irradiation with higher energy X-ray beams. When the very powerful X-ray from the X-ray source collides with a sample, it causes the tightly bound electrons in the inner shells of the atoms of the elements present in the sample to be removed. This process leaves empty vacancies in the atoms' inner shells, which must be filled for an element to regain its previous stability or structural arrangement. As a result, electrons from elements' outer shells are quickly transferred to their inner shells to replace any open voids. Energy is released during the process in the form of secondary X-ray fluorescence. The energy of secondary X-ray emission is proportional to the concentration of each element in the sample, and the intensity of the energy of secondary X-ray emission is what is assessed as a characteristic of elemental concentrations in the sample. The electronic energy level and its distinctive energy value are the major factors used to identify an element. Since each element has a distinct ionization potential, fluorescence emission happens independently, allowing XRF to quantify the concentrations of numerous elements in a single scan (Darko, Dodd, Nkansah, Aduse-Poku, et al., 2017).

2.6 Source Apportionment of Potentially Toxic Elements in Dust Samples

It has been established that the heavy metals in dust from various sources have varying bioavailabilities, which lead to varying levels of health risk (Tawabini et al., 2023). Determining the many components of urban dust, their quantities, and their origins is crucial for managing and assessing the risks associated with them (C. Huang et al., 2022). It may be possible to identify complicated pollutant interactions that reflect the connections between urban dust and detrimental human health by quantifying health risks based on sources rather than individual pollutants (Kaonga et al., 2021).

Receptor models and isotopic analysis are the two methods that are most frequently used to apportion sources of urban dust (Watson & Chow, 2014). Chemical mass balance (CMB) analyses, enrichment factor (EF) analyses, and statistical multivariate factor analyses, including principal component analysis (PCA), positive matrix factorization

(PMF), clustering analysis (hierarchical cluster analysis), and multivariate curve resolution are examples of receptor models (Rutherford et al., 2021). The typical descriptive statistical studies are unable to provide information regarding the correlation between contaminants and their sources, as is the case with multivariate approaches (Kaonga et al., 2021). While PCA can clarify current links between environmental (meteorological) parameters and heavy metal concentrations, correlation analysis can be used to examine chemical-environmental associations among heavy metals that may suggest possible relationships among their origins (C. Huang et al., 2022). When used exclusively, source-apportionment approaches are, however, flawed or insufficient (Wang et al., 2022). In this regard, the enrichment factor, correlation analysis, and principal component analysis were employed to identify potential sources of potentially harmful components in the dust samples.

2.6.1 Enrichment Factor

Enrichment factor (EF) analysis has been used to investigate pollutant sources by distinguishing between anthropogenic and natural sources in sample matrices such as soils and urban dust (Mirzaei Aminiyan et al., 2018). This method compares the relative concentration of an analyte in the dust to that in the background. A reference element is distinguished by high soil stability and the absence of vertical mobility and/or degradation (Mihankhah et al., 2020). An EF value close to one implies that the element did come from the soil (Moni et al., 2023), whereas EF values of more than one often indicate that the sample is enriched from anthropogenic sources (Fosu-Mensah et al., 2018).

2.6.2 Principal Component Analysis

To reduce the number of variables to a few uncorrelated components, a data reduction approach called PCA is used (Mirzaei Aminiyan et al., 2018). Its goal is to explain the majority of the variance in the data. Using principal component analysis (PCA), it is possible to categorize people and groups of variables based on the principal component scores and loadings, or the correlations between the variables and the principal components (Huang et al., 2022). The output of PCA software is typically a graph known as "scores" (equal to the variables), which is estimated using bilinear modeling techniques, where information carried by many variables is condensed onto a small number of underlying variables (Jolliffe et al., 2016). Every model component of every sample has a score. The scores, which display the samples' locations along each model component, can be used to identify sample trends, clusters, similarities, or discrepancies (Rabin et al., 2023). One of the additional graphs created by PCA is referred to as a "loading," which is determined using bilinear modeling techniques where data from multiple variables is condensed onto a small number of components. Every variable is loaded along every part of the model (Mirzaei Aminiyan et al., 2018). The loadings demonstrate how well the model's components account for each variable. They can be used to interpret variable relationships and determine how much each variable contributes to the meaningful variance in the data. They help decipher the significance of each model component as well (Jolliffe et al., 2016). For PCA, numerous computing algorithms have been created. While some computation techniques discover the most important component first, followed by the next component, and so on, others locate all components at once (Huang et al., 2022).

2.6.3 Correlation Analysis

A statistical technique used in research to determine the association between two variables and gauge the strength of their linear relationship is correlation analysis (Braeken & Van Assen, 2017). A high correlation indicates a strong association between the two variables, whilst a low correlation indicates a poor correlation between the two variables (Liu et al., 2021). When an increase in one variable causes an increase in the other, there is a positive correlation between the two variables (Zhu et al., 2022). A negative correlation, on the other hand, indicates that when one variable rises, the other falls, and vice versa (Suryawanshi et al., 2016). The correlation coefficient, denoted by the symbol r and typically a value without units falling between 1 and -1, is the unit of measurement used to determine the intensity of the linear relationship between the variables involved in correlation analysis (Braeken & Van Assen, 2017). There might be a positive correlation, a negative correlation, or no connection between two variables. A very high positive correlation, or the idea that they both rise at the same time, is indicated by any score between +0.5 and +1 (Zhu et al., 2022). Any score between -0.5 and -1 denotes a high negative correlation, meaning that as one measure rises, the other falls proportionately (Suryawanshi et al., 2016). There is no correlation or relationship between the two variables, as shown by a score of 0 (Braeken & Van Assen, 2017).

2.7 Human Health Risk Assessment

An evaluation of the risks to human health that may come from exposure to environmental hazards is known as a human health risk assessment (US EPA, 2022). Additionally, it is defined as the process of estimating the type and likelihood of unfavorable health impacts in individuals who may be exposed to chemicals in polluted environmental media in the present or the future (Zhang et al., 2023). In this method, a hazard is identified, measured, and a numerical number is chosen to reflect the possible danger. These tools come from science, engineering, and statistics (Erickson, 1996; Hayes, 2023).

2.7.1 Hazard Identification

Identifying hazards entails determining whether a substance is causally linked to specific health impacts or not (US EPA, 2022). It deliberately assesses the strength of the evidence for harmful effects in humans based on an evaluation of all pertinent information on toxicity and mode of action (Hayes, 2023). The two main problems that are addressed by hazard identification are whether a substance could be harmful to people's health and under what conditions a hazard might manifest itself (Mishra et al., 2019). Numerous end-points are frequently seen after exposure to a particular chemical. The first substantial adverse impact that normally appears with increasing doses is known as the critical effect (Mishra et al., 2019).

2.7.2 Dose-response

In the dose-response stage, it is determined how much exposure has occurred and how likely it is that the relevant health effects will manifest (US EPA, 2022). It is a procedure for describing the association between the dose of an agent given or received and the occurrence of an adverse health consequence (Mishra et al., 2019). It is commonly accepted that there is a dose or concentration below which harmful effects will not occur (i.e., a threshold) for the majority of toxic effects, such as organ-specific, neurological/behavioral, immunological, non-genotoxic carcinogenesis, reproductive, or developmental impacts (Hayes, 2023). For other hazardous effects, there is presumed to be a chance of harm at any exposure level (i.e., non-threshold). For mutagenesis and genotoxic carcinogenesis, the non-threshold assumption is typically used (Zhang et al., 2023).

2.7.3 Exposure Assessment

Exposure assessment can be viewed as an analogous phase in the process of hazard identification and dose-response assessment, which aims to determine the type and extent of interaction with chemicals experienced or anticipated under various conditions (US EPA, 2022). In exposure assessment, the risk of the toxic agent is calculated based on the amount taken into the body through any combination of oral, inhalational, and dermal exposure routes, as well as the overall exposure of the toxic agent in the environment (USEPA, 2017). Exposure may be stated as an ambient concentration in certain assessments that are exclusive to one exposure route. To determine the concentrations to which human populations or environmental spheres (water, soil, and air) may be exposed, exposure assessment necessitates the determination of a substance's emissions, routes, rates of movement, and transformation or degradation (US EPA, 2022). The numerical result of an exposure assessment may be an estimation of the intensity, rate, duration, or frequency of contact exposure or dose, depending on its intended use. The three primary exposure pathways—dermal, oral, and respiratory—are identified during exposure assessment (Neisi et al., 2016).

Typically, the outcome of risk assessments based on dose-response relationships includes an estimate of the dose. It is significant to remember that the toxicological outcome of a particular exposure is determined by the internal dose and not the level of exterior exposure (Hayes, 2023). The phrase "worst-case exposure" has traditionally meant the most exposure conceivable, or the scenario in which all plausible events would occur to increase exposure. In most risk assessments, the exposure assessment is the "weakest link" because it reflects a hypothetical person and an extreme combination of circumstances that are typically not experienced in an actual population (USEPA, 2017). Biomarkers may be used to gather information regarding contamination. On the other hand, pollution frequently happens in hotspots as a result of point sources, therefore it is incorrect to assume that everyone is exposed to the same, perhaps average, level of contaminants (Mishra et al., 2019). Through the source-pathway receptor paradigm, it is possible to determine a more accurate contaminant intake and subsequently the hazards by maintaining the spatial distribution of soil contamination levels and receptors (US EPA, 2022).

2.7.4 Risk Characterization

The goal of the final step in the risk assessment process, risk characterization, is to provide risk managers and contractors with the crucial scientific data and rationale concerning the risk they need to make decisions (USEPA, 2017). To determine the actual likelihood of risk to exposure populations, all the information from the hazard identification, dose-response, and exposure steps is quantitatively compared with doses that are associated with potential health effects (Dome et al., 2015). The phrase "risk management" refers to all the steps necessary to decide whether an associated risk needs to be eliminated or at least reduced (Hayes, 2023). Regulatory, non-regulatory, economic, advisory, or technological risk management strategies or approaches can be generally categorized but are not mutually exclusive (Zhang et al., 2023). The key decision-making variables, such as population size, available resources, target-meeting expenses, and the scientific rigor of risk assessment and the ensuing managerial judgments, change greatly depending on the decision setting (US EPA, 2022).

CHAPTER THREE

3.0 MATERIALS AND METHODS

3.1 Study Area

Sekyere South district is situated in the northeastern portion of the Ashanti region. It is thirty-seven (37) kilometers away from Kumasi along the Kumasi-Mampong trunk route. Agona serves as the administrative center. The district share boundary with Offinso Municipal to the west, Mampong Municipal to the east, Sekyere East to the east, Kwabre East to the south, and Ejura Sekyedumasi to the north. The district’s total land area is 416.8 square kilometers or about 1.7% of the Region's 24,389 square kilometers of land. According to the 2021 Population and Housing Census, 120,076 people are living in the district, including 58,065 men and 62,011 women. The area's latitude ranges from 6° 50°N to 70°N and its longitude from 10° 40°W to 10° 25°W (Asamoah et al., 2018; SSDA., 2017).

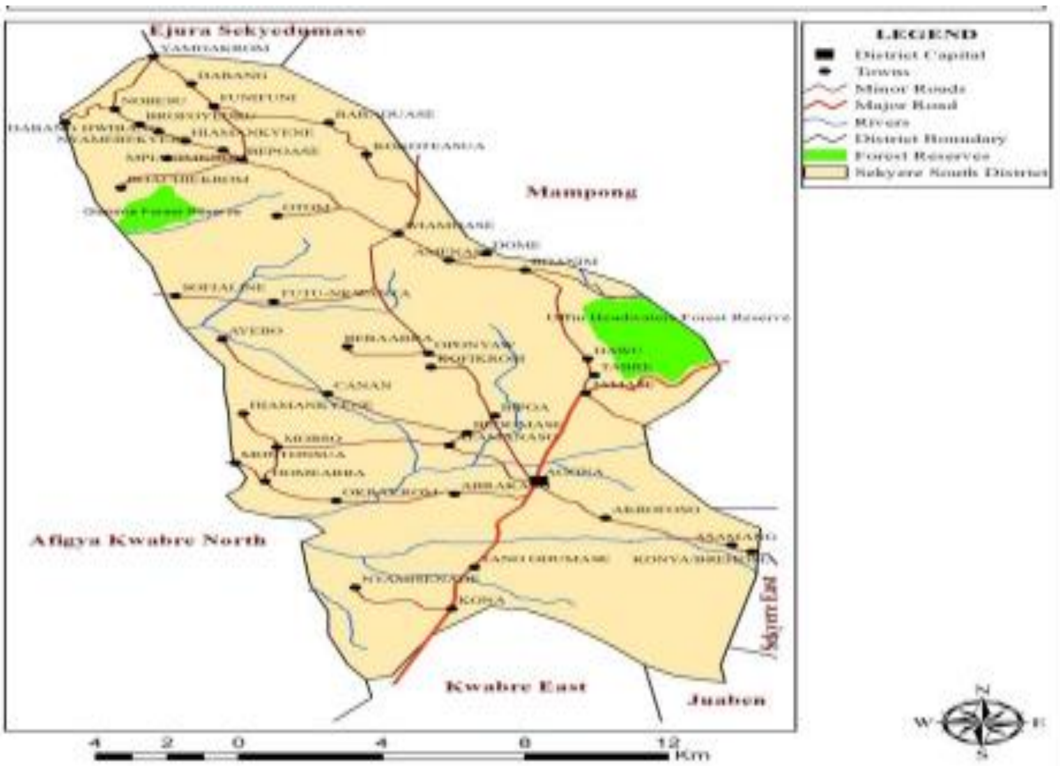

Figure 3.1. Map of Sekyere South District. Source: Sekyere South district assembly, (2020).

Tropical forest covers practically the whole Sekyere South district. There are numerous sorts of lumber wood in the area. There are typically 120 rainy days per year, however, the majority fall between March and July, sometimes known as the "rainy seasons." In addition, Sekyere South undergoes the Harmattan dry season, which lasts from late November to early February and is a significant factor in the drying up of tiny streams. Farmers make up about two-thirds of the district's workforce, with the majority of the remaining workers working in the service industry. The main food crops are maize, cassava, plantains, and yams. Cocoa, citrus fruits, coffee, and palm oil are the main cash crops. Kente weaving and regional types of pottery are widely practiced.

The district is experiencing a surge in several activities on various scales. The Sekyere South district has activities involving automobile traffic, furniture manufacturing, metal fabrication, leather crafts, petrol and gasoline filling, electronic repair shops, auto mechanic work, metal construction work, and welding industries.

3.2 Dust Sampling

In this study, dust from the surfaces of soils, pavements, and tarred roadsides was sampled from the beginning of December 2022 to the end of January 2023, which corresponds to the dry harmattan season, when the dust is more prevalent than usual in the study area. The sampling sites covers Agona and its environs, Akrofonso, Jamasi, and Odumase towns. Seven different land use zones, including residential areas, educational establishment (schools) areas, auto mechanic workshop areas, roadside areas, market areas, playground areas, and lorry park areas provided a total of 107 samples of dust. The samples were gathered using systematic sampling techniques, and samples were taken at least 100 meters apart. From six distinct blocks located at least 20 meters apart, thirty (30) samples were taken from Seventh Day Adventist Senior High School Agona. On consecutive days for five days, five samples from a particular location in each of the blocks were taken. Table 3.1 shows the GPS coordinates of each of the sampling locations that were taken.

Table 3.1 Sampling locations with their GPS coordinates of dust samples

LOCATION	LATITUDE	LONGITUDE	LOCATION	LATITUDE	LONGITUDE
School	N6.927930	W-1.484130	Auto mechanic shop	N6.934435	W-1.488790
	N6.927653	W-1.483650		N6.934523	W-1.489073
	N6.927562	W-1.483143		N6.934371	W-1.489078
	N6.927832	W-1.483143		N6.934593	W-1.489418
	N6.928233	W-1.483215		N6.938183	W-1.503107
	N6.927773	W-1.483542		N6.938482	W-1.503275
Roadside	N6.918480	W-1.466962		N6938392	W-1.503702
	N6.917908	W-1.462708		N6930767	W-1.491788
	N6.918155	W-1.465545	Playground	N6.934440	W-1.489788
	N6.945700	W-1.485515		N6.934453	W-1.490192
	N6.944382	W-1.485967		N6. 934355	W-1.490645
	N6.932522	W-1.487968	Lorry Park	N6.934193	W-1.488495
	N6.943150	W-1.486308		N6.932920	W-1.490695
	N6.934585	W-1.488653		N6.933064	W-1.488957
	N6.937607	W-1.488175		N6.933525	W-1.488547
	N6.935298	W-1.488603		N6.934015	W-1.488733
	N6.931615	W-1.490762	Residential	N6.921195	W-1.467607
	N6.934062	W-1.488335		N6.922093	W-1.468175
	N6.931231	W-1.491255		N6.922397	W-1.469845
	N6.933152	W-1.487088		N6.921498	W-1.469008
	N6.932537	W-1.486607		N6.921447	W-1.469290
	N6.931787	W-1.485582		N6.920520	W-1.468757
Market	N6.934060	W-1.488370		N6.919638	W-1.468187
	N6.933707	W-1.487797		N6.919980	W-1.467350
	N6.933407	W-1.488017		N6.933291	W-1.491085
	N6.933342	W-1.487712			
	N6.932897	W-1. 488302			
	N6.932436	W-1. 488037			
	N6.931865	W-1.488485			
	N6.932202	W-1. 487880			
	N6.932978	W-1.487377			

The dust samples were collected by sweeping the dust into plastic sampling containers using a plastic dustpan and brush. Dust sample were collected from about 1.5m^2 area and weighed between 200 and 400g. To prevent sample contamination, the dustpan and paintbrush were cleaned, dried, or repeatedly wiped with tissue paper after being used to collect samples from each location. All samples were brought to the laboratory of the Department of Chemistry at KNUST in well-labeled polythene zip bags for storage and additional processing before analysis.

3.3 Sample preparation

The dust samples were screened to remove any remaining plant fragments, stones, or other materials using a 2.0 mm nylon mesh sieve. To obtain fine dust particles with the same average particle size, the sample was homogenized by grinding it with a mortar and pestle and then passing it through a screen with a mesh size of 250 µm using USA Standard Testing Sieving ASTM E11. Before further investigation, the samples were placed on plastic sheets, allowed to dry for at least a week in the shade, and then placed in appropriately labeled polythene zip bags. The mortar and pestle, as well as the sieves, were cleaned with fresh tissue paper after each grinding and sieving to prevent cross-contamination.

3.4 Instrumental Analysis

Using a Thermo Scientific Niton XL3 portable X-ray fluorescence (XRF) spectrometer, the quantities of the potentially toxic elements Pb, As, Zn, Cu, Fe, Mn, Cr, V, Ti, Ni, and Cd in the dust samples were determined. Darko et al., (2017), used the XRF analysis approach in prior investigations. The sieved dust sample was placed halfway into the sample holder, which was then wrapped in a Mylar film. To get the desired result, the cupped sample was then put in the XRF shroud and scanned for 180s. The treatment of each sample was the same. The average of the findings was calculated after each XRF sample analysis was completed in triplicate. Before being employed for the analysis of the potentially toxic elements concentration, the XRF instrument was calibrated using certified standard reference material (NIST 2710a).

3.5 Quality Assurance and Quality Control

In this investigation, several quality assurance and control procedures were used to assure the validity, reliability, and accuracy of the data. To prevent contamination, dust samples were handled very carefully both on the job site and in the laboratory. To prevent sample contamination and muddling, the samples were placed in polyethylene zip-lock bags that were securely sealed and marked with permanent ink. To lessen the chance of cross-contamination, all sampling and sieving tools, including the dustpan, brush, test sieve, mortar, and pestle, were thoroughly cleaned. Samples were screened for potentially toxic elements using a Niton XL3 field portable X-ray fluorescence spectrometer following the United States Environmental Protection Agency Method 6200 (Gyamfi et al., 2021) for metal analysis. A system check of the XRF was completed and a NIST 2710a reference material was run before the analysis of the dust each day. This gave a recovery of $\geq 75 \pm 5\%$ always. The reproducibility test conducted generated an acceptable average relative percent difference (21% for As, 11% for Cu, 9.2% for Ni, 13% for Pb, and 7.7% for Zn). Each sample analysis was performed in triplicate and the average of the readings was computed.

3.6 Statistical Analysis

In this investigation, Statistical Package for the Social Sciences (SPSS) version 26 was used to calculate descriptive statistics such as mean, standard deviation, skewness, kurtosis, and minimum and maximum concentrations. Microsoft Excel was used to calculate the pollutant indices, risk assessments, and Pearson's correlation analyses (version 2019) whereas JASP (version 0.17.2.1) was used to determine the principal component analysis. Kurtosis and skewness values were used to examine the results of the normalcy tests. According to Hair et al. (2010) and Bryne (2010), data is regarded as normal if the skewness and kurtosis are within a range of -2 to +2 and -7 to +7, respectively. The data set for statistical analysis were excluded from the results that were reported as being below the technique detection limit.

To assess and identify the potential source of potential toxic elements contamination in the dust samples, principal component analysis (PCA) was applied. Principal component analysis is frequently used to condense data and identify a few key latent factors for examining correlations between the observed variables. Using the covariance or correlation matrix will have a significant impact on the PCA findings if there are significant disparities in the standard deviations of the variables. The PCA with VARIMAX normalized rotation, which can maximize the variances of the factor loadings across variables for each factor, was also done to make the results easier to understand. As recommended by the Kaiser criterion, all primary factors that were retrieved from the variables were preserved with eigenvalues > 1.0 (Braeken & Van Assen, 2017). To ascertain the degree of association between the potentially toxic elements in the dust samples from the various sampling points, an inter-elemental correlation analysis was also carried out.

3.7 Contamination Assessment Methods

By comparing the collected data to background reference data, using pollution indices, and the potential ecological risk index (PERI), one can determine the degree of potentially harmful element contamination. In this study, contamination was assessed through the use of pollution indices and the comparison of site-specific data to background reference data. To make an educated judgment regarding the site's quality, the potential toxic elements concentrations found in the dust samples were compared to their corresponding WHO maximum permissible concentrations, which are frequently utilized as regulatory guideline limits, the Dutch guidelines (VROM, 2000) and the Canadian soil quality guidelines, (CCME, 2007). The maximum permissible concentration is the level of a contaminant in the atmosphere, water, soil, or sediment that should shield all species within an ecosystem from the substance's harmful effects (James et al., 2020).

3.8 Pollution Indices

For the assessment of the level of contamination in the environment caused by the accumulation of potentially toxic elements, five pollution index factors were utilized. They are the enrichment factor (EF), contamination factor (CF), geo-accumulation index (Igeo), pollution load index (PLI), and modified degree of contamination (mCd). These variables serve as environmental contamination level indicators. The following equations taken from (Darko, et al., 2017; Fosu-Mensah et al., 2018; Kadhum, 2020; Liu et al., 2021) are used to calculate the geo-accumulation index, enrichment factor, contamination factor, pollution load index, and modified degree of contamination indices, respectively:

$$\text{Geo-accumulation index (Igeo)} = \log_2 \left[\frac{Cn}{1.5Cr}\right] \qquad \text{Eqn. 1}$$

$$\text{Enrichment factor (EF)} = \frac{Cn \times Fer}{Cr \times Fes} \qquad \text{Eqn.2}$$

$$\text{Contamination factor (CF)} = \frac{Cn}{Cr} \qquad \text{Eqn. 3}$$

$$\text{Pollution load index (PLI)} = [CF_1 \times CF_2 \times CF_3 \times \cdots \times CF_n]^{1/n} \qquad \text{Eqn. 4}$$

$$\text{Modified degree of contamination} = \quad mC_d = \frac{\sum_{i=1}^{n} C_f}{n} \qquad \text{Eqn. 5}$$

Where 1.5 is used to adjust the background matrix for any variances brought on by lithospheric effect (Tawabini et al., 2023), Cn is the observed element concentration in the dust sample, Cr is the background reference value for one potentially harmful element in the dust samples, Fer is the background reference value for the element Fes. CFn is the contamination factor of the nth element. n is the number of potentially toxic elements assessed.

The different classes of potentially toxic elements contamination taken from (Kadhum, 2020; Rabin et al., 2023; Rahimi, 2020; Trujillo-González et al., 2016) in dust based on the Geo-accumulation index, Enrichment factor, Contamination factor, Pollution load index, and Modified degree of contamination, values are shown in Table 3.1 and 3.2.

Table 3.2. Classes of geo-accumulation index

Geo-accumulation index	Igeo class	Pollution intensity
Igeo ≥ 5	6	Very strongly polluted
4 ≤ Igeo< 5	5	Strong to very strongly polluted
3 ≤ Igeo< 4	4	Strongly polluted
2 ≤ Igeo< 3	3	Moderately to strongly polluted
1 ≤ Igeo< 2	2	Moderately polluted
0 ≤ Igeo< 1	1	Unpolluted to moderately polluted
Igeo< 0	0	Practically unpolluted

Table 3.3. Classes of enrichment factor, contamination factor, pollution load index, and modified degree of contamination.

Enrichment factor	**Risk category**
EF<2	Deficiency to minimal enrichment
2<EF<5	Moderate enrichment
5<EF<20	Significant enrichment
20<EF<40	Very high enrichment
EF>40	Extremely high enrichment
Contamination factor	**Contamination level**
CF<1	Low contamination
1 ≤ Cf< 2	Low to moderate contamination
2≤CF<3	Moderate contamination
3≤ Cf< 4	Moderate to high contamination
4 ≤ Cf< 5	High contamination
5≤CF<6	High to very high contamination
CF>6	Extreme contamination
Pollution load index	**Pollution level**
≤1	No metal pollution
>1	Metal pollution exists
Modified degree of contamination	**Contamination status**
mCd<1.5	Nil to a very low degree of contamination
1.5≤mCd<2	Low degree of contamination
2≤mCd<4	A moderate degree of contamination
4≤mCd<8	A high degree of contamination
8≤mCd<16	A very high degree of contamination
16≤mmCd≤32	An extremely high degree of contamination
mCd≤32	Ultrahigh degree of contamination

3.8.1 Geo-accumulation Index (Igeo)

Muller (1969) proposed the geo-accumulation index to evaluate the concentration of possibly harmful elements accumulated in dust over the baseline concentration (Kabir & Rashid, 2022). It is divided into seven classes and is used to estimate the contamination level of potentially toxic elements concentrations in the dust by comparing total element component concentrations measured to their reference level or background value of concentrations (Tawabini et al., 2023). The geo-accumulation index can be determined using Equation 1. Table 3.2 categorizes the seven geo-accumulation index classes from essentially unpolluted to extremely polluted (Chonokhuu et al., 2019).

3.8.2 Enrichment Factor (EF)

The effect of anthropogenic activities on the concentration of potentially toxic elements in dust is measured by the enrichment factor (Kadhum, 2020). The content of potentially harmful elements defined by low variability of occurrence, Fes, is utilized as a reference, both in the examined samples and in the background reference, to identify the expected impact of anthropogenesis on the concentrations of the potentially toxic elements in the dust (Hemati & Rahimi, 2020). Fe, Al, Ca, Ti, Sc, or Mn are common reference elements (Hemati & Rahimi, 2020). EF is determined using the formula in Equation 2, and the classification of the enrichment factor is shown in Table 3.3. If the enrichment factor is between 0.5 and 1.5, it can be concluded that natural processes are to blame for the presence of that specific potentially harmful element in the dust. However, if the value of EF is greater than 1.5, there may have been anthropogenic contamination of potentially toxic elements (Kadhum, 2020; Rabin et al., 2023).

3.8.3 Contamination Factor (CF)

The contamination factor is the ratio of the concentration of potentially toxic elements in the dust samples to the element's reference value (Rabin et al., 2023; Barbieri, 2016). The contamination factor, which can be computed using equation three (3), can be used to assess the contamination of dust samples. The contamination factor is classified into seven classes, as shown in Table 3.3.

3.8.4 Pollution Load Index (PLI)

The total pollution level of a given area is calculated using the pollution load index. It can also be defined as the evaluation of the overall toxicity of dust samples (Aguilera et al., 2021; Kadhum, 2020). The equation four (4) can be used to compute the pollutant load index: In Table 3.3 gives the classification of the pollution load index.

3.8.5 Modified Degree of Contamination (mC_d)

The modified degree of contamination aids in determining how many potentially toxic elements are present overall in the samples of dust (Vineethkumar et al., 2020). The cumulative index used to determine the degree of contamination is created by adding together the various contamination components (Cd) (Suryawanshi et al., 2016). For improved assessment value, the modified degree of contamination might be applied. The following relation in equation five (5) can be used to compute the modified degree of contamination. In Table 3.3, the authors (Vineethkumar et al., 2020) categorize the modified degree of contamination (mCd) into seven distinct groups.

3.9 Potential Ecological Risk Assessment Index (PERI)

Based on the contamination factor of potentially toxic elements (CF) and the environment's reaction to the contamination (Trf), the potential ecological risk index (PERI) was utilized to gauge the level of potentially toxic elements pollution in the dust (Tawabini et al., 2023). According to Darko et al. (2017), the PERI was calculated as the total of individual potential ecological risk factors (PER) as follows:

$$PER = CF \times Trf \qquad \text{Eqn. 6}$$

$$PERI = \sum_{i}^{n} (Trf \times CF) \qquad \text{Eqn. 7}$$

Potentially harmful elements have toxic response factors (Trf) of Zn = 1, Cr = 2, Pb = 5, Ni = 6, As = 10, Cd = 30, Mn = 1, V = 2, Cu = 5, and Hg = 40 taking from (Kabir &

Rashid, 2022; Nkansah et al., 2017; Tawabini et al., 2023). Table 3.4 classifies ecological danger according to its level.

Table 3.4. The different classes of potential ecological risk taken from (Darko, Dodd, Nkansah, Aduse-Poku, et al., 2017; Kabir & Rashid, 2022; Trujillo-González et al., 2016).

Degree of ecological risk	Classified
PER< 40	low risk
40 ≤ PER < 80	moderate risk
80 ≤ PER < 160	considerable risk
160 ≤ PER < 320	high risk
PER ≥ 320	very high risk
PERI ≤ 150	Low
150 ≤ PERI < 300	Moderate
300 ≤ PERI < 600	Considerable
600 ≤ PERI	Very high

3.10 Health Risk Assessment Methods

Evaluation of the degree of exposure, expressed as an expected daily intake, is implied by risk assessment (Nkansah et al., 2017). The intake of potentially toxic elements from dust samples through ingesting, inhalation, and skin absorption depends on four different types of factors: contact rate, exposure frequency, exposure duration, and body weight of the population that may be exposed (Aguilera et al., 2021).

To evaluate the risk of potentially toxic elements found in soil to human health, both cancer-causing and non-cancerous, the United States Environmental Protection Agency has developed a model (Aguilera et al., 2021; Mmaduakor et al., 2022). Using the following hypotheses, this model can be used to describe dust samples: Humans are exposed to dust via three main pathways: ingestion, inhalation, and dermal contact.

Relevant exposure parameters of children and adults in the study areas are similar to those of reference populations. The overall non-carcinogenic and carcinogenic risk for each potentially toxic element can be calculated by adding the individual risks from the study areas (Aguilera et al., 2021).

3.10.1 Exposure Assessment

To determine the estimated daily intake (EDI) in mg/kg per day via ingestion (EDI_{ing}), inhalation (EDI_{inh}), and dermal contact (EDI_{dermal}), as well as the lifetime average daily dose (LADD), the following formulae are widely used (Huang et al., 2022; Liu et al., 2021; Mihankhah et al., 2020):

$$EDI_{ing} = \frac{C\ x\ IngR\ x\ EF\ x\ ED\ x\ CF}{BW\ x\ AT} \quad \text{Eqn. 8}$$

$$EDI_{inh} = \frac{C\ x\ InhR\ x\ EF\ x\ ED}{PEF\ x\ BW\ x\ AT} \quad \text{Eqn. 9}$$

$$EDI_{derma}l = \frac{C\ x\ SA\ x\ AF\ x\ ABS\ x\ EF\ x\ ED\ x\ CF}{BW\ x\ AT} \quad \text{Eqn. 10}$$

$$EDI_{LADD} = \frac{C}{PEF\ x\ ATcan}\ x\ \left(\frac{CRchld\ x\ EFchild\ x\ EDchild}{BWchild} + \frac{CRadult\ x\ EFadult\ x\ EDadult}{BWadult}\right) \quad \text{Eqn 11}$$

C represents the concentration of potentially toxic elements in urban dust; IngR and InhR represent the rates of ingestion and inhalation, respectively; The exposure frequency is EF, the exposure duration is ED, the body weight is BW, and the average time for non-carcinogens is AT_{noncan}. PEF is for particle emission factor; SA stands for exposed skin area; SF stands for skin adherence factor; and ABS stands for dermal absorption factor taking from (Aguilera et al., 2021).

The contact (or absorption) rate is denoted by CR. For ingesting, CR = IngR, for inhalation CR = InhR, and for cutaneous contact, CR = SA x AF x ABS.

Table 3.5. Most commonly reported exposure factors for human health risk assessment provided by (Aguilera et al., 2021; Fabiana Meijon Fadul, 2019).

Factor [units]	Value Child	Adult
Ingestion rate (IngR) [mg/day]	200	100
Inhalation rate (InhR) [m^3 /day]	7.6	20
Particle emission factor (PEF)	1.36E+09	1.36E+09
Surface of exposed skin area (SA) [cm^2]	2800	5700
Dermal absorption factor (ABS)	0.001	0.001
Skin adherence factor (AF) [mg/cm^2]	0.2	0.07
Duration of exposure (ED) [years]	6	24
Frequency of exposure (EF) [days/year]	350(180)	350(180)
Average time non-carcinogens (AT) [days]	ED*365	ED*365
Average time for carcinogens (At_{can}) [days]	70*365	70*365
Body weight (BW) [kg]	15	70
Heavy metal concentration (C) [mg/kg]	95 percent UCL	
Conversion factor (CF)	1×10^{-6}	

UCL: upper confidence limit, mg: milligrams, m^3: cubic metres, cm^2: square centimetres, kg: kilograms.

3.10.2 Non-Carcinogenic Risk Assessment

Hazard Quotient (HQ)

Ingestion, inhalation, and dermal contact hazard quotients ($HQ_{ing/inh/derm}$) are calculated by dividing the EDI by the reference dose (RfD) (Nkansah et al., 2017; Tawabini et al., 2023), as shown in Equation 12:

$$HQ_{ing/inh/derm} = \frac{EDI\ ing\ /\ inh\ /\ derm}{RfD} \qquad \text{Eqn. 12}$$

The most popular RfD is shown in Table 5. when HQ ≤ 1 denotes the absence of any negative health impacts and HQ > 1 denotes the likelihood of negative health consequences. Because it is believed that, after inhalation, the absorption of the particle-bound toxicants will cause similar health consequences to when the particles had been consumed, the inhalation reference dose values are occasionally replaced by oral reference doses (Aguilera et al., 2021).

Table 3.6. Reference doses (RfD) taken from (Aguilera et al., 2021; Fabiana Meijon Fadul, 2019; Nkansah et al., 2017)

Potentially Toxic Element	Oral RfD	Dermal RfD	Inhalation RfD	SF
As	3.00E-04	1.23E-04	3.01E-04	1.51E+00
Cd	1.00E-03	1.00E-05	1.00E-03	6.30E+00
Co	2.00E-02	1.60E-02	5.71E-06	
Cr	3.00E-03	6.00E-05	2.86E-05	4.20E+01
Cu	4.00E-02	1.20E-02	4.02E-02	
Fe	8.40E+00	7.00E-02	2.20E-04	
Hg	3.00E-04	2.10E-05	8.57E-05	
Mn	4.60E-02	1.85E-03	1.43E-05	
Ni	2.00E-02	5.40E-03	2.06E-02	8.40E-01
Pb	3.50E-03	5.25E-04	3.52E-03	
V	7.00E-03	7.00E-05	7.00E-03	
Zn	3.00E-01	6.00E-02	3.00E-01	

RfD: reference doses, E: exponential, SF: slope factor

Hazard Index (HI)

The sum of the HQ for each of the three exposure pathways (ingestion, inhalation, and skin contact) is given as the hazard index (HI). The HI can be used to assess the danger to human health: if the value is larger than 1, non-carcinogenic consequences may occur;

if it is less than 1, the opposite may be anticipated (Aguilera et al., 2021; Rabin et al., 2023).

$$HI = \sum HQ \quad \text{Eqn. 13}$$

3.10.3 Carcinogenic Risk Assessment

The following equation is frequently used to determine the incremental lifetime cancer risk (ILCR) for the carcinogens As, Cr, Ni, and Cd:

$$ILCR = LADD \times CSF \quad \text{Eqn. 14}$$

The acceptable or manageable risk is between 1×10^{-6} and 1×10^{-4}. A risk number of 1×10^{-6} indicates that there is no carcinogenic risk to health from the dust, whereas a risk value of $>1 \times 10^{-4}$ indicates a high chance of acquiring cancer (Kabir & Rashid, 2022; Rabin et al., 2023). These figures show that one more case in a population of 1,000,000 to 10,000 is tolerable (Aguilera et al., 2021). The CSF refers to the cancer slope factor.

CHAPTER FOUR

4.0 RESULTS AND DISCUSSION

4.1 Concentration of Potentially Toxic Elements from Different Land Use Areas

In this study, eleven potentially toxic elements were found, including Pb, As, Zn, Cu, Fe, Mn, Cr, V, Ti, Ni, and Cd in the 107 dust samples that were collected from seven different land use areas. These include residential areas, educational establishment areas (schools), auto mechanic shops, roadsides, playground areas, lorry stations (lorry parks), and market areas in the Sekyere South district in the Ashanti region of Ghana. In appendix 1, descriptive statistics for the concentrations of potentially harmful elements in dust from seven distinct land uses are shown along with background values based on the global average shale value.

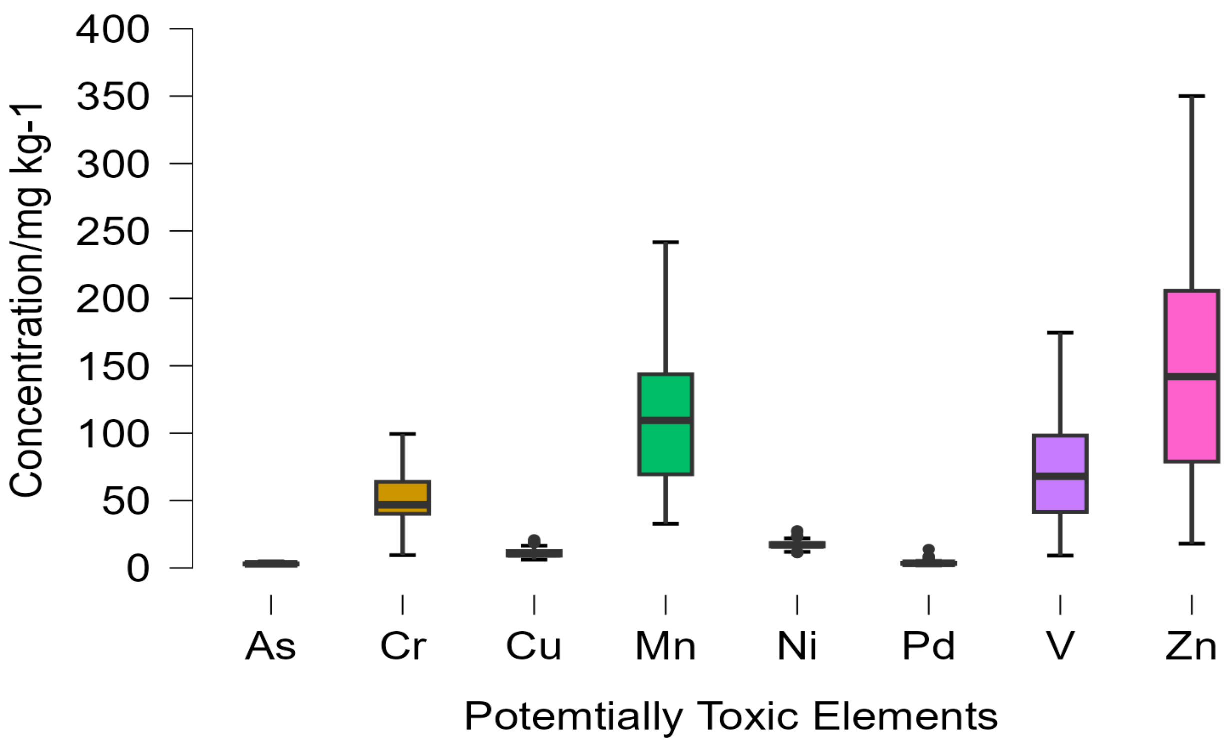

Figure 4.1. The concentration (mg kg^{-1}) of potentially toxic elements from different land use areas

The average concentrations of potentially toxic elements in dust samples from different land use areas of Sekyere South district, the WHO recommended maximum permissible concentrations (MPC) in soil, the Dutch guidelines (VROM, 2000), and the Canadian soil quality guidelines, (CCME, 2007), (mg kg^{-1}) taken from James et al., (2020), R. Ogunlana, A.L. Korode, (2020), Shi-bao et al., (2018) are shown in Table 4.1.

Table 4.1. The mean concentration (mg kg^{-1}) of toxic elements, CCME, 2007, VROM, 2000, and MPC values

Land Use Areas	School	Roadside	Market	Auto mechanic shop	Playground	Lorry Park	Residential Area	Soil MPC	Canada-CCME	Dutch Target
Pb	5.1	10.7	4.1	42.1	3.6	3.5	4.5	100.0	140.0	85
As	3.6	3.1	3.0	4.6	2.9	3.1	4.0	10.0	12.0	29
Zn	216.9	90.9	151.5	272.9	43.2	181.9	250.0	200.0	200.0	140
Cu	19.5	17.6	12.1	54.6	15.4	12.9	20.3	100.0	63.0	36
Fe	12792.1	18906.2	16573.8	26491.2	14179.0	16040.7	28202.3	50000.0	N.A	N.A
Mn	149.7	113.2	101.9	321.4	127.9	181.7	148.5	1500.0	N.A	NA
Cr	44.4	62.7	54.7	127.4	64.5	52.3	68.5	100.0	64.0	100
V	53.8	64.0	78.6	123.7	75.6	77.2	105.8	N.A	130.0	NA
Ti	2051.9	1947.6	2918.8	3746.9	2651.5	2542.9	3436.4	N.A	N.A	NA
Ni	18.9	16.6	16.0	16.1	17.2	16.0	17.4	50.0	50.0	35
Cd	5.9	5.4	5.2	5.8	5.3	5.3	5.8	3.0	10.0	0.8

N.A means not available

4.1.1 Arsenic

Except for the data from the auto mechanic shop, where the maximum concentration (13.07 mg kg^{-1}) was slightly higher than the background value, the arsenic concentrations obtained from the other land use zones were below the background values (13 mg kg^{-1}). With values ranging from 2.10 to 3.54 mg kg^{-1}, the market had the lowest mean of 3.01 mg kg^{-1}. The concentration of arsenic in the seven different land-use zones of the Sekyere South district is depicted in Figure 4.2. The auto mechanic shop had the highest mean concentration, 4.58 mg kg^{-1}, with a range of values from 2.25 to 13.07 mg kg^{-1}. Arsenic concentrations from the roadside, playground, lorry park, residential, and school varied between 1.72 -7.32, 2.32 – 3.42, 1.96 – 4.28, 1.65 – 10.24, and 1.90 – 8.18 mg kg^{-1} with the mean values 3.12, 2.67, 3.12, 4.04, and 3.57 mg kg^{-1} respectively. The mean concentrations had no significant variations ($p > 0.05$).

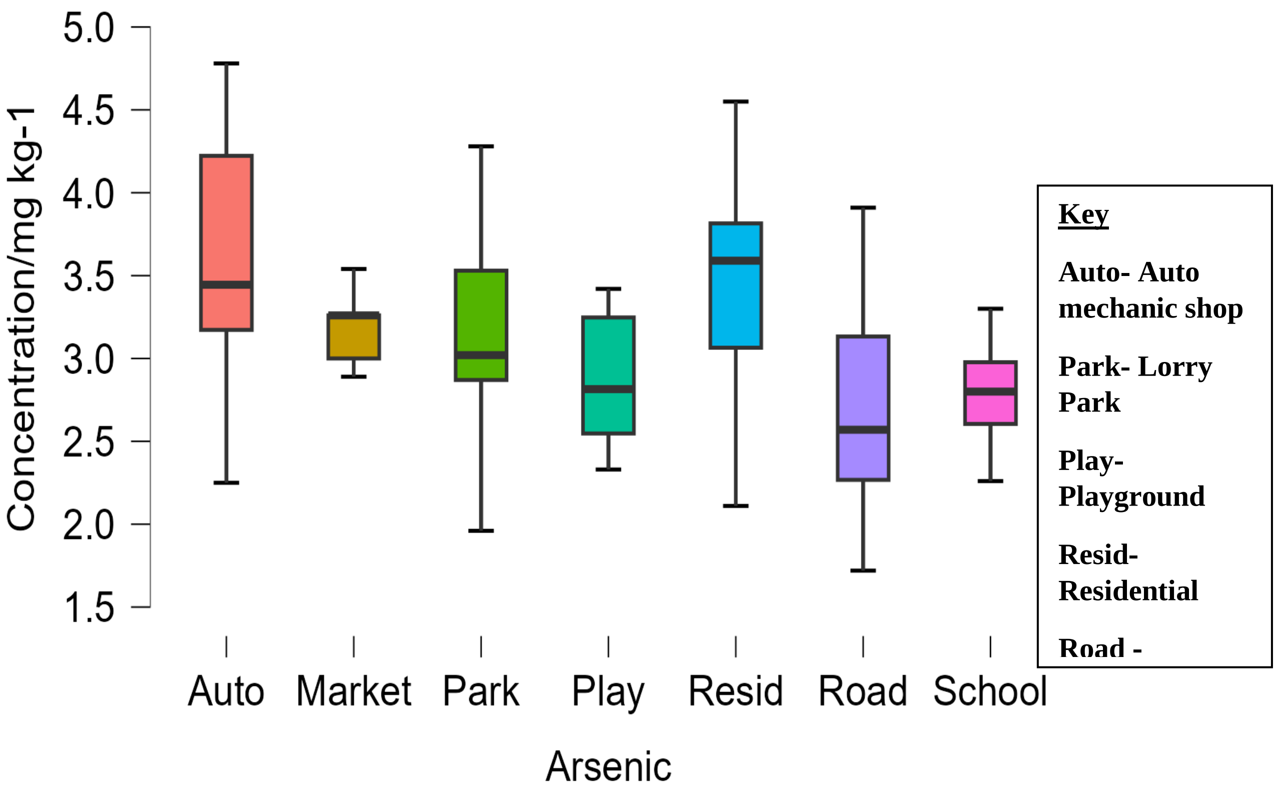

Figure 4.2. The concentration of arsenic in dust samples from different land use areas of Sekyere South

Comparing the amounts of all the potentially toxic elements examined in the various land use zones, arsenic concentrations were found to be the lowest at all sampling locations. This is consistent with the findings of earlier research by Nkansah et al., (2017). With an average mean of 3.5 mg kg^{-1}, the observed concentration of arsenic from the study locations ranged from 1.7 to 13.1. This median result (3.5 mg kg^{-1}) is lower than the median value (6.2 mg kg^{-1}) reported in a prior study that was conducted using fuel station dust in the Kumasi metropolis (Nkansah et al., 2017). The auto mechanic shop dust samples had the highest concentration of arsenic, whereas the residential areas samples had the lowest concentration. When the WHO, Canadian, and Dutch maximum permitted levels for arsenic were compared to the average values of arsenic from the various land use areas, all of the mean samples were below the limits. The burning of fossil fuels in motor vehicles, industrial sources like the smelting and microelectronic industries, and the use of wood preservatives, herbicides, pesticides, fungicides, and paints are some anthropogenic activities that could raise the level of arsenic in the affected areas (Engwa et al., 2019). Since arsenic is a non-essential element, excessive exposure to it can cause cardiovascular illness, diabetes mellitus, hypertension, lung disease, neurological issues, peripheral vascular disease, and skin lesions (Balali-Mood et al., 2021).

4.1.2 Cadmium

Figure 4.3. shows the mean distribution of cadmium in the study sites. The amount of cadmium measured from the study sites was very high compared to the corresponding background value (0.3 mg kg^{-1}). The market recorded the lowest mean concentration of 5.25 mg kg^{-1} with values ranging from 4.00 – 6.68 mg kg^{-1} whiles the school recorded the highest mean concentration of 5.94 mg kg^{-1}. The second highest mean concentration was obtained from residential, 5.84 mg kg^{-1}, with varied values from 4.59 – 9.57 mg kg^{-1}. Concentrations of cadmium measured from the roadsides, auto mechanic shop, playgrounds, and lorry parks varied between 4.03 – 7.09 mg kg^{-1}, 3.84 – 6.95 mg kg^{-1}, 4.35 – 6.74 mg kg^{-1}, and 3.73 – 6.61 mg kg^{-1} respectively with the mean concentrations 5.35, 5.81, 5.27 and 5.29. The average mean concentration of cadmium from the different land use areas was 18.4 times higher than the world average shale value (0.3 mg kg^{-1}). The mean concentrations had no significant variations ($p > 0.05$).

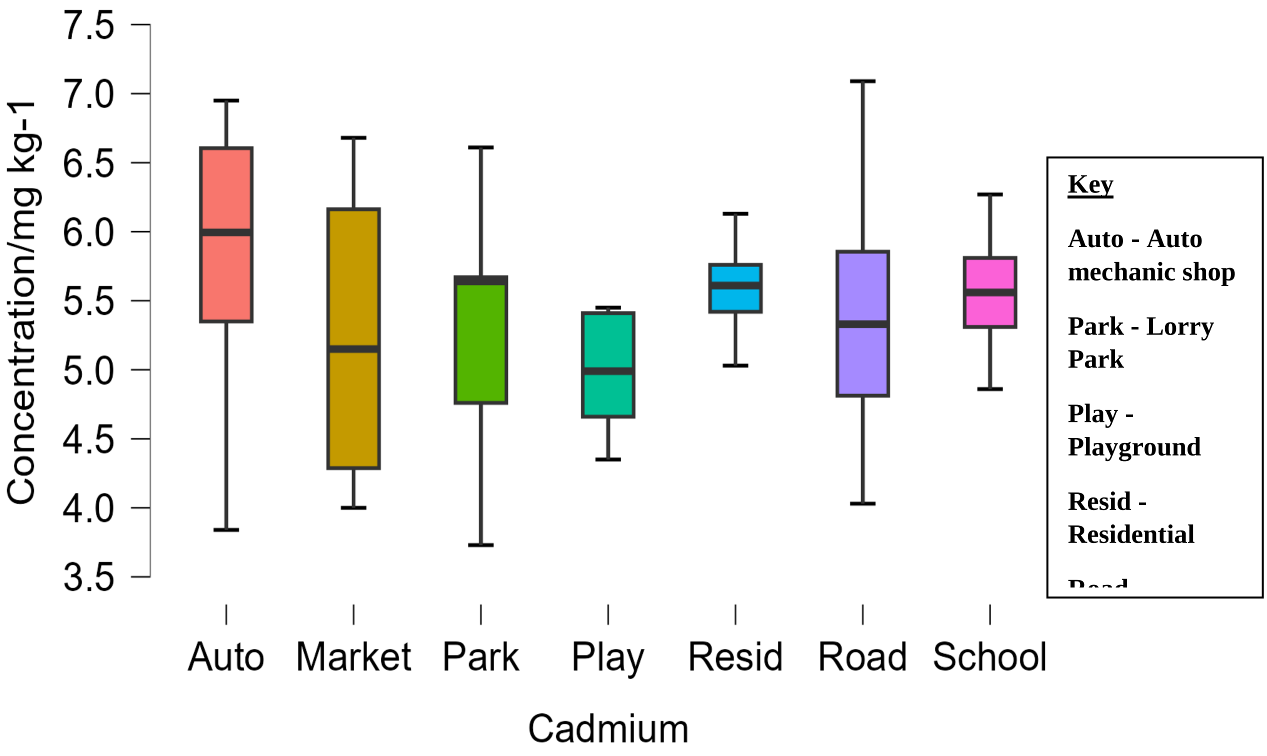

Figure 4.3. The concentration of Cadmium in Dust samples from different land use areas of Sekyere South

Human health is impacted in several ways by cadmium and its compounds. The inability of the human body to remove cadmium makes the health impacts of cadmium exposure worse (Engwa et al., 2019). All of the sample sites had similar levels of cadmium exposure, with mean values between 5.2 and 5.9 mg kg^{-1}. The average mean concentration of cadmium (5.5 mg kg^{-1}) exceeded the WHO and VROM, (2000) maximum allowed limits by more than 1.8 times and 6.9 times, respectively, as well as the background value (0.3 mg kg^{-1}) by 18.3 times. In comparison to similar research, this study's average mean cadmium content was higher than the 1.33 mg kg^{-1} reported by Kadhum, (2020), 2.65 mg kg^{-1} reported by Kabir & Rashid, (2022), and 0.46 mg kg^{-1} reported by Darko, Dodd, Nkansah, Aduse-Poku, et al., (2017). Because cadmium is used as an additive in lubricating oils for automobiles and the vulcanization of tires, it is possible that the high levels of cadmium found in auto mechanic shops, along roadsides, and in lorry parks were caused by the release of lubricating oil, car parts, brake lining wear, tire wear, and engine exhausts from moving vehicles (Darko, Dodd, Nkansah, Aduse-Poku, et al., 2017). The burning of municipal garbage containing used Ni-Cd batteries and plastics containing Cd pigments, as well as cigarette smoking, are other potential sources of cadmium in the research region (Engwa et al., 2019). Due to cadmium's protracted bodily retention, even modest doses of Cd can cause kidney damage by causing cadmium to accumulate in the kidneys. Possible long-term consequences include stomach pain, brittle bones, and lung damage (Balali-Mood et al., 2021; Engwa et al., 2019).

4.1.3 Chromium

Compared to other land-use regions, the results of the chromium concentration in dust from different land-use areas (Figure 4.4) consistently showed greater concentrations in auto mechanic shops, ranging from 62.06 to 327.71 mg kg^{-1} with a mean value of 127.4 mg kg^{-1}. This suggests that the high amount of chromium in the auto business results from anthropogenic activity. The highest and mean values at the auto mechanic shop were respectively 3.64 and 1.42 times greater than the background value. The mean values of chromium concentrations at the roadsides and the markets were 62.72 mg kg^{-1} and 54.74 mg kg^{-1} respectively. The values at the playground varied between 28.81 – 102.68 mg kg^{-1} and lorry park ranged from 19.09 – 75.55 mg kg^{-1}. The average chromium level of residential and school was 68.54 mg kg^{-1} and 44.42 mg kg^{-1} with concentrations varying from 9.55 – 211.56 mg kg^{-1} and 24.28 – 72.92 mg kg^{-1} respectively. Mean concentrations of chromium in the different land use areas are ranked in the following order: auto mechanic shop > residential > playground > roadside > market > lorry Park > school. There were however no significant variations ($p > 0.05$) in their mean concentrations.

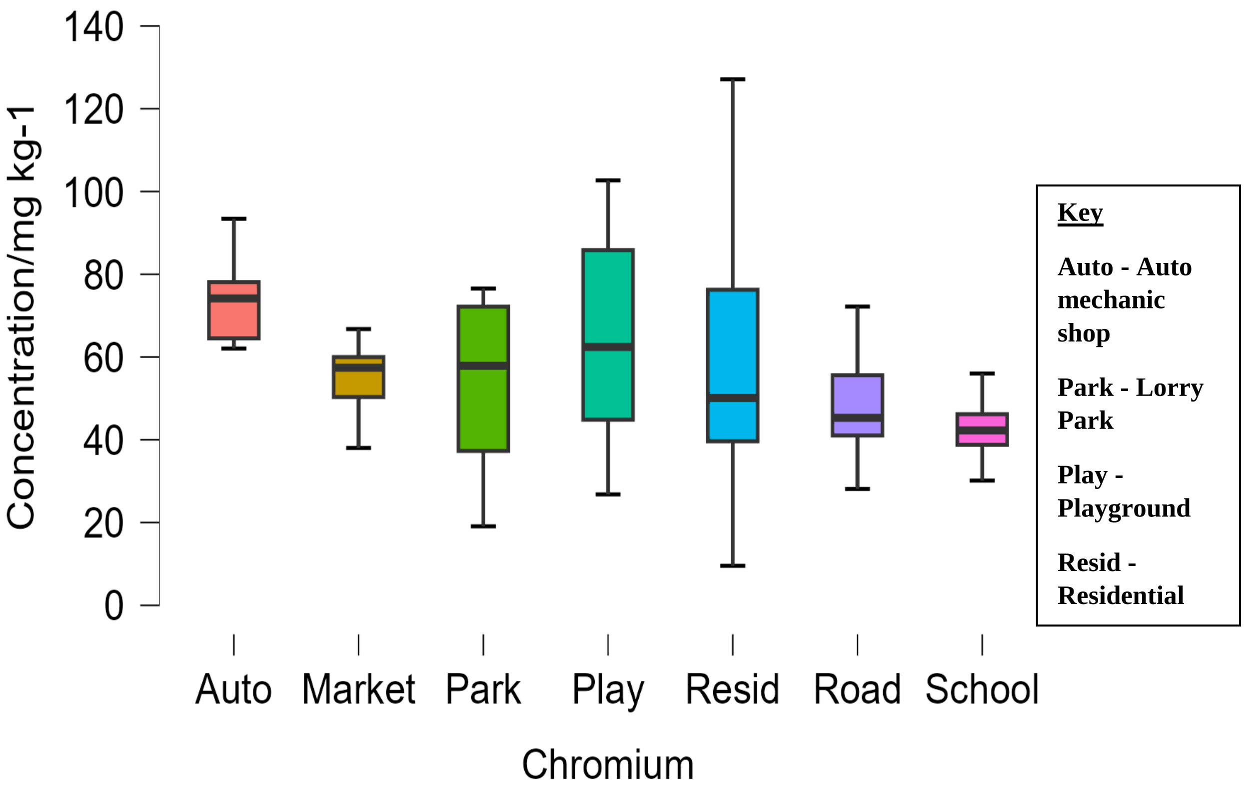

Figure 4.4. The concentration of chromium in dust samples from different land use areas of Sekyere South

In the human body, the insulin molecule needs chromium to transport glucose to the cells for glycolysis (Mafuyai et al., 2014). Hexavalent chromium is poisonous and harmful to human health (Balali-mood et al., 2021; Engwa et al., 2019). In all land use zones, a range of 9.6 to 327.7 mg kg^{-1} of Chromium is found in the dust samples. The mean average concentration of Chromium (67.8 mg kg^{-1}) found in this study is lower than the mean concentration of 148.8 mg kg^{-1} reported by Suryawanshi et al., (2016) from road dust in Delhi, India, and 2.5 times higher than the mean concentration of 26.7 mg kg^{-1} found in a related study carried out in the commercial and residential areas of Zhengzhou, China (Faisal et al., 2022). Except for the mean value obtained from the auto mechanic shop (127.4 mg kg^{-1}), which was above the recommended limit of 100 mg kg-1, the mean concentrations of chromium in all of the sampling areas were below the WHO guidelines values. Additionally, the mean concentration of chromium in s, playgrounds, and residential areas exceeded 64 mg kg^{-1}, which is the limit permitted in residential soils in Canada. Chromium is a metal found in coal and oil well drilling, chromium steel, pigment oxidants, fertilizers, catalysts, and tanneries used for metal plating. Chromium is widely utilized in a variety of industries, including pulp and paper production, electroplating, metallurgy, the manufacture of paints and pigments, tanning, and wood preservation (Mafuyai et al., 2014). These businesses contribute significantly to chromium contamination that negatively impacts biological and ecological species (Engwa et al., 2019). The release of chromium into the environment may be caused by human-caused anthropogenic activities, sewage disposal, and fertilizer use (Balali-Mood et al., 2021). The vehicle mechanic and nearby businesses that deal with steel and metal plating may be potential sources of the metal The lining of the nose can get irritated and develop ulcers when exposed to high concentrations of chromium (VI) in the air (Eneji et al., 2015). Additionally, it can harm sperm and the male reproductive system and cause anemia, small intestine, and stomach ulcers, and other health issues (Engwa et al., 2019; Masindi & Muedi, 2018).

4.1.4 Copper

The values of copper measured from different land use areas were between 6.33 and 164.03 mg kg^{-1}. It was observed that the auto mechanic shop recorded the highest mean of 54.56 mg kg^{-1} with values ranging from 10.14 – 164.03 mg kg^{-1}. Roadside values averaged 17.60 mg kg^{-1} with values ranging from 6.24 to 63.27 mg kg^{-1}, playground recorded a mean of 15.36 mg kg^{-1} with values between 8.65 – 33.27 mg kg^{-1}, lorry park values averaged 12.86 mg kg^{-1} with values ranging between 6.33 to 21.48 mg kg^{-1}, residential values averaged 20.27 mg kg^{-1} with values ranging from 6.24 to 65.35 mg kg^{-1}, the school recorded mean value of 19.49 mg kg^{-1} with the values ranging from 6.24 –

106.01 mg kg^{-1} and market recorded the lowest mean value of 12.09 mg kg^{-1} with values between 8.95 – 22.27 mg kg^{-1} of copper. Figure 4.5 illustrates the level of copper in the different land-use areas of Sekyere South. The mean copper concentrations did not differ significantly from one another ($p > 0.05$). Even while the maximum and mean copper concentrations from the auto mechanic shop were higher than the corresponding background value (45 mg kg^{-1}), the mean copper concentrations from the other various land use regions were lower than the corresponding reference values.

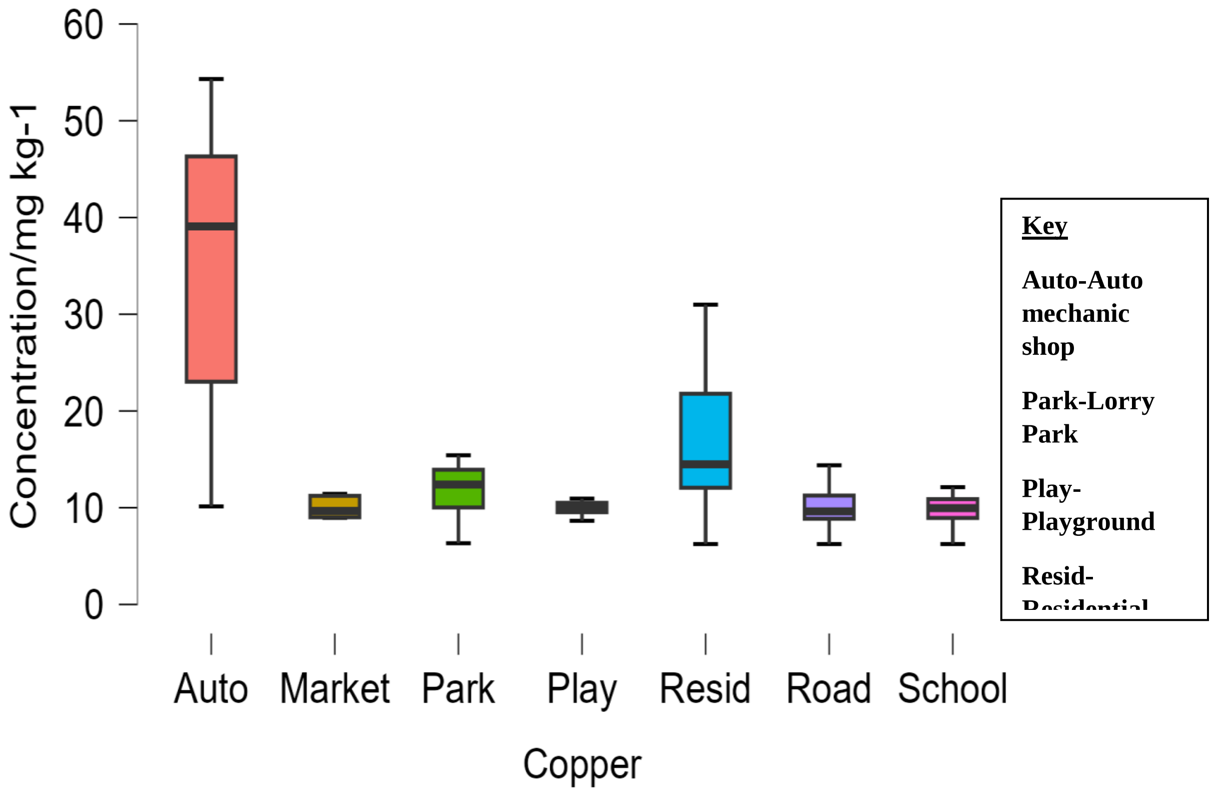

Figure 4.5 Concentration of copper in dust samples from different land use areas of Sekyere South

In this investigation, copper concentrations measured ranged from 6.2 to 164 mg kg^{-1} (Figure 4.5). The residential area had the lowest copper concentration, whereas the auto mechanic shop had the highest. Except for the mean value obtained from the auto mechanic shop (54.6 mg kg^{-1}), which was higher than the Dutch Target (VROM, 2000) of 36 mg kg^{-1}. The mean copper values obtained from the other land use sectors were within the suggested permissible limits (Table 4.1). According to Kabir & Rashid, (2022), copper levels in Mymensingh City, Bangladesh, ranged from 29.5 to 72.2 mg kg^{-1}, which is similar to the current study's trend. Additionally, the mean value (191 mg kg^{-1}) published in a study of a similar kind by Suryawanshi et al., (2016) was 8.8 times higher than the mean concentration of copper (21.7 mg kg^{-1}) obtained in this investigation. Kabir & Rashid, (2022) observed that the deposition of particles from automobiles, such as exhaust particles, brake lining, and lubricating oil residue, is primarily responsible for the elevated levels of Cu, Zn, Cr, and Pb in urban road dust. As a result, the high levels of Cu found in auto mechanic shops may have been caused by the distribution of engine exhausts, wear and tear on brake linings and tires, and corrosion of vehicle components. Although copper is necessary for human survival, excessive amounts can harm the stomach, liver, and kidneys (Mafuyai et al., 2014).

4.1.5 Iron

In comparison to other potentially harmful elements investigated, iron concentrations in dust samples from the study area were very high, with residential areas recording the highest mean value of 28202.34 mg kg^{-1} and maximum and minimum values ranging from 7027.65 to 80170.68 mg kg^{-1}. The lowest value was found in the school area, where mean concentrations ranged from 8229.97 to 20271.29 mg kg^{-1}. Roadside and market measurements ranged from 6365.21 - 78245.44 mg kg^{-1} and 8886.16-24192.97 mg kg^{-1}, respectively, with averages of 18906.25 mg kg^{-1} and 16573.81 mg kg^{-1}. The concentrations of auto repair shop ranged from 13115.65 mg kg^{-1} to 70774.88 mg kg^{-1}, with a mean value of 26491.16 mg kg^{-1}; that of playgrounds were 5559.98 mg kg^{-1} to 26606.25 mg kg^{-1}, with a mean value of 14179.0 mg kg^{-1}; and those of Lory Park had a mean value of 16040.65 mg kg^{-1} ranging from 7210.42 to 22671.34 mg kg^{-1}. At a 95%

confidence level, statistical analysis revealed no appreciable variation in the mean concentration between the various land use areas. The distribution of iron in the sampling area is depicted in Figure 4.6 for the various land use zones. Maximum concentration from residential areas, auto mechanic shops, and roadside areas were 1.7, 1.5, and 1.7 times higher than comparable reference values, respectively. However, the mean values across all the various land use zones were less than the background levels.

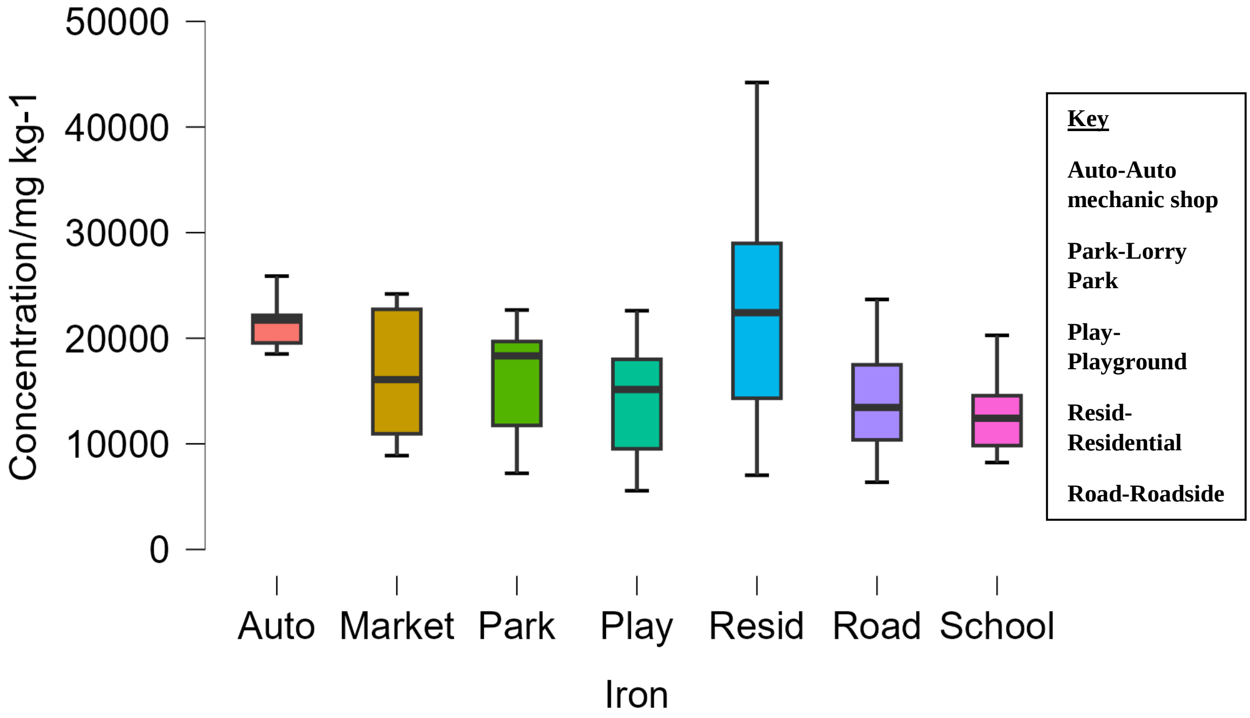

Figure 4.6. The concentration of iron in dust samples from different land use areas of Sekyere South

The earth's crust contains the highest concentration of iron (Fe), a vital element that comes from both anthropogenic and natural sources. In the study, dust samples from residential areas had the highest content of iron (80170.7 mg kg^{-1}) while playground dust had the lowest concentration (5560 mg kg^{-1}). In general, Fe concentration in dust across the sampling sites scored highest when compared to the concentration of other potentially harmful components. The data from all sites fell within the acceptable range when the mean iron results were compared to the WHO.'s maximum allowable concentration for iron, which is 50,000 mg kg^{-1}. However, the WHO limit was exceeded by the maximum concentration from residential (80170.7 mg kg^{-1}), auto mechanic shop (70774.9 mg kg^{-1}), and roadside (78245.4 mg kg^{-1}). The mean value of 37226.43 mg kg^{-1} recorded in urban dust of various land uses in Tehran's urban area was higher than the mean value of iron computed from the various land-use areas in this study (Kabir & Rashid, 2022). The largest concentrations of Fe are found in residential areas, which suggests that the particles come from the weathering of a particular type of local geological material brought on by construction work, wind erosion, and residential and traffic-related activities (Mafuyai et al., 2014). According to the results of the study by Darko, Dodd, Nkansah, Aduse-Poku, et al., (2017), corrosion of some motor vehicle parts was believed to be the cause of the second-highest iron pollution detected in the auto mechanic shop. Hypertension, blood coagulation in the blood vessels, and a sharp rise in heart rate are all effects of high iron intake in humans (Engwa et al., 2019).

4.1.6 Lead

The concentration of Pb in dust samples collected from various land uses ranges from 2.00 to 112.35 mg kg^{-1}. Samples from the lorry park had the lowest mean concentration, 3.51 mg kg^{-1}, ranging from 2.00 to 5.04 mg kg^{-1}, whereas the greatest mean concentration was found in the auto mechanic shop, 42.08 mg kg^{-1}, with values between 13.90 and 112.35 mg kg^{-1}. Other findings from the market, roadside, playground, residential, and school areas revealed Pb values ranging from 3.28 to 5.65, 2.01 to 88.40, 3.11 to 4.31, 2.01 to 13.46, and 2.00 to 17.60 mg kg^{-1}, with the mean concentrations being 4.14, 10.60, 3.62, 4.52, and 5.13 mg kg^{-1}, respectively. The lead concentration in the various land use zones is depicted in Figure 4.7. Except for the data from the auto mechanic shop, which are 2.10 times higher than the background value (20 mg kg^{-1}), the mean Pb concentrations obtained from the various land use zones were below the soil average shale value utilized as the background values. This demonstrates the Pb pollution in the vicinity of the auto mechanic shop. Additionally, the highest concentrations found in the auto mechanic shop and along the roadway were 4.42 and 5.62 times higher than the equivalent background levels. These high values could be attributed to vehicular emissions and the activities of auto repairers. Statistics were not significant for the mean Pb amounts found in the various land use zones ($p > 0.05$).

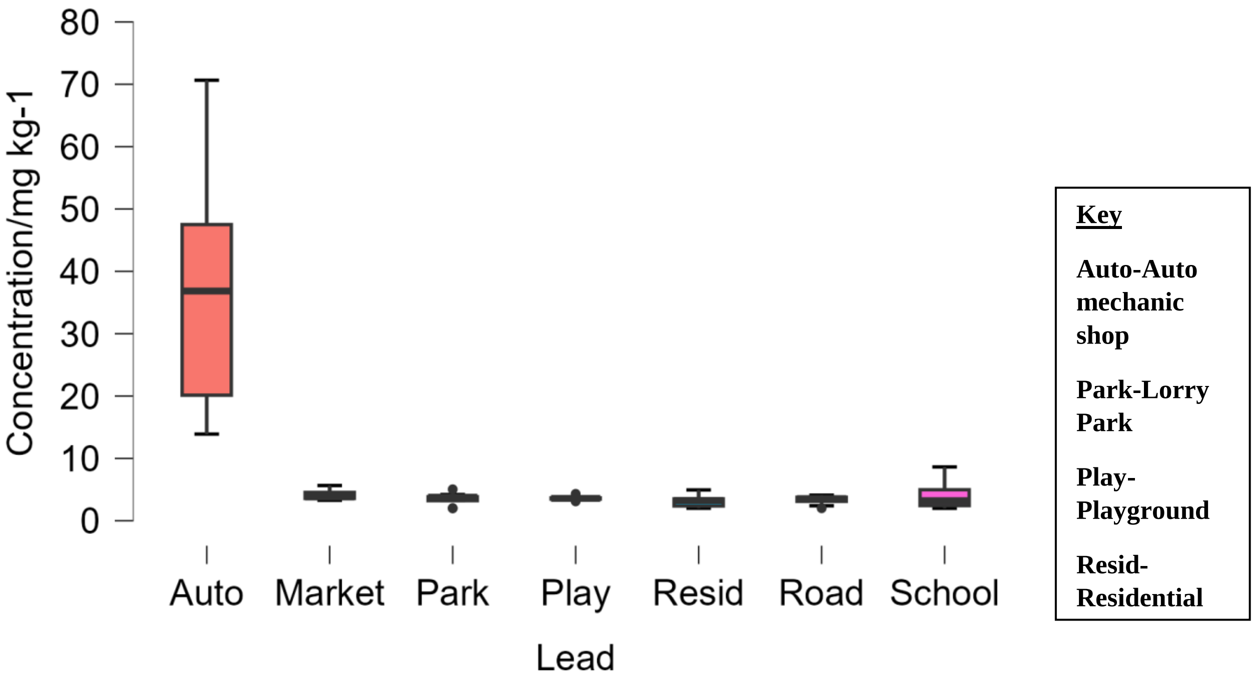

Figure 4.7. The concentration of lead in dust samples from different land use areas of Sekyere South

The mean Pb concentrations ranged from 3.5 to 42.1 mg kg^{-1} and were below the Dutch, Canadian, and WHO standards values in the dust collected from all the various land use zones. However, the greatest amount of lead measured from the auto mechanic shop was higher than the maximum allowed concentrations (MPC) in soil that the WHO, the Dutch Government (VROM, 2000), and the Canadian Government (CCME, 2007) recommendations for residential areas all indicate. In this study, the average mean lead concentration was 7.3 times lower than the mean value of 77 mg kg^{-1} published in a study of a similar kind by Shi-Bao et al., (2018) and about 5 times lower than the mean concentration (54 mg kg^{-1}) reported by Darko, et al., (2017). Residents in and around the locations may be at risk of exposure to excessive amounts of lead because the maximum concentration of lead measured in the auto mechanic shop dust exceeded the allowed value. According to Balali-Mood et al., (2021); Engwa et al., (2019); and Singh et al., (2017), lead may come from gasoline, paints, storage batteries, solders, ceramic ware, plastics, and faucets. Environmental contamination can lead to chronic lead exposure, which can cause birth defects, mental retardation, autism, psychosis, allergies, paralysis, weight loss, dyslexia, hyperactivity, muscle weakness, kidney damage, brain damage, coma, and even death (Aradpour et al., 2021).

4.1.7 Manganese

The concentration of manganese found in roadside areas, marketplaces, auto mechanic shops, playgrounds, lorry parks, residential areas, and schools (Figure 4.8) ranges from 33.28 to 223.58, 42.25 to 140.29, 107 to 700.50, 82.80 to 228.54, 51.19 to 355.20, 32.76 to 423.95, and 35.64 to 860.14 mg kg^{-1}, respectively. The market area had the lowest mean results, 101.95 mg kg^{-1}, while the area with the highest mean values, 321.44 mg kg^{-1}, was the auto mechanic shop. The average values at the following locations were also measured: roadside (113.18 mg kg^{-1}), playground (127.95 mg kg^{-1}), Lorry Park (181.69 mg kg^{-1}), residential (148.50 mg kg^{-1}), and school (149.66 mg kg^{-1}). Manganese concentrations were below background levels of 850 mg kg^{-1} in various land use zones. This demonstrates that the site is free of manganese contamination and that manganese is present in the environment naturally.

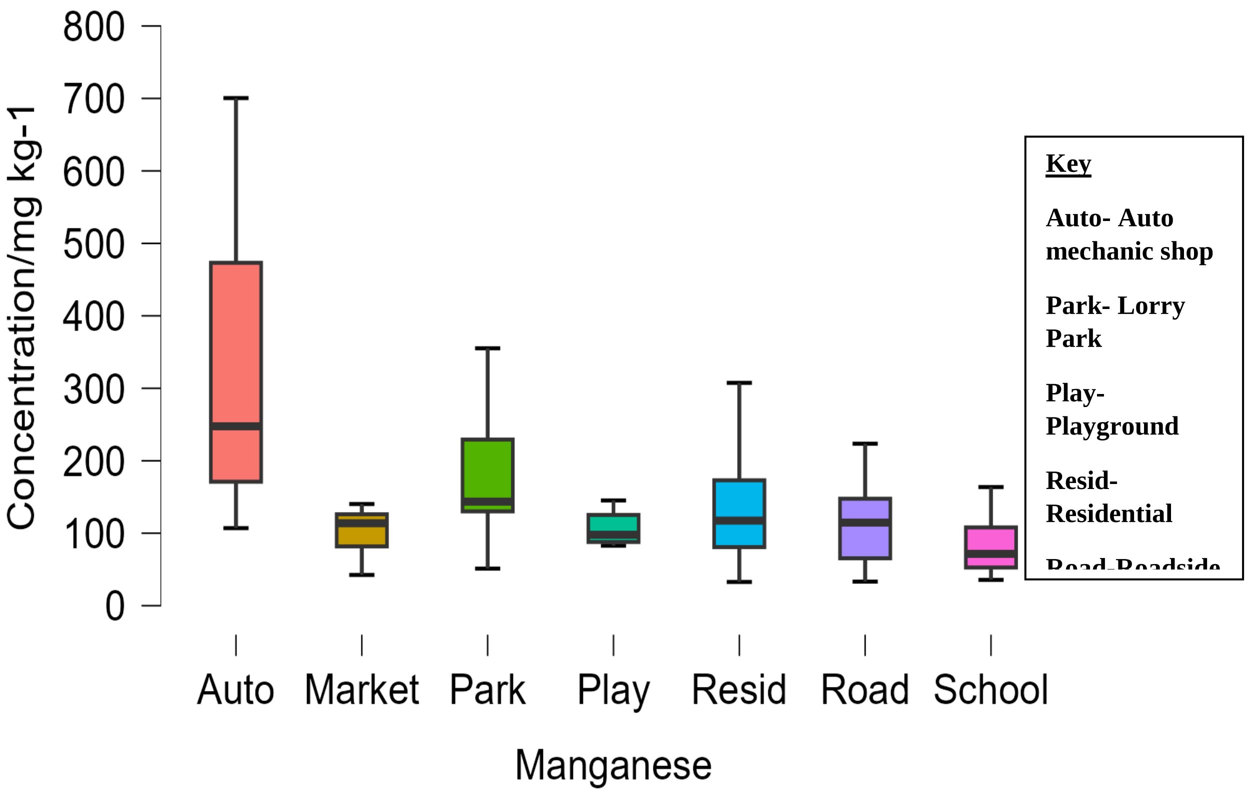

Figure 4.8. The concentration of manganese in dust samples from different land use areas of Sekyere South

In general, the dust samples in Sekyere South across the sampling sites rank manganese third in terms of concentration, behind only titanium and iron. From 32.8 mg kg^{-1} to 860 mg kg^{-1}, manganese concentrations have been measured over all of the locations. School buildings had the highest concentration, whereas residential areas had the lowest concentration. The concentration of manganese showed a similar pattern, according to a study (Kabir & Rashid, 2022) in the Bangladeshi city of Mymensingh. It can be seen that all of the samples fall below the WHO acceptable concentration for manganese, which is 1500 mg kg^{-1} when compared to the results of manganese measurements. Manganese-rich fuel burning and municipal solid waste incineration are two examples of anthropogenic activity at the sites that cause high amounts of manganese (Engwa et al., 2019). Although Mn is a necessary nutrient for plants and animals, exposure to extremely high amounts may be hazardous (Mafuyai et al., 2014). Manganism, a neurological condition marked by rigidity, action tremor, a mask-like expression, gait difficulties, bradykinesia, memory and cognitive failure, and mood instability, can be brought on by exposure to high quantities of manganese (Engwa et al., 2019).

4.1.8 Nickel

Nickel concentrations in seven different land use areas were generally moderate compared to the concentration of the other potentially toxic elements. Individual nickel values ranged from 11.29 – 45.16 mg kg^{-1} in the nickel concentrations recorded at the seven different land use areas. The mean levels were, roadside 16.54 mg kg^{-1} (values ranging from 11.41 – 23.63 mg kg^{-1}), market 15.97 mg kg^{-1} (values ranging from 11.56 – 18.04 mg kg^{-1}), auto mechanic shop 16.05mg kg^{-1} (values ranging from 11.55 – 20.19 mg kg^{-1}), playground 17.21 (values ranging from 12.81 – 19.32 mg kg^{-1}), lorry park 16.03 (values ranging 11.44 – 18.60 mg kg^{-1}), residential 17.39 mg kg^{-1} (values ranging from 11.29 – 27.75 mg kg^{-1}), and school 18.86 mg kg^{-1} (values ranging from 11,91 – 45.16 mg kg^{-1}) as shown in Figure 4.9.

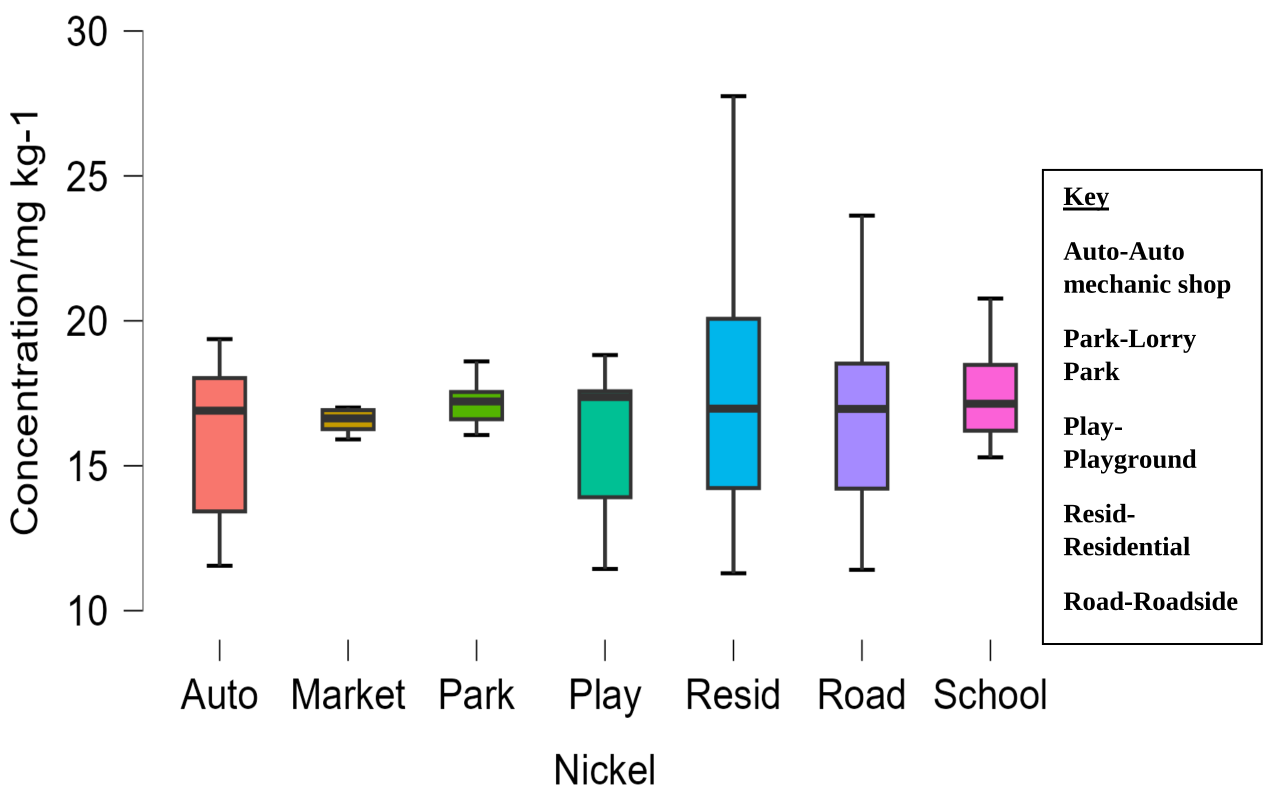

Figure 4.9. The concentration of Nickel in dust sample from different land use areas of Sekyere South

Batteries, nickel-plated jewelry, machine parts, steel, cigarettes, wire, electrical components, and other items all contain nickel. Additionally, it can be discovered in a variety of foods, including commercial peanut butter, unprocessed grains and cereals, hydrogenated vegetable oils, fake whip cream, and tainted alcoholic beverages (Engwa et al., 2019). The average nickel content found throughout the study locations (Table 4.1) was lower than the average of 106.4 mg kg^{-1} found in dust from middle and southern Iraq (Kadhum, 2020) and equivalent to the range of 22.7 to 34.2 mg kg^{-1} found in road dust in Mymensingh, Bangladesh (Kabir & Rashid, 2022). Similar research on dust was done in Delhi, India, by (Suryawanshi et al., 2016), and they found that the mean nickel concentration ranged from 27.2 to 61.7 mg kg^{-1}, which is greater than the mean value found in this study. All samples had nickel concentrations below the threshold of 50 mg kg^{-1} when results for nickel were compared to WHO and Canadian international norms.

An allergic reaction, such as a skin rash, is the most frequent adverse health effect of Ni in people. Workers in nickel processing companies who breathed dust containing high quantities of nickel compounds while doing their jobs have developed lung and nasal sinus cancers (Mafuyai et al., 2014).

4.1.9 Titanium

Figure 4.10 shows the concentration of titanium in the study area. Roadside recorded the lowest mean of 1947.56 mg kg^{-1} with values ranging from 508.52 – 3259.45 mg kg^{-1}, the market recorded a mean of 2918.84mg kg^{-1} with values ranging from 1593.76 – 5880.31 mg kg^{-1}, while playground recorded a mean of 2651.49 mg kg^{-1} with values ranging from 1122.27 – 5719.89 mg kg^{-1}. The highest mean concentration of titanium was 3746.93 mg kg^{-1} recorded at the auto mechanic shop, with varied values from 1242.76 – 5426.28 mg kg^{-1}. Concentrations of titanium obtained from lorry parks, residential and schools varied between 814.49 – 4165.34, 1009.62 – 6277.12, and 290.48 – 3714 mg kg^{-1} respectively with mean results 2542.89, 3436.44, and 2051.88 mg kg^{-1}. The mean concentrations had no significant variations ($p > 0.05$). The research area is not polluted with titanium since the mean concentrations of titanium found in the various land-use areas were less than the relevant background value.

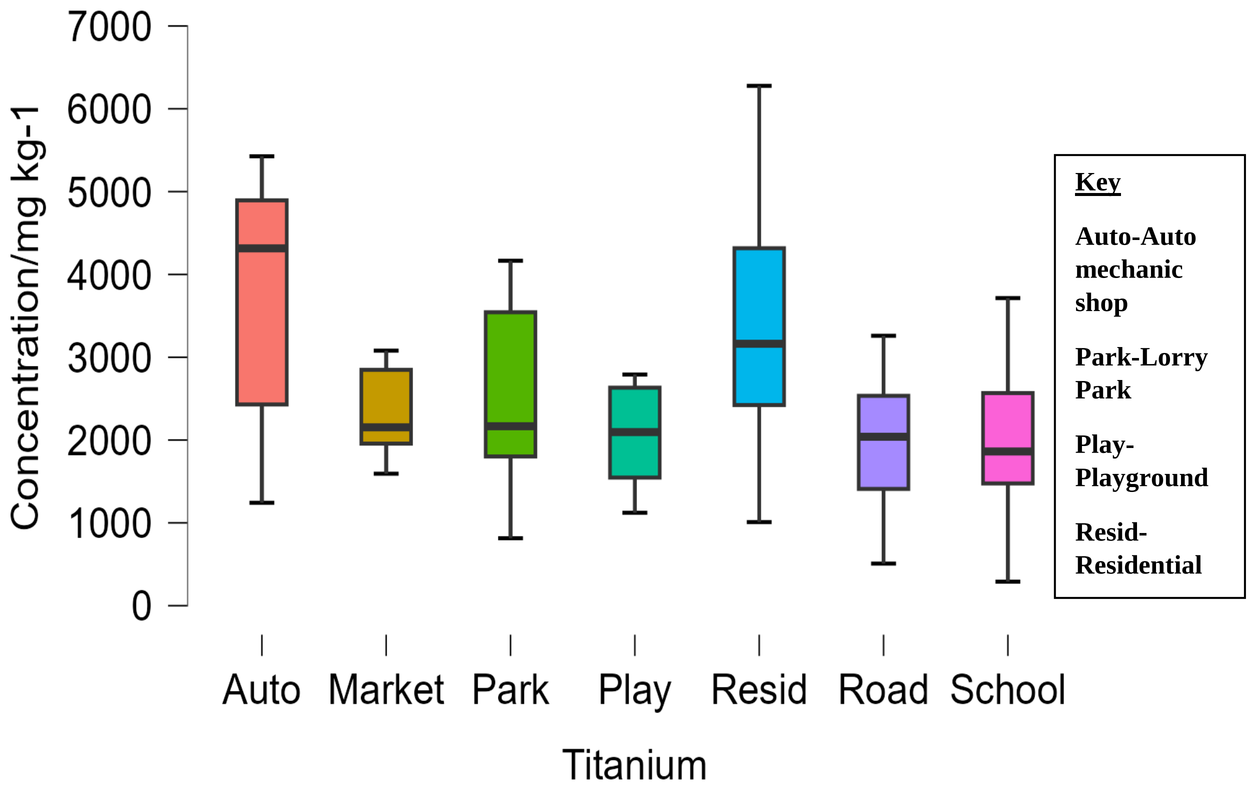

Figure 4.10. The concentration of titanium in dust samples from different land use areas of Sekyere South

The tenth most common element in the earth's crust, titanium is a gray metal with an atomic number of 22 and a relative atomic mass of 47.9. It is also extensively dispersed (Brueck, 2015). Numerous items, including cosmetics, paintings, foods, medications, dental implants, and medical implant materials, employ titanium (Fabiana Meijon Fadul, 2019). The crust of the earth contains 4400 mg kg^{-1} of titanium on average (Shi et al., 2013). The amounts of titanium in the dust samples ranged from 290.50 to 6277.10 mg kg^{-1}, making it the second-highest concentration of potentially hazardous substances identified in the study. The maximum titanium concentration was found in the dust sample from the auto mechanic shop, which is 1.4 times greater than the typical titanium concentration in the earth's crust. The mean titanium concentrations across all study sites were, however, lower than those found in the earth's crust. There is no guideline range for titanium, according to a comparison of the mean results with the worldwide guidelines values for hazardous elements. The burning of fossil fuels and the incineration of trash containing titanium are the main causes of titanium contamination in the environment in general (Götschi et al., 2005; Vearrier et al., 2009).

4.1.10 Vanadium

Figure 4.11 shows the distribution of vanadium in soil dust collected from different land use areas in Sekyere south with concentration values ranging from 22.92 - 134.73 mg kg^{-1}, 41.05 – 160.93 mg kg^{-1} 43.19 – 255.43 mg kg^{-1}, 28.83 – 164.81 mg kg^{-1}, 28.93 – 130.43 mg kg^{-1}, 24.50 – 273.77 mg kg^{-1}, and 9.21 – 102.84 mg kg^{-1} for roadsides, markets, auto mechanic shop, playgrounds, lorry parks, residential and school areas respectively. The mean concentrations of the following areas, respectively, were 63.99, 78.63, 123.69, 75.64, 77.17, 105.75, and 53.81 mg kg^{-1}: roadsides, market, auto mechanic shop, playground, lorry park, residential, and school. When compared to the same background values, the vanadium concentration from roadsides, markets, auto mechanic shops, playgrounds, lorry parks, residential areas, and schools were 4.92, 6, 9.5, 5.8, 5.94, 8, and 4 times higher. Vanadium was also found to be enriched to an extremely high level in places including the roadsides, markets, auto mechanic shops, playgrounds, lorry parks, residential areas, and schools, where it was found to be present more than background levels by 79.68%, 83.47%, 89.49%, 82.81%, 83.15%, 87.70 and 75.84%. At a 95% confidence level, there was no statistically significant difference in the mean concentrations between the various land use areas.

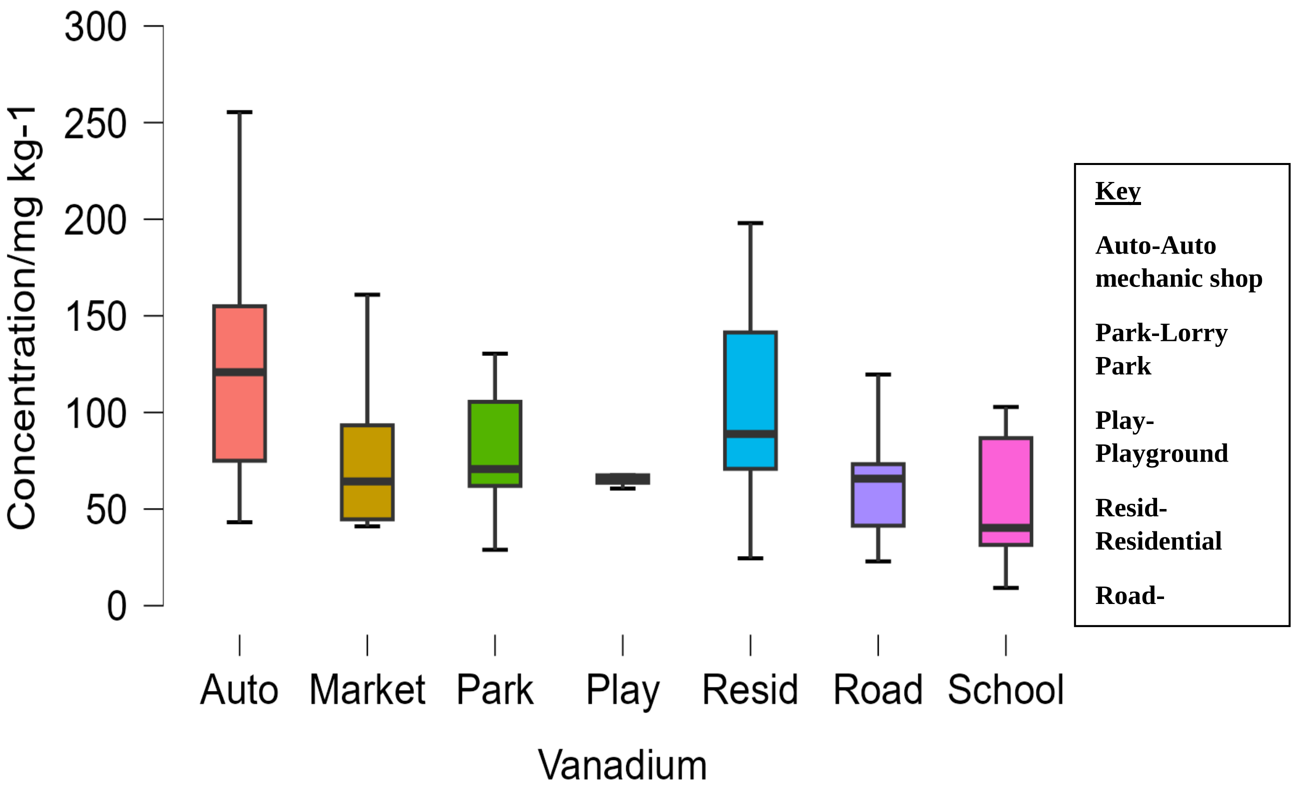

Figure 4.11. The concentration of vanadium dust samples from different land use areas of Sekyere South

With values ranging from 9.2 to 273.8 mg kg^{-1}, the concentration of vanadium detected in this study is highest near the roadside and lowest near the school zones. All samples were within the limit of 130 mg kg^{-1} when the mean vanadium concentration was compared to the Canadian soil quality requirements for vanadium. Except for the concentration from the lorry park, which is equal to the limit, the maximum concentration measured from all of the sampled places was above the recommended limit. In a comparable investigation, Darko, Dodd, Nkansah, Aduse-Poku, et al., (2017) found 173.10 mg kg^{-1} of V in dust in Kumasi, Ghana.

4.1.11 Zinc

The dust samples collected from different land use areas in the study area exhibited distinct variations in the levels of zinc with concentration ranges of 18.01 – 266.61 mg kg^{-1} from the roadsides with a mean of 90.91, 74.67 – 281.95 mg kg^{-1} from the markets with a mean of 151.49 mg kg^{-1}, 71.81 – 770.15 mg kg^{-1} from auto mechanic shop with mean 272.90 mg kg^{-1}, 32.98 – 52.89 mg kg^{-1} from the playgrounds with mean 43.20 mg kg-1, 67.92 – 344.92 mg kg^{-1} from lorry parks with mean 181.90 mg kg^{-1}, 28.83 – 1047.99 mg kg^{-1} from residential areas with mean 249.98 mg kg^{-1}, and 99.47 – 556.01 mg kg^{-1} from schools with mean 216.91 mg kg^{-1}. The results showed that the mean zinc concentrations in the markets, auto mechanic shops, lorry parks, residential areas, and schools were 1.6, 2.9, 1.9, 2.6, and 2.3 times higher than the corresponding reference values (95 mg kg^{-1}) (James et al., 2020). All land use zones, except those near playgrounds, had maximum concentrations that were higher than background levels. Zinc concentrations from various Sekyere South land use zones are depicted in Figure 4.12. The average zinc content found in the various land use zones was not statistically significant ($p > 0.05$).

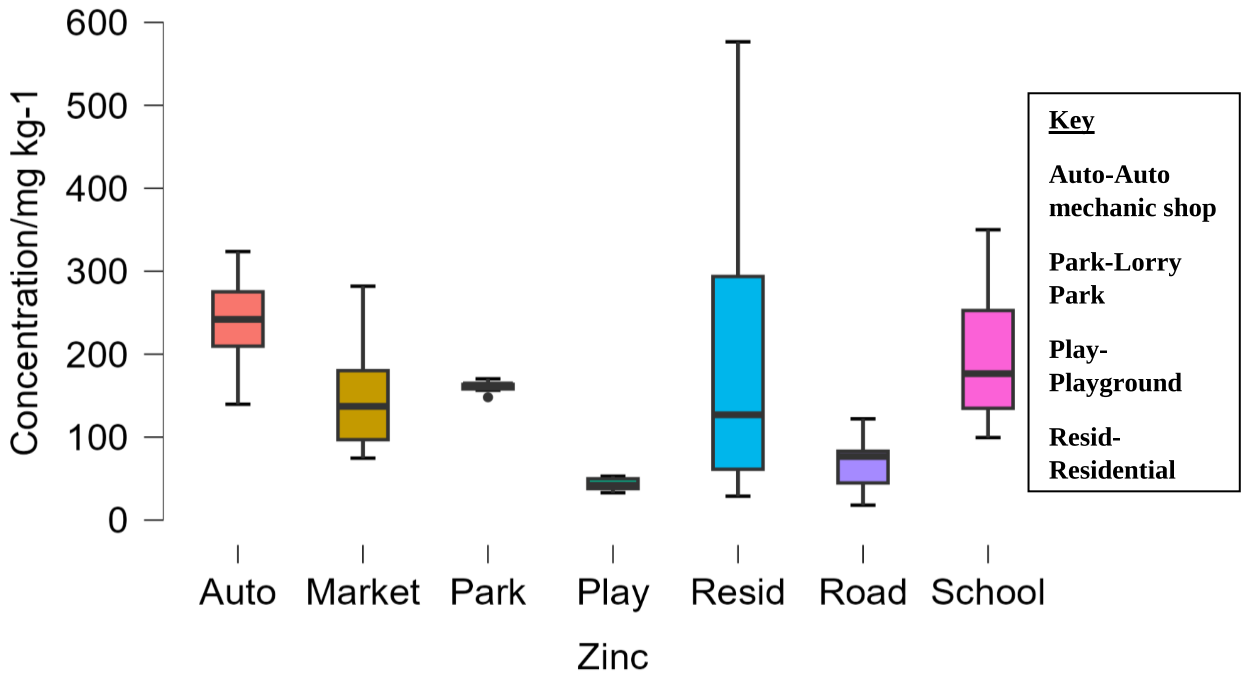

Figure 4.12. The concentration of zinc in dust samples from different land use areas of Sekyere South

Being deficient in zinc can have negative effects on our health, and being overly exposed to it can also be hazardous (Engwa et al., 2019). With an overall mean of 172.5 mg kg^{-1} across all sites, the mean Zn concentration ranges from 43.20 to 272.9 mg kg^{-1}. While the playground had the lowest mean value, the auto mechanic shop had the highest mean Zn concentration. The mean concentration of zinc found in this study is lower than the mean value of 284 mg kg^{-1} found in a study of a similar nature carried out in Delhi, India, (Suryawanshi et al., 2016) and the southern part of Iraq (Kadhum, 2020). When the zinc mean concentrations from this study were compared to the MPC and CCME worldwide criteria, it was discovered that samples from the residential, auto mechanic shop, and school areas were above the limit while samples from roadsides, markets, playgrounds, and lorry parks were below the limit. The average findings from roadways, playgrounds, lorry parks, marketplaces, schools, and other commercial and residential areas were above the Dutch target (VROM, 2000). According to (Mafuyai et al., 2014), the zinc concentration that has been found, results from motor vehicles wearing out their tires and engine components. This occurs in car repair facilities and transportation hubs. A unique short-term illness known as metal fume fever can be brought on by inhaling excessive levels of Zn as dust or fumes. This immunological reaction is thought to affect the lungs and body temperature (Anyanwu et al., 2018; Eneji et al., 2015).

4.2 Pearson's Correlation Analysis of Potentially Toxic Elements in Dust from Different Land Use Areas.

At $p < 0.05$, Pearson correlation analysis was employed to investigate the associations between the concentration of potentially harmful components in dust from the study area and the outcomes shown in Table 4.2. According to the findings, lead (Pb) exhibited very strong significant positive correlations with copper (r=0.98) and chromium (r=0.95), strong positive correlations with arsenic (r=0.76) and manganese (r=0.89), and a moderately strong positive association with iron, vanadium, and titanium. Arsenic showed a strong significant positive correlation with Zn, Cu, Fe, Mn, Cr, V, Ti, and Cd. The other significant very high positive correlations were Cu – Cr, Cu – Mn, and V – Ti. While the other high positive significant correlations were Cu – V, Fe – Cr, Fe – V, Mn – Cr, Mn – V, Cr – V, Ti – Fe, and Cd – Zn. Nickel showed a low negative or positive correlation with the other elements.

Table 4.2. Correlation of potentially toxic elements

	Pb	As	Zn	Cu	Fe	Mn	Cr	V	Ti	Ni	Cd
Pb	1.00										
As	0.76*	1.00									
Zn	0.48	0.86*	1.00								
Cu	0.98**	0.86*	0.59	1.00							
Fe	0.56	0.79*	0.61	0.61	1.00						
Mn	0.89*	0.80*	0.65	0.92**	0.52	1.00					
Cr	0.95**	0.76*	0.43	0.95**	0.70*	0.86*	1.00				
V	0.69	0.77*	0.59	0.74*	0.87*	0.73*	0.85*	1.00			
Ti	0.57	0.70*	0.58	0.63	0.78*	0.62	0.74	0.96**	1.00		
Ni	-0.34	0.04	0.06	-0.18	-0.28	-0.27	-0.40	-0.45	-0.40	1.00	
Cd	0.38	0.82*	0.78*	0.55	0.45	0.47	0.33	0.32	0.30	0.59	1.00

Except nickel, there is either a very strong, strong, or moderately significant positive association between the potentially harmful elements, according to the study in Table 4.2, demonstrating that human activities such as those in the industrial, commercial, automotive, and traffic sectors (where fossil fuels are burned, tires wear, and car parts corrode), as well as in agriculture (where fertilizers and pesticides are used), are the main source of the harmful substances (Mirzaei Aminiyan et al., 2018). Only nickel displayed a weak or negative connection with the other elements except with cadmium, suggesting the different points of origin.

4.3 Principal Component Analysis

The variables were condensed into three models, which accounted for 66.2% of the total variance, and three principal components (PCs) whose eigenvalues were greater than one were extracted. The outcomes of the main component analysis are presented in Tables 4.3, 4.4, and Figure 4.13. Vanadium, titanium, iron, and chromium were the dominant elements in PC1, which accounted for 36.4% of the total variance, with coefficients of 0.957, 0.871, 0.734, and 0.720, respectively. Lead, manganese, arsenic, copper, and zinc dominated the PC2 with coefficients of 0.846, 0.830, 0.693, 0.567, and 0.412, respectively, accounting for 19.6% of the total variance. Cadmium and nickel dominated the PC3, accounting for 10.2% of the total variance, with coefficients of 0.851 and 0.562, respectively.

Table 4.3. Component Characteristics

	Unrotated solution			Rotated solution		
	Eigenvalue	Proportion var.	Cumulative	SumSq. Loadings	Proportion var.	Cumulative
Component 1	4.008	0.364	0.364	3.137	0.285	0.285
Component 2	2.157	0.196	0.560	2.721	0.247	0.533
Component 3	1.121	0.102	0.662	1.429	0.130	0.662

Table 4.4. Component Loadings

	PC1	PC2	PC3	Uniqueness
V	0.957			0.039
Ti	0.871			0.184
Fe	0.734		0.422	0.253
Cr	0.710			0.440
Ni	-0.455	0.424	0.562	0.297
Pb		0.846		0.285
Mn		0.830		0.249
As		0.693		0.440
Cu		0.567		0.613
Zn		0.412		0.643
Cd			0.851	0.268

Note. The applied rotation method is varimax.

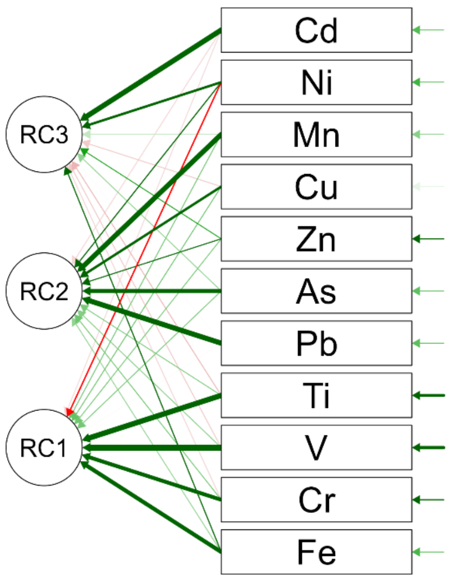

Figure 4.13. Path Diagram of principal component analysis

In the first component, vanadium, titanium, chromium, and iron had very strong correlations, indicating that their sources were similar. V, Cr, Fe, and Ti have strong correlations in PC1, which points to a natural cause. Darko, et al., (2017) observed the elemental (V, Cr, Fe, and Ti) pollution in the auto mechanic shop in the Kumasi metropolis which was attributed to the automobile operations and metal processing works in the area. Chromium, titanium, and vanadium pollution are caused by vehicle emissions, waste incineration, fertilizer use, and fuel combustion (Ryder et al., 2020). Lead, manganese, arsenic, copper, and zinc are among the PC2 elements that may have come from natural sources and anthropogenic sources. Lead, copper, arsenic, and manganese, on the other hand, exhibit low to moderate enrichment, suggesting a natural crustal origin with evidence of human intervention. A high anthropogenic influence is suggested by the moderate to significant enrichment value of zinc. Lead, copper, and zinc contamination (Nkansah et al., 2017) is influenced by industrial emissions, inappropriate motor oil disposal, and considerable vehicular emissions. Incineration of waste, corroding of paints, and widespread use of agrochemicals are three possible causes of cadmium and nickel (Kubier et al., 2019; Nkansah et al., 2017).

4.4 Contamination Assessment of Potentially Toxic Elements in Dust from Different Land Use Areas

The degree of heavy metal contamination in the dust sample from various land use zones was determined using pollution indices.

4.4.1 Contamination Factor

One of the measures used to evaluate the degree of contamination with potentially harmful substances in the dust samples was the contamination factor. In Table 4.5, the derived values for the contamination factor are shown. The lead, arsenic, copper, iron, manganese, and chromium contamination factors were all less than one (1), indicating low contamination, except lead and copper values from the auto mechanic shop, which ranged from 0.7 to 5.62 with a mean of 2.1 and 0.23 to 3.65 with a mean of 1.21, respectively. From the auto mechanic shop, chromium had a mean contamination factor of 1.42. The lead and copper contamination factors show a range of contamination in the auto mechanic shop from very low to very high. All the different land use areas recorded a contamination factor of more than one (1) for cadmium and vanadium. The contamination factor values of Cd range from 12.43 – 31.90 with mean values of 19.80, 17.85, 17.49, 19.33, 17.56, 17.62, and 19.46 from school, roadside, market, auto mechanic shop, playground, lorry park, and residential areas respectively. The contamination factor results obtained for cadmium indicate that the study sites are extremely contaminated with cadmium. The mean contamination values for vanadium were; school 4.14 representing high contamination, roadside 4.92 indicating high contamination, market 6.25

representing extreme contamination, auto mechanic shop 9.51 representing extreme contamination, playground 5.82 representing very high contamination, lorry park 5.94 representing very high contamination and residential 8.13 extreme contamination. The contamination factor for zinc from the land use areas ranges from 0.30 to 11. 03 representing low contamination to extreme contamination of the sites. The average contamination factor of the potentially toxic elements follows the decreasing order Cd > V > Zn > Cr > Pb > Cu > Ti > Fe > As > Ni > Mn.

Table 4.5. Contamination factor for potentially toxic elements in dust samples from Sekyere South

Land Use Areas		Pb	As	Zn	Cu	Fe	Mn	Cr	V	Ti	Ni	Cd
School	Mean	0.26	0.27	2.28	0.43	0.28	0.18	0.49	4.14	0.47	0.28	19.80
	Minimum	0.10	0.15	1.05	0.14	0.18	0.04	0.27	0.71	0.07	0.18	14.53
	Maximum	0.88	0.63	5.85	2.36	0.44	1.01	0.81	7.91	0.84	0.66	25.30
Road	Mean	0.53	0.24	0.96	0.39	0.41	0.13	0.70	4.92	0.44	0.24	17.85
	Minimum	0.10	0.13	0.19	0.14	0.14	0.04	0.31	1.76	0.12	0.17	13.43
	Maximum	4.44	0.56	2.81	1.41	1.70	0.26	1.47	10.36	0.74	0.35	23.63
Market	Mean	0.21	0.23	1.59	0.27	0.36	0.12	0.61	6.05	0.66	0.23	17.49
	Minimum	0.16	0.16	0.79	0.20	0.19	0.05	0.42	3.16	0.36	0.17	13.33
	Maximum	0.28	0.27	2.97	0.49	0.53	0.17	0.74	12.38	1.34	0.27	22.27
Auto shop	Mean	2.10	0.35	2.87	1.21	0.58	0.38	1.42	9.51	0.85	0.24	19.38
	Minimum	0.70	0.17	0.76	0.23	0.29	0.13	0.69	3.32	0.28	0.17	12.80
	Maximum	5.62	1.01	8.11	3.65	1.54	0.82	3.64	19.65	1.23	0.30	23.17
Playground	Mean	0.18	0.22	0.45	0.34	0.31	0.15	0.72	5.82	0.60	0.25	17.56
	Minimum	0.16	0.18	0.35	0.19	0.12	0.10	0.30	2.22	0.26	0.19	14.50
	Maximum	0.22	0.26	0.56	0.74	0.49	0.27	1.14	12.68	1.30	0.28	22.47
Lory Park	Mean	0.18	0.24	1.91	0.29	0.35	0.21	0.58	5.94	0.58	0.24	17.62
	Minimum	0.10	0.15	0.71	0.14	0.16	0.06	0.21	2.23	0.19	0.17	12.43
	Maximum	0.25	0.33	3.63	0.48	0.49	0.42	0.85	10.03	0.95	0.27	22.03
Residential	Mean	0.23	0.31	2.63	0.45	0.61	0.17	0.76	8.13	0.78	0.26	19.46
	Minimum	0.10	0.13	0.30	0.14	0.15	0.04	0.11	1.88	0.23	0.17	15.13
	Maximum	0.67	0.79	11.03	1.45	1.74	0.50	2.35	21.06	1.43	0.41	31.90
	Average	0.83	0.32	2.47	0.72	0.53	0.25	0.89	7.33	0.65	0.26	18.86

For the most part, the mean contamination factor estimates for the various land use areas revealed low contamination for the hazardous elements Pb, As, Cu, Fe, Mn, Cr, Ni, and

Ti. The median results of the zinc contamination factor (2.47 on average) revealed a moderate contamination factor (2≤CF<3) in the dust from residential, auto mechanic shops, and schools. High levels of vanadium contamination (4 ≤ Cf< 5) were found in the dust from schools and roadsides, very high levels of vanadium contamination (5≤CF<6) were found in the dust from playgrounds and lorry parks, and extreme levels (CF>6) were found in the dust from markets, auto mechanic shop, and residential areas. With an average contamination ratio of 7.33, cadmium revealed extremely high contamination levels in dust collected from all land use regions. These findings demonstrated that vanadium and cadmium contamination of dust in Sekyere South is very high to extremely high, while lead, arsenic, iron, manganese, chromium, nickel, and zinc contamination is very low to nonexistent. This contradicts earlier research from Suryawanshi et al., (2016) which found that road dust is considerably contaminated by Zn and Pb, followed by a significant amount of contamination by Cu and Cd.

4.4.2 Pollution Load Index and Modified Degree of Contamination

In Table 4.6, the estimated pollution load index and the modified degree of contamination of the potentially harmful elements are displayed. Since the mean pollution load index from the auto mechanic shop (1.36) was higher than one (1), it can be concluded that the area is polluted with potentially toxic elements. The average pollution load index values from the remaining various land use areas were below one (1), indicating that the sites were not contaminated with harmful elements. But the highest pollutant load indexes from schools, roadsides, lorry parks, and residential areas were 1.68, 1.73, 1.03, and 2.23, respectively, indicating that some of the sampling regions were polluted.

The modified degree of contamination ranges from 1.50, which represents a low degree of contamination, to 6.67, which represents a high degree of contamination, as shown in

Table 4.6. The high level of cadmium in the sampling sites can be blamed for the highest mean degree of contamination value, which was obtained from the auto mechanic shop and was 3.50. The average results from the school, roadside, market, playground, lorry park, and residential areas were 2.63, 2.44, 2.53, 2.42, 2.56, and 3.07, respectively. These values point to a moderate level of pollution (2 ≤ mCd <4) in the area.

Table 4.6. Pollution Load Index and Modified Degree of Contamination

Land Use Areas		PLI	mCd
School	Mean	0.69	2.63
	Minimum	0.27	1.58
	Maximum	1.68	4.25
Roadside	Mean	0.69	2.44
	Minimum	0.25	1.50
	Maximum	1.73	4.34
Market	Mean	0.65	2.53
	Minimum	0.40	1.73
	Maximum	0.97	3.79
Auto Shop	Mean	1.36	3.54
	Minimum	0.54	1.77
	Maximum	2.91	6.25
Playground	Mean	0.59	2.42
	Minimum	0.35	1.69
	Maximum	0.91	3.67
Lory Park	Mean	0.68	2.56
	Minimum	0.31	1.50
	Maximum	1.03	3.61
Residential area	Mean	0.87	3.07
	Minimum	0.26	1.67
	Maximum	2.23	6.67
	Average	0.92	3.01

The mean pollution load index values calculated for all the study areas were low (1), indicating no toxic elements pollution in the areas except for the values obtained from the auto mechanic shop areas, which were higher than one (>1), indicating potentially toxic element pollution in the area, requiring remediation to prevent further pollution (Rabin et al., 2023).

The modified degree of contamination shows the overall effect of all contaminants in a place (Kabir & Rashid, 2022). The mean values of the modified degree of contamination by eleven hazardous components in the dust samples from seven different land-use zones vary from 2.42 to 3.54, reflecting a moderate degree of pollution ($2 \leq mCd < 4$). The proportions of cadmium, vanadium, zinc, chromium, lead, copper, titanium, iron, arsenic, nickel, and manganese to the moderate degree of contamination by the eleven toxic elements in the dust samples are 57%, 22.1%, 7.5%, 2.7%, 2.5%, 2.2%, 2%, 1.6%, 1%, and 0.79%, respectively. The degree of the different land use areas contamination follows the decreasing order auto mechanic shop > residential areas > schools > lorry parks > markets > roadsides > playgrounds

4.4.3 Geo-accumulation index (Igeo)

Table 4.7 displays the results of the potentially toxic elements' geo-accumulation index values for each distinct land use area. For all the distinct land use regions, the mean geo-accumulation index values for Pb, As, Zn, Cu, Fe, Mn, Cr, Ti, and Ni were less than one (1), falling within the class Igeo < 1, indicating unpolluted to moderately polluted areas. Market (1.21), auto mechanic shop (1.91), playground (1.17), Lory Park (1.19), and residential areas (1.63) all had mean geo-accumulations of vanadium that were greater than one ($1 \leq Igeo < 2$) indicating moderately polluted locations. From all the land use zones, cadmium registered geo-accumulation values greater than one. The greatest geo-accumulation values of cadmium, which ranged from 3.09 to 6.40 and indicated strongly to very heavily polluted locations, occurred in residential areas. The school's geo-accumulation index cadmium scores, which ranged from 2.92 to 5.08 and represented areas with moderate to strong to very significant pollution, were the second highest. Roadside 2.0 to 4.74, market 2.68 to 4.47, auto mechanic shop 2.57 to 4.65, playground 2.91 to 4.51, and Lory Park 2.49 to 4.42 were the geo-accumulation values of cadmium that were acquired from other distinct land use areas. These values indicate moderate to strong to very strong pollution.

Table 4.7. Geo-accumulation

Land Use Areas		Pb	As	Zn	Cu	Fe	Mn	Cr	V	Ti	Ni	Cd
School	Mean	0.05	0.06	0.46	0.09	0.06	0.04	0.10	0.83	0.09	0.06	3.97
	Minimum	0.02	0.03	0.21	0.03	0.04	0.01	0.05	0.14	0.01	0.04	2.92
	Maximum	0.18	0.13	1.17	0.47	0.09	0.20	0.16	1.59	0.17	0.13	5.08
Roadside	Mean	0.11	0.05	0.19	0.08	0.08	0.03	0.14	0.99	0.09	0.05	3.58
	Minimum	0.02	0.03	0.04	0.03	0.03	0.01	0.06	0.35	0.02	0.03	2.70
	Maximum	0.89	0.11	0.56	0.28	0.34	0.05	0.29	2.08	0.15	0.07	4.74
Market	Mean	0.04	0.05	0.32	0.05	0.07	0.02	0.12	1.21	0.13	0.05	3.51
	Minimum	0.03	0.03	0.16	0.04	0.04	0.01	0.08	0.63	0.07	0.03	2.68
	Maximum	0.06	0.05	0.60	0.10	0.11	0.03	0.15	2.48	0.27	0.05	4.47
Auto Shop	Mean	0.42	0.07	0.58	0.24	0.12	0.08	0.28	1.91	0.17	0.05	3.89
	Minimum	0.14	0.03	0.15	0.05	0.06	0.03	0.14	0.67	0.06	0.03	2.57
	Maximum	1.13	0.20	1.63	0.73	0.31	0.17	0.73	3.94	0.25	0.06	4.65
Playground	Mean	0.04	0.04	0.09	0.07	0.06	0.03	0.14	1.17	0.12	0.05	3.52
	Minimum	0.03	0.04	0.07	0.04	0.02	0.02	0.06	0.45	0.05	0.04	2.91
	Maximum	0.04	0.05	0.11	0.15	0.10	0.05	0.23	2.54	0.26	0.06	4.51
lory Park	Mean	0.04	0.05	0.38	0.06	0.07	0.04	0.12	1.19	0.12	0.05	3.54
	Minimum	0.02	0.03	0.14	0.03	0.03	0.01	0.04	0.45	0.04	0.03	2.49
	Maximum	0.05	0.07	0.73	0.10	0.10	0.08	0.17	2.01	0.19	0.05	4.42
Residential area	Mean	0.05	0.06	0.53	0.09	0.12	0.04	0.15	1.63	0.16	0.05	3.91
	Minimum	0.02	0.03	0.06	0.03	0.03	0.01	0.02	0.38	0.05	0.03	3.04
	Maximum	0.14	0.16	2.21	0.29	0.35	0.10	0.47	4.23	0.29	0.08	6.40

The dust samples of Sekyere south in all the different land use zones were unpolluted to moderately polluted (0 < Igeo < 1) by toxic elements lead, arsenic, zinc, copper, manganese, iron, chromium, and titanium, according to the geo-accumulation data (Table 4.7). Vanadium moderately polluted the market, auto mechanic shop, playground, and lorry park areas (1 ≤ Igeo < 2) while cadmium strongly polluted the dust samples from all land uses.

4.4.4 Enrichment Factor (EF) of dust particles

With iron (Fe) serving as the reference element for normalization, enrichment factors of potentially harmful elements were determined (Table 4.8) for the dust samples taken from seven different land use areas in Sekyere South. Compared to the other elements, cadmium had the greatest mean enrichment factor values, ranging from 31.75 to 71.19. Cadmium demonstrated extremely high enrichment at schools (EF = 71.19), playgrounds (EF = 56.95), markets (EF = 48.54), Lory Park (EF = 45.72), and roadside (EF = 43.42). It also demonstrated very high enrichment (20 < EF < 40) in auto mechanic shops and residential areas. Titanium showed deficient to low enrichment values ranging from 1.27 to 1.96 while vanadium showed significant enrichment (EF = 11.98 to 18.88) for all the varied land use zones. Measured enrichment factors for arsenic, manganese, and nickel from the study area revealed deficient to minimal enrichment (EF < 2), except in the auto mechanic shop, where the EF of lead and copper were 3.65 and 2.11, respectively, suggesting moderate enrichment, lead, and copper were deficient or had minimal enrichment factors across all land use sectors. Chromium levels in the auto mechanic shop and playground were moderately enriched (EF > 2), but they were deficient to minimal enriched (EF = 1.24 to 1.77) in the other research locations. In contrast, zinc showed moderate enrichment (EF = 2.33) at the roadside, significant enrichment (EF = 5.43) at Lory Park, and deficiency to minimal enrichment (EF = 1.48) at the playground. It also showed moderate enrichment (EF = 4.29 to 4.99) for the market, auto mechanic shops, and residential areas.

Table 4.8: Enrichment factors (EF) of potentially toxic elements in dust samples from Sekyere south

Land Use Areas		Pb	As	Zn	Cu	Mn	Cr	V	Ti	Ni	Cd
School	Mean	0.92	0.99	8.21	1.56	0.63	1.77	14.88	1.68	1.00	71.19
	Minimum	0.56	0.82	5.85	0.78	0.23	1.51	3.96	0.37	0.98	81.23
	Maximum	2.00	1.43	13.28	5.35	2.30	1.84	17.95	1.92	1.51	57.41
Roadside	Mean	1.30	0.58	2.33	0.00	0.32	1.70	11.98	1.08	0.60	43.42
	Minimum	0.73	0.96	1.37	1.00	0.28	2.26	12.74	0.84	1.21	97.08
	Maximum	2.61	0.33	1.65	0.00	0.15	0.86	6.09	0.44	0.20	13.89
Market	Mean	0.57	0.64	4.43	0.75	0.33	1.69	16.79	1.84	0.65	48.54
	Minimum	0.85	0.84	4.07	1.03	0.26	2.19	16.35	1.88	0.88	69.02
	Maximum	0.54	0.52	5.64	0.94	0.31	1.41	23.54	2.54	0.50	42.34
Auto shop	Mean	3.65	0.61	4.99	2.11	0.66	2.46	16.52	1.48	0.41	33.64
	Minimum	2.44	0.61	2.65	0.79	0.44	2.42	11.65	0.99	0.60	44.89
	Maximum	3.65	0.65	5.27	2.37	0.54	2.37	12.77	0.80	0.19	15.06
Playground	Mean	0.59	0.72	1.48	1.11	0.49	2.37	18.88	1.96	0.82	56.95
	Minimum	1.29	1.48	2.87	1.59	0.81	2.32	18.35	2.11	1.56	50.52
	Maximum	0.44	0.54	1.13	1.50	0.55	2.32	25.80	2.65	0.55	119.96
Lory Park	Mean	0.50	0.69	5.49	0.82	0.61	1.67	17.02	1.66	0.68	45.72
	Minimum	0.64	0.96	2.87	0.90	0.38	1.35	14.20	1.18	1.07	50.52
	Maximum	0.51	0.67	7.37	0.97	0.85	1.73	20.36	1.92	0.55	79.32
Residential area	Mean	0.37	0.51	4.29	0.73	0.28	1.24	13.27	1.27	0.42	31.75
	Minimum	0.64	0.83	1.99	0.91	0.25	0.69	12.34	1.50	1.09	99.06
	Maximum	0.39	0.45	6.33	0.83	0.29	1.35	12.08	0.82	0.82	18.30
	Average	1.20	0.75	4.46	1.24	0.52	1.79	15.12	1.47	0.78	55.71

Based on Gyam et al., (2020) and Kadhum, (2020), enrichment factor values lower than 1.5 imply that harmful elements come from natural sources, whereas enrichment factor values higher than 1.5 imply that poisonous elements come from anthropogenic sources. The enrichment factor can be a useful technique for separating anthropogenic from natural sources of potentially hazardous elements in the dust (Balali-Mood et al., 2021; Kabir & Rashid, 2022). The dust samples' average enrichment factor values for lead, arsenic, copper, manganese, chromium, titanium, and nickel were all under two (2), indicating that they came from natural sources (Table 4.8). When compared to other elements, zinc, vanadium, and cadmium had average enrichment factors that were higher than two (2), indicating that these metals come from anthropogenic sources. The zinc and vanadium enrichment values found in this study are lower than those found in road dust in Mymensingh City, Bangladesh (Zn = 7.27, Cu = 4.5) (Kabir & Rashid, 2022). A different study, (Kadhum, 2020), discovered that the cities of Baghdad, Najaf, Smawah, Amarah, and Basra, respectively, had enrichment factor values for Cadmium of 14, 5, 10.9, 6.8, and 12.7.

4.5 Potential Ecological Risk (PER) and Potential Ecological Risk Index (PERI)

The potential ecological risk and the potential ecological risk index of Pb, As, Zn, Cu, Mn, Cr, V, Ni, and Cd values calculated from all the different land use areas in Sekyere South are shown in Table 4.9. The values of Pb, As, Zn, Cu, Mn, Cr, and Ni in the school, roadside, market, auto mechanic shop, playground, lorry park, and residential areas range from 0.04 to 28.09 representing a low potential risk to the areas. The potential ecological risk posed by vanadium in all the land use areas indicates low risk (PER < 40) except the maximum risk value obtained from the residential areas ($Er = 42.22$) which showed moderate risk. The mean ecological risk values of cadmium obtained from schools, roadside, markets, auto mechanic shops, playgrounds, lorry parks, and residential areas were 593.93, 535.39, 524.67, 581.25, 526.67, 528.56, and 583.92 respectively representing a very high potential ecological risk (PERI ≥ 320). The findings are consistent with those published by Kabir et al in comparable investigations in 2022, who showed a high ecological risk of cadmium. Therefore, Cadmium poses a very significant ecological danger to the local ecology, prompting the implementation of protective measures in sensitive areas (Kabir et al., 2022). The other harmful metals under investigation displayed a "low potential ecological risk" threshold ($Er < 40$) in the Sekyere South dust from various land use areas. The outcome shows that these potentially harmful elements may not be affecting the ecosystem at all. The average ecological risk values were in the following order: Cd > V > Pb > Cu > As > Zn > Cr > Ni > Mn.

According to Table 4.9, the potential ecological risk index (PERI) ranged from 382.37 to 1036.30, with a value of 597.53 as the average. The market areas had the lowest mean PERI (545.80), which indicated high risk ($300 \leq PERI \leq 600$), while the auto mechanic shop had the highest mean PERI (627.88), which indicated a very high risk ($PERI > 600$). The results of the PERI from Sekyere South show that dust samples may be contaminated with potentially harmful elements, which could endanger the ecosystem. As a result, the authorities must take the necessary action to reduce the contamination of the environment with potentially toxic elements. Cadmium is the major environmental risk contributor, contributing 94.69% to the PERI on average, out of all the potentially harmful elements, making it the riskiest element overall. Vanadium contributes 2.45% to the PERI on average, making it the second-highest contributor, and the remaining elements all contribute an average of 2.86%.

Table 4.9. Potential Ecological Risk (PER) and Potential Ecological Risk Index (PERI)

Land Use Areas		Pb	As	Zn	Cu	Mn	Cr	V	Ni	Cd	PERI
school	Mean	1.28	2.74	2.28	2.17	0.18	0.99	8.28	1.66	593.93	613.51
	Minimum	0.50	1.46	1.05	0.69	0.04	0.54	1.42	1.05	436.00	442.75
	Maximum	4.40	6.29	5.85	11.78	1.01	1.62	15.82	3.98	759.00	809.76
Roadside	Mean	2.67	2.40	0.96	1.96	0.13	1.39	9.84	1.47	535.39	556.21
	Minimum	0.50	1.32	0.19	0.69	0.04	0.62	3.53	1.01	403.00	410.91
	Maximum	22.21	5.63	2.81	7.03	0.26	2.94	20.73	2.09	709.00	772.69
market	Mean	1.04	2.31	1.59	1.34	0.12	1.22	12.10	1.41	524.67	545.80
	Minimum	0.82	1.62	0.79	0.99	0.05	0.85	6.32	1.02	400.00	412.45
	Maximum	1.41	2.72	2.97	2.47	0.17	1.48	24.76	1.59	668.00	705.58
Auto mechanic shop	Mean	10.52	3.52	2.87	6.06	0.38	2.83	19.03	1.42	581.25	627.88
	Minimum	3.48	1.73	0.76	1.13	0.13	1.38	6.64	1.02	384.00	400.26
	Maximum	28.09	10.05	8.11	18.23	0.82	7.28	39.30	1.78	695.00	808.66
playground	Mean	0.91	2.21	0.45	1.71	0.15	1.43	11.64	1.52	526.67	546.68
	Minimum	0.78	1.79	0.35	0.96	0.10	0.60	4.44	1.13	435.00	445.14
	Maximum	1.08	2.63	0.56	3.70	0.27	2.28	25.36	1.70	674.00	711.57
Lorry Park	Mean	0.88	2.40	1.91	1.43	0.21	1.16	11.87	1.41	528.56	549.84
	Minimum	0.50	1.51	0.71	0.70	0.06	0.42	4.45	1.01	373.00	382.37
	Maximum	1.26	3.29	3.63	2.39	0.42	1.70	20.06	1.64	661.00	695.39
Residential	Mean	1.13	3.11	2.63	2.25	0.17	1.52	16.27	1.53	583.92	612.55
	Minimum	0.50	1.27	0.30	0.69	0.04	0.21	3.77	1.00	454.00	461.78
	Maximum	3.37	7.88	11.03	7.26	0.50	4.70	42.12	2.45	957.00	1036.30
Average		4.16	3.23	2.47	3.60	0.25	1.77	14.65	1.57	565.83	597.53

4.6 Human Health Risk Assessment

The human health risk assessment was conducted evaluating noncarcinogenic and carcinogenic risks of potentially toxic elements.

4.6.1 Noncarcinogenic Health Risk

4.6.1.1 Exposure assessment

For the elements Pb, As, Zn, Cu, Fe, Mn, Cr, V, Ti, Ni, and Cd, the estimated daily intake (EDI) that people are exposed to through ingestion (EDI_{ing}), inhalation (EDI_{inh}), and dermal contact (EDI_{dermal}) were calculated for both children and adults using the mean concentration of the potentially toxic elements in the dust samples of Sekyere South and the results shown in Table 4.10. Children, estimated ingested exposure values vary from 2.12×10^{-1} to 7.17×10^{-5}, whereas adults' estimates range from 2.64×10^{-2} to 7.69×10^{-6}. The range of the estimated daily intake through dermal contact pathway values measured for all the elements in children and adults is 1.0×10^{-4} to 1.26×10^{-7} and 1.05×10^{-4} to 1.92×10^{-8}, respectively. Compared to adults, children are exposed to higher daily doses through ingestion, inhalation, and skin contact pathways.

Table 4.10. Estimated Daily Intake through Ingestion (EDI_{ing}), Inhalation (EDI_{inh}), and Dermal Contact (EDI_{dermal}) values (mg kg^{-1}) for Adults and Children.

elements	Mean	EDIing children	adult	EDIinh children	adult	EDIdermal children	adult
Pb	10.52	1.36E-04	1.46E-05	3.81E-09	2.15E-09	3.82E-07	5.83E-08
As	3.47	4.50E-05	4.82E-06	1.26E-09	7.09E-10	1.26E-07	1.92E-08
Zn	172.47	2.24E-03	2.40E-04	6.25E-08	3.52E-08	6.26E-06	9.56E-07
Cu	21.75	2.82E-04	3.02E-05	7.88E-09	4.44E-09	7.89E-07	2.34E-08
Fe	19026.47	2.47E-01	2.64E-02	6.89E-06	3.89E-06	6.91E-04	1.05E-04
Mn	163.48	2.12E-03	2.27E-04	5.92E-08	3.34E-08	5.93E-06	9.06E-07
Cr	67.81	8.79E-04	9.42E-05	2.46E-08	1.38E-08	2.46E-06	3.76E-07
V	82.67	1.07E-03	1.15E-04	2.99E-08	1.69E-08	3.00E-06	4.58E-07
Ti	2756.57	3.57E-02	3.83E-03	9.98E-07	5.63E-07	1.00E-04	1.53E-05
Ni	16.88	2.19E-04	2.34E-05	6.11E-09	3.45E-09	6.13E-07	9.35E-08
Cd	5.53	7.17E-05	7.69E-06	2.00E-09	1.13E-09	2.01E-07	3.07E-08

According to Table 4.10, the ingestion pathway is the largest contributor to the overall risk to both children and adults, followed by skin contact and inhalation. Iron had the highest daily intake in mg kg^{-1} day^{-1} for children and adults in all routes of exposure (ingestion, inhalation, and cutaneous), but arsenic had the lowest overall daily intake value of all the elements. In their investigation of heavy metals/metalloids in the dust surrounding petrol filling stations from the Kumasi Metropolis, Ghana, Nkansah et al., (2017) arrived at similar conclusions. According to the data, children are exposed to higher potentially harmful dust-bound elements than adults, suggesting that children are more likely to be exposed to these elements. Children are more at risk than adults due to their desire to play in the dirt and their frequent practice of putting their hands in their mouths, as mentioned (Kabir & Rashid, 2022).

4.6.1.2 Hazard Quotient (HQ)

The estimated daily intake through ingestion, inhalation, and dermal contact values of the potentially toxic elements were divided by their corresponding reference dose values (Table 3.5) of the element to determine the hazard quotient. Appendix 2 and Figure 4.14 display the findings of the hazard quotient values. The HQ values for children and adults through ingestion range from 0.15 to 0.007 and 0.012 to 0.00076, respectively; for children and adults through inhalation, they range from 0.03 to 0.000011 and 0.018 to 0.00000012, respectively; and for children and adults through dermal contact, they range from 0.12 to 0.000066 and 0.018 to 0.000002, respectively. The elements' hazard quotient values for ingestion, inhalation, and skin contact were in the following order: ingestion > dermal > inhalation.

All potentially harmful elements examined in the dust samples of Sekyere South have hazard quotient values of less than one (HQ < 1) for both children and adults, indicating no non-carcinogenic adverse health effects. This is demonstrated by the values for the three (3) exposure pathways. When consumed, HQ declines as follows: CR > V > As > Cd > Mn > Pb> Fe > Ni > Zn > Cu; when inhaled, Fe > Mn > Cr > V > As > Cd> Pb > Ni > Zn > Cu; and when applied topically, V > Cr > Cd > Fe > Mn > As > Pb > Ni > Zn > Cu.

4.6.1.3 Hazard Index (HI)

The hazard index values from Sekyere South's dust samples are displayed in Appendix 2 and Figure 4.14 as the total of the hazard quotient values. For the elements Pb, As, Zn, Cu, Fe, Mn, Cr, V, Ni, and Cd, the hazard index values for children were 0.04, 0.15, 0.0076, 0.0071, 0.071, 0.053, 0.33, 0.2, 0.011, and 0.092 respectively, while the values for adults ranged from 0.038 to 0.00076. In comparison to adults, children have greater values for the hazard index. The hazard index values are below one and therefore are not likely to pose non-carcinogenic adverse health effects.

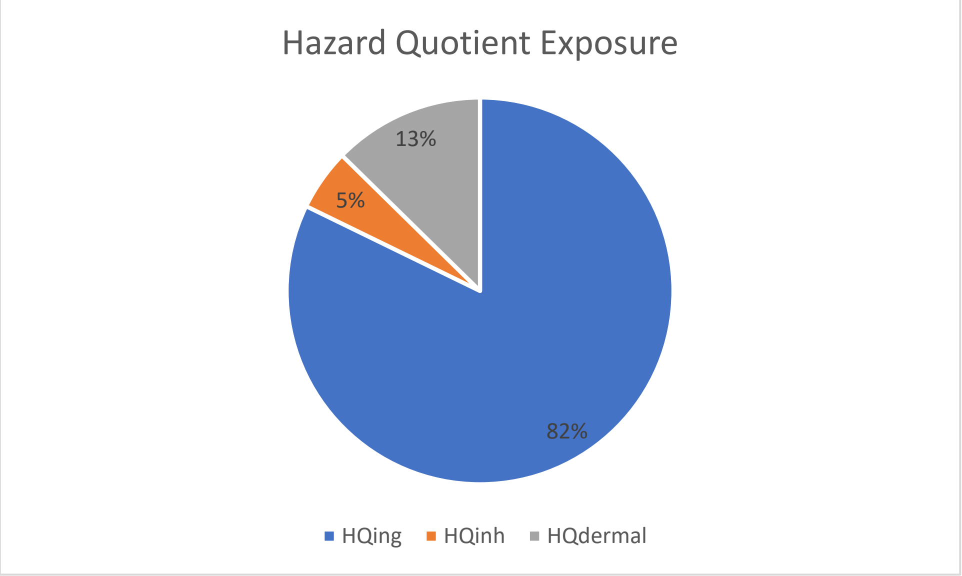

Figure 4.14 Hazard quotient exposure through ingestion, inhalation, and dermal contact

Children were exposed to risk index values in dust samples in Sekyere South ranging from 0.33 to 0.0076, which were greater than the corresponding values for adults for all elements. As Cr > V > As > Cd > Fe > Mn> Pb> Ni> Zn> Cu, the trends in the hazard index (children) diminish. In contrast, the order for adults is Cr > V > Fe > As > Cd > Mn> Pb> Ni > Zn > Cu. The total hazard index of all potentially harmful elements in children (0.96) or in adults (0.13) did not exceed the safe limit value of one (1) for the three exposure pathways. This demonstrates that the body's cumulative exposure to all potentially harmful substances does not increase the risk of non-cancer health effects in both children and adults. This conclusion is consistent with Kabir & Rashid, (2022) in related research on road dust in Mymensingh City.

4.5.2 Cancer Risk

Table 4.11 displays calculated values for the lifetime average daily dosage and incremental lifetime cancer risk for the carcinogenic elements' arsenic, chromium, nickel, lead, and cadmium by ingestion, inhalation, and dermal exposure. For these elements, the incremental lifetime cancer risk varies between arsenic (6.08 x 10^{-9} to 1.92 x 10^{-11}), chromium (3.38 x 10^{-6} to 1.03x10^{-8}), nickel (1.63 x 10^{-8} to 5.16 x 10^{-11}), lead (4.83 x 10^{-10} to 1.53 x10^{-12}) and cadmium (3.99 x 10^{-8} to 1.26 x 10^{-10}). The elements As, Cr, Ni, Pb, and Cd do not present a risk for human cancer in the Sekyere South since the values are below the range of permissible limits (1.0 x 10^{-6} to 1.0 x 10^{-4}). Table 3.5 shows the cancer slope factors for the elements As, Cr, Ni, Pb, and Cd.

Table 4.11. Lifetime average daily Dose (LADD) and incremental lifetime cancer risk (ILCR)

LADD		As	Cr	Ni	Cd	Pd
LADDingestion	Children	2.82E-09	5.46E-08	1.36E-08	4.43E-09	8.46E-09
	Adult	1.21E-09	2.34E-08	5.84E-09	1.90E-09	3.63E-09
LADDinhalation	Children	1.07E-10	2.08E-09	5.17E-10	1.68E-10	3.22E-10
	Adult	2.42E-10	4.68E-09	1.17E-09	3.80E-10	7.25E-10
LADDdermal	Children	7.90E-12	1.53E-10	3.81E-11	1.24E-11	2.37E-11
	Adult	4.82E-12	9.34E-11	2.33E-11	7.58E-12	1.45E-11
CRingestion	Children	4.26E-09	2.29E-06	1.14E-08	2.79E-08	3.38E-10
	Adult	1.83E-09	9.83E-07	4.90E-09	1.20E-08	1.45E-10
CRinhalation	Children	1.62E-10	8.72E-08	4.35E-10	1.06E-09	1.29E-11
	Adult	3.65E-10	1.97E-07	9.80E-10	2.39E-09	2.90E-11
CRdermal	Children	1.19E-11	6.42E-09	3.20E-11	7.82E-11	9.48E-13
	Adult	7.28E-12	3.92E-09	1.96E-11	4.77E-11	5.79E-13
ILCRingestion		6.08E-09	3.28E-06	1.63E-08	3.99E-08	4.83E-10
ILCRinhalation		5.27E-10	2.84E-07	1.42E-09	3.45E-09	4.19E-11
ILCRdermal		1.92E-11	1.03E-08	5.16E-11	1.26E-10	1.53E-12

CR means cancer risk

CHAPTER FIVE

5.0 CONCLUSION AND RECOMMENDATIONS

5.1 Conclusion

This research was conducted in Sekyere South District, Ghana to investigate the presence and concentration of potentially toxic elements in dust from different land use areas. The pollution indices such as contamination factor, pollution load index, modified degree of contamination, geo-accumulation index, enrichment factor, and potential ecological risk were also used to estimate the extent of the potentially toxic elements contamination. This study also sought to determine the relationship between the potentially toxic elements analyzed and to identify possible sources. Finally, the study sought to determine the risk to human health.

Baseline information has been provided by the study regarding the concentration, pollution status, and risk to human health posed by exposure to potentially toxic elements in the dust and soil taken from Sekyere South. The findings of this study showed that all soil and dust samples from the various land use zones contained lead, arsenic, zinc, copper, iron, manganese, chromium, vanadium, titanium, nickel, and cadmium. Among the potentially toxic elements, iron had the highest mean values while arsenic recorded the lowest. The potentially harmful elements were found to be evenly distributed throughout the study areas, with slightly greater concentrations in the vicinity of the auto mechanic shops. In dust samples from Sekyere South, the average concentrations of potentially harmful elements distribution followed the order: Fe > Ti > Zn > Mn > V > Cr > Cu > Ni > Pb > Cd > As. Except for mean values of zinc obtained from the roadside and playground areas, which were below background values, the recorded mean concentrations of cadmium, vanadium, and zinc were above the world average shale values used as background values, indicating that the potentially toxic elements were contaminating the sampling areas from both anthropogenic and natural sources. Furthermore, the mean concentrations of potentially toxic elements were lower when compared to the World Health Organization's recommended maximum permissible concentrations (MPC) in soil, the Dutch guidelines (VROM, 2000), and the Canadian soil quality guidelines (CCME, 2007) for residential areas, except cadmium, which was above both the MPC and VROM guidelines. The mean zinc values reported from schools, auto mechanic shops, and residential areas were higher than the international guideline threshold.

The coefficient of variation values obtained at a 95% confidence level across the seven land use zones revealed no significant difference in the mean concentrations of potentially toxic elements in dust from Sekyere South ($p>0.05$). Most of the elements showed a very strong, strong, and moderately significant positive correlation. This means that the contamination levels in the various land use zones were nearly the same, which might be attributable to both natural and anthropogenic sources such as motor vehicles, metal works, chemical use, and waste incineration. In terms of source identification, the results of the principal component analysis grouped the potentially toxic elements into three groups. Group one, which contained Ti, V, Cr, and Fe, may have come from natural sources. Group two, which includes Mn, Cu, Zn, As, and Pb, could have come from both anthropogenic (traffic emissions) and natural sources. Cd and Ni, which make up Group 3, may be derived by waste incineration, eroding of paints, and chemical application.

Pollution indices were used to evaluate the contamination level of potentially toxic elements in the dust and soil from various land-use regions in Sekyere South. The geo-accumulation index values show that the dust samples from Sekyere South were in the range of unpolluted to moderately polluted by lead, arsenic, zinc, copper, iron, manganese, chromium, titanium, nickel, and vanadium and strongly polluted by cadmium, which was further demonstrated by the contamination factors. The contamination factor and the pollution load index showed that the dust from the vicinity of the auto mechanic shop was highly contaminated with cadmium. The enrichment factor showed that all of the land use regions were moderately enriched by zinc, chromium, and titanium, significantly enriched by vanadium, and severely enriched by cadmium. A moderate degree of dust contamination from Sekyere South was identified by the modified degree of contamination estimate. Except for cadmium, whose values showed very high ecological risk in all land use regions, all the potentially harmful elements' potential ecological risk values showed minimal risk to the ecology across the research areas. Cadmium contributes 94.64% of the danger to the environment, according to the average potential ecological risk index value, which showed a high risk of hazardous elements contamination.

Three different pathways of exposure (ingestion, skin contact, and inhalation) were used to evaluate the risk to human health associated with exposure to potentially harmful elements contamination in dust from Sekyere South. The findings show that children are more susceptible to exposure to toxic elements than adults. Additionally, it was found that all of the potentially toxic elements tested were at safe levels when determined by the hazard quotient and hazard index because they were less than one. The toxic elements in the dust of Sekyere South did not pose a cancer risk. Ingestion > skin contact > inhalation is the sequence of exposure pathways in which children and adults are exposed to potentially harmful elements.

5.2 Recommendations

1. Further investigation Should be carried out by the Sekyere South Assembly to determine the causes of the elevated amounts of cadmium in the district because cadmium is the main polluter in all of the indices.
2. The Sekyere South District Assembly should set up a security task force to enforce the relocation of auto mechanic industries sited close to markets, schools, churches, and residential areas to the new industrial site since this will keep auto shops away from human habitation for good health.
3. Efforts should be made by the Government of Ghana and the Sekyere South District Assembly to tar the streets of Sekyere South to reduce dust exposure since the dust contain toxic elements in their elevated amount.
4. The Health and Environmental Safety division of the Sekyere South Assembly must organize regular education for the inhabitants in the district to stop or reduce the rampant and indiscriminate application of chemicals, burning of solid refuse, as well as avoid open disposal of waste as it increases potential toxic elements concentration.
5. To evaluate the bioaccessibility of the potentially toxic elements in the district, more research must be done by the Sekyere South Assembly as this help device preventive measures to reduce exposure.
6. Further research on seasonal monitoring of potentially toxic elements in dust and soil before, after, and during the dry season is required by the Sekyere South Authorities since this will provide data on the level of exposure at all seasons.

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APPENDIX

Appendix 1. The concentration (mg kg^{-1}) of potentially toxic elements from different land use areas

		Potential Toxic Elements										
Land Use Areas		Pb	As	Zn	Cu	Fe	Mn	Cr	V	Ti	Ni	Cd
School	Mean	5.1	3.6	216.9	19.5	12792.1	149.7	44.4	53.8	2051.9	18.9	5.9
	Median	3.6	2.9	176.6	10.9	12424.8	102.2	43.0	40.3	1862.3	17.3	5.7
	Standard Deviation	3.7	1.8	112.7	22.2	3352.8	179.6	10.8	28.9	836.8	5.9	0.9
	Kurtosis	3.4	1.9	3.2	9.3	0.1	10.1	0.9	-1.3	-0.6	14.9	-0.4
	Skewness	1.8	1.8	1.7	3.0	0.9	3.1	0.8	0.5	0.2	3.6	0.6
	Range	15.6	6.3	456.5	99.8	12041.3	824.5	48.6	93.6	3423.8	33.3	3.2
	Minimum	2.0	1.9	99.5	6.2	8230.0	35.6	24.3	9.2	290.5	11.9	4.4
	Maximum	17.6	8.2	556.0	106.0	20271.3	860.1	72.9	102.8	3714.3	45.2	7.6
	Coefficient of Variation	72.8	49.7	51.9	114.0	26.2	120.0	24.3	53.8	40.8	31.2	14.6
	Confidence Level(95.0%)	1.4	0.7	42.8	8.5	1275.3	68.3	4.1	11.0	318.3	2.2	0.3
Roadside	Mean	10.7	3.1	90.9	17.6	18906.2	113.2	62.7	64.0	1947.6	16.6	5.4
	Median	3.7	2.7	79.1	10.7	14228.7	114.7	51.4	66.9	2039.8	17.0	5.3
	Standard Deviation	20.4	1.4	62.2	15.4	16324.3	55.3	31.1	31.7	763.1	3.5	0.8
	Kurtosis	14.4	3.9	2.9	3.7	11.2	-0.7	0.3	0.1	-0.6	-0.5	-0.1
	Skewness	3.7	1.9	1.7	2.0	3.2	0.3	1.2	0.7	-0.2	0.1	0.4
	Range	86.8	5.6	248.6	57.0	71880.2	190.3	104.1	111.8	2750.9	12.2	3.1
	Minimum	2.0	1.7	18.0	6.2	6365.2	33.3	28.1	22.9	508.5	11.4	4.0
	Maximum	88.8	7.3	266.6	63.3	78245.4	223.5	132.2	134.7	3259.5	23.6	7.1
	Coefficient of Variation	191.4	45.2	68.4	87.3	86.3	48.8	49.5	49.5	39.2	21.1	15.1

	Confidence Level(95.0%)	10.2	0.7	30.9	7.6	8117.9	27.5	15.4	15.8	379.5	1.7	0.4
Market	Mean	4.14	3.01	151.49	12.09	16573.81	101.95	54.74	78.63	2918.84	15.97	5.25
	Median	3.81	3.13	137.12	10.45	16082.43	113.79	57.41	64.30	2500.94	16.64	5.15
	Standard Deviation	0.90	0.50	76.41	5.10	6787.05	37.44	10.13	46.09	1553.45	2.27	1.15
	Kurtosis	0.36	2.38	0.77	5.09	-2.42	-0.47	0.51	1.56	3.51	4.16	-1.83
	Skewness	1.14	-1.37	1.04	2.21	0.10	-0.90	-0.83	1.37	1.79	-1.90	0.20
	Range	2.37	1.44	207.28	13.32	15306.81	97.84	28.73	119.88	4286.55	6.48	2.68
	Minimum	3.28	2.10	74.67	8.95	8886.16	42.45	38.03	41.05	1593.76	11.56	4.00
	Maximum	5.65	3.54	281.95	22.27	24192.97	140.29	66.76	160.93	5880.31	18.04	6.68
	Coefficient of Variation	21.62	16.61	50.44	42.17	40.95	36.73	18.50	58.62	53.22	14.24	21.93
	Confidence Level(95.0%)	0.94	0.52	80.19	5.35	7122.57	39.29	10.63	48.37	1630.25	2.39	1.21
Auto shop	Mean	42.1	4.6	272.9	54.6	26491.2	321.4	127.4	123.7	3746.9	16.1	5.8
	Median	38.4	3.5	242.0	40.8	21855.1	247.5	80.0	120.8	4315.1	16.9	6.0
	Standard Deviation	28.2	2.9	171.4	48.3	15493.3	193.8	95.5	65.2	1536.1	2.9	0.9
	Kurtosis	2.6	7.3	7.5	2.0	6.7	-0.7	1.5	-0.1	-1.3	-1.2	0.0
	Skewness	1.5	2.6	2.4	1.7	2.4	0.7	1.7	0.6	-0.6	-0.4	-0.8
	Range	98.5	10.8	698.3	153.9	57659.2	593.5	265.7	212.2	4183.5	8.6	3.1
	Minimum	13.9	2.3	71.8	10.1	13115.7	107.0	62.1	43.2	1242.8	11.6	3.8
	Maximum	112.4	13.1	770.2	164.0	70774.9	700.5	327.7	255.4	5426.3	20.2	7.0
	Coefficient of Variation	66.9	64.1	62.8	88.6	58.5	60.3	75.0	52.7	41.0	18.0	16.3
	Confidence Level(95.0%)	17.9	1.9	108.9	30.7	9844.0	123.1	60.7	41.5	976.0	1.8	0.6
Playground	Mean	3.6	2.9	43.2	15.4	14179.0	127.9	64.5	75.6	2651.5	17.2	5.3
	Median	3.6	2.8	42.2	10.7	15148.2	111.6	62.4	66.0	2364.1	17.6	5.2

	Standard Deviation	0.4	0.4	8.0	9.5	6422.0	54.7	29.4	46.1	1631.1	2.3	0.8
	Kurtosis	2.4	-1.8	-1.8	2.8	-1.2	2.3	-1.8	4.3	3.2	3.7	1.7
	Skewness	0.9	0.2	0.1	1.8	-0.2	1.5	0.1	1.8	1.6	-1.8	1.1
	Range	1.2	1.1	19.9	24.6	17046.3	145.7	75.9	136.0	4597.6	6.5	2.4
	Minimum	3.1	2.3	33.0	8.7	5560.0	82.8	26.8	28.8	1122.3	12.8	4.4
	Maximum	4.3	3.4	52.9	33.3	22606.3	228.5	102.7	164.8	5719.9	19.3	6.7
	Coefficient of Variation	10.9	15.7	18.5	62.1	45.3	42.8	45.6	60.9	61.5	13.4	15.9
	Confidence Level(95.0%)	0.4	0.5	8.4	10.0	6739.5	57.4	30.9	48.4	1711.7	2.4	0.9
Lory Park	Mean	3.5	3.1	181.9	12.9	16040.7	181.7	52.3	77.2	2542.9	16.0	5.3
	Median	3.8	3.0	163.1	13.4	18332.9	143.6	57.9	70.7	2166.7	16.8	5.6
	Standard Deviation	1.0	0.7	77.9	4.3	5398.2	90.1	20.5	31.6	1207.5	2.4	0.8
	Kurtosis	0.0	-0.2	2.1	1.3	-1.3	0.6	-1.2	-0.4	-1.3	0.6	0.5
	Skewness	-0.5	-0.1	1.1	0.6	-0.3	0.7	-0.4	0.3	0.2	-1.3	-0.4
	Range	3.0	2.3	277.0	15.2	15460.9	304.0	57.5	101.5	3350.9	7.2	2.9
	Minimum	2.0	2.0	67.9	6.3	7210.5	51.2	19.1	28.9	814.5	11.4	3.7
	Maximum	5.0	4.3	344.9	21.5	22671.3	355.2	76.6	130.4	4165.3	18.6	6.6
	Coefficient of Variation	28.0	22.7	42.8	33.5	33.7	49.6	39.2	41.0	47.5	14.9	15.8
	Confidence Level(95.0%)	0.8	0.5	59.9	3.3	4149.4	69.3	15.8	24.3	928.2	1.8	0.6
Residential Area	Mean	4.5	4.0	250.0	20.3	28202.3	148.5	68.5	105.8	3436.4	17.4	5.8
	Median	3.4	3.7	156.5	15.5	25317.7	123.9	57.0	93.5	3162.9	17.0	5.6
	Standard Deviation	3.1	1.8	252.2	12.6	17997.1	90.8	43.8	55.9	1544.2	4.6	1.2
	Kurtosis	2.3	5.1	2.8	5.7	2.1	2.1	3.7	1.9	-0.7	-0.2	7.3
	Skewness	1.8	1.9	1.7	2.1	1.5	1.4	1.7	1.1	0.3	0.5	2.7
	Range	11.5	8.6	1019.2	59.1	73143.0	391.2	202.0	249.3	5267.5	16.5	5.0
	Minimum	2.0	1.7	28.8	6.2	7027.7	32.8	9.6	24.5	1009.6	11.3	4.5

Maximum	13.5	10.2	1048.0	65.4	80170.7	424.0	211.6	273.8	6277.1	27.8	9.6
Coefficient of Variation	68.7	43.8	100.9	62.3	63.8	61.2	64.0	52.9	44.9	26.6	20.0
Confidence Level(95.0%)	1.3	0.7	101.9	5.1	7269.2	36.7	17.7	22.6	623.7	1.9	0.5
Average shale	20	13	95	45	46000	850	90	13	NA	68	0.3

Appendix 2. Hazard Quotient and Hazard Index values

	HQing		HQinh		HQdermal		HI	
Elements	children	adult	children	adult	children	adult	children	adult
Pb	3.9E-02	4.2E-03	1.1E-06	6.1E-07	7.3E-04	1.1E-04	4.0E-02	4.3E-03
As	1.5E-01	1.6E-02	4.2E-06	2.4E-06	1.0E-03	1.6E-04	1.5E-01	1.6E-02
Zn	7.5E-03	8.0E-04	2.1E-07	1.2E-07	1.0E-04	1.6E-05	7.6E-03	8.1E-04
Cu	7.0E-03	7.6E-04	2.0E-07	1.1E-07	6.6E-05	2.0E-06	7.1E-03	7.6E-04
Fe	2.9E-02	3.1E-03	3.1E-02	1.8E-02	9.9E-03	1.5E-03	7.1E-02	2.2E-02
Mn	4.6E-02	4.9E-03	4.1E-03	2.3E-03	3.2E-03	4.9E-04	5.3E-02	7.8E-03
Cr	2.9E-01	3.1E-02	8.6E-04	4.8E-04	4.1E-02	6.3E-03	3.3E-01	3.8E-02
V	1.5E-01	1.6E-02	4.3E-06	2.4E-06	4.3E-02	6.5E-03	2.0E-01	2.3E-02
Ni	1.1E-02	1.2E-03	3.0E-07	1.7E-07	1.1E-04	1.7E-05	1.1E-02	1.2E-03
Cd	7.2E-02	7.7E-03	2.0E-06	1.1E-06	2.0E-02	3.1E-03	9.2E-02	1.1E-02
SUM	8.1E-01	8.7E-02	3.6E-02	2.0E-02	1.2E-01	1.8E-02	9.6E-01	1.3E-01