

**Assessment of Heavy Metals (HMs) and Particulate
Matters (PMs) in Selected Buildings in Eastern
and Western Regions of Saudi Arabia**

BY

Mubarak Mufarreh Alenazi

A Thesis Presented to the

COLLEGE OF GRADUATE AND INTERDISCIPLINARY STUDIES

KING FAHD UNIVERSITY OF PETROLEUM & MINERALS

DHAHRAN, SAUDI ARABIA

In Partial Fulfillment of the
Requirements for the Degree of

MASTER OF SCIENCE

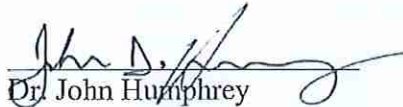
In

ENVIRONMENTAL SCIENCE

MAY 2024

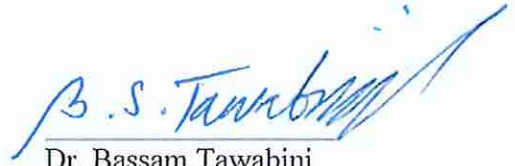
KING FAHD UNIVERSITY OF PETROLEUM & MINERALS
DHAHRAN- 31261, SAUDI ARABIA
DEANSHIP OF GRADUATE STUDIES

This thesis, written by **Mubarak Mufarreah Alenazi** under the direction of his thesis advisor and approved by his thesis committee, has been presented and accepted by the Dean of Graduate Studies in partial fulfillment of the requirements for the degree of **MASTER OF SCIENCE IN ENVIRONMENTAL SCIENCES.**


Dr. John Humphrey
Department Chairman


Dr. Suliman S. Al-Homidan
Dean of Graduate Studies

12/5/2024
Date


Dr. Bassam Tawabini
(Advisor)


Dr. Ashraf Farahat"
(Member)


Dr. Husam Baalousha
(Member)



© Mubarak Alenazi
2024

This thesis is consecrated to my parents, family, and friends for their support during my study journey.

ACKNOWLEDGMENTS

This work is dedicated to those who have supported me throughout my journey, believed in me, and pushed me towards excellence. I want to thank Allah for his countless blessings and all the gifts He has given me. I am grateful to the Deanship of Graduate Studies and the Department of Geosciences at King Fahd University of Petroleum and Minerals (KFUPM) for allowing me to pursue my postgraduate studies.

I genuinely thank my supervisor, Dr. Bassam Tawabini, for his unwavering guidance, support, and patience throughout this research. His immense knowledge and expertise in environmental science have been a great source of inspiration for me. I sincerely appreciate my committee members, Dr. Ashraf Farahat and Dr. Husam Baalousha, for their valuable advice and comments, which helped me improve and complete the work.

I also express my highest gratitude to Dr. Mansour Algamdi and his team for their support and effort in helping me to collect the samples from the Western province. I also thank Dr. Ahsan Mushir for his assistance and guidance during the analysis stage at the Research Institute. I also want to thank my colleagues at KFUPM for their assistance and support in preparing this thesis. Additionally, I thank all the building staff and personnel for providing me with the necessary assistance during my data collection. I am also grateful to Mr. Ahmed Alfifi, who helped me collect samples and procedures practicing in the field. I want to thank my family and friends for their endless support. Last but not least, I want to thank my friends for their unending love and support during this journey. I am eternally grateful for their unwavering belief in me and relentless encouragement.

TABLE OF CONTENTS

ACKNOWLEDGMENTS.....	III
LIST OF TABLES.....	VI
LIST OF FIGURES.....	VII
LIST OF ABBREVIATIONS	IX
ABSTRACT	XI
ملخص الرسالة.....	XIII
CHAPTER 1 INTRODUCTION	1
1.1 Background of the Study.....	1
1.2 Research Problem Statement.....	6
1.3 Significance of the Study	7
1.4 Research Objectives.....	7
CHAPTER 2 LITERATURE REVIEW	8
2.1 Heavy Metals (HMs).....	8
2.2 Particulate Matter (PMs).....	10
2.3 Global Outlook for PM and Dust Contamination by HMs	11
2.4 Assessment of HMs and PMs Pollution in Saudi Arabia.....	13
2.5 Air Quality Guidelines	16
2.6 Potential Health and Environmental Effects of PMs and HMs	17
CHAPTER 3 RESEARCH METHODOLOGY	22
3.1 Study Area Description	22
3.2 Dust Collection.....	25
3.3 Sample Digestion.....	26
3.4 ICP-OES An Analyzing.....	27
3.5 PMs Measurement	28
3.6 HMs Characterizing	29
3.6.1 Enrichment Factor (EF).....	30
3.6.2 Geo-accumulation Index (Igeo)	31
3.6.3 Degree and Factor of Contamination (Cd, Cf).....	32
3.6.4 Pollution Load Index (PLI).....	33
3.6.5 Potential Risk assessment of ecological.....	34
3.7 Risk Assessment of Human Health	35
3.7.1 Daily Average Dose.....	36

3.7.2	Non-carcinogenic Risk	36
3.7.3	Carcinogenic Risk.....	39
3.8	Health Risk Analysis of PMs	41
CHAPTER 4 RESULTS AND DISCUSSION.....		44
4.1	Concentration of HMs in Jubail	44
4.2	Concentration of HMs in Dammam and Khobar	46
4.3	Concentration of HMs in Jeddah	50
4.4	Descriptive Statistics of HM Concentrations	54
4.5	HMs Pollution Characteristics	62
4.5.1	Contamination Factors (C_f) Degree of Contamination (C_d)	62
4.5.2	Pollution Load Index (PLI).....	68
4.5.3	Enrichment Factor (EF).....	69
4.5.4	Geo – Accumulation Index (I_{geo}).....	72
4.5.5	Ecological Risk Assessment (ER)	76
4.6	Risk assessment of human health	82
4.6.1	Average daily dose.....	83
4.6.2	Non-carcinogenic Risk	85
4.6.3	Carcinogenic Risk.....	93
4.7	PM Instantaneous Measuring.....	100
4.7.1	PMs Instantaneous Measuring and AQI for Jubail.....	102
4.7.2	PMs Instantaneous Measuring and AQI for Dammam	104
4.7.3	PMs Instantaneous Measuring and AQI for Khobar	106
4.7.4	PMs Instantaneous Measuring and AQI for Jeddah.....	108
CHAPTER 5 CONCLUSIONS AND RECOMMENDATION.....		110
5.1	Conclusion	110
5.2	Recommendation	111
REFERENCE		112
VITAE		128

LIST OF TABLES

TABLE 1 Saudi Arabia Air Quality Guidelines Levels (Mofarrah et al., 2010)	17
TABLE 2 Enrichment Factor (EF) Classifications	31
TABLE 3 Geo-Accumulation Index (Igeo) Classifications	32
TABLE 4 Contamination Factor (Cf) Classification	33
TABLE 5 Contamination Degree (Cd) Classification	33
TABLE 6 Pollution Load Index (PLI) Classification	34
TABLE 7 Ecological Risk (ER) Classification	35
TABLE 8 Ecological Risk (ERI) Classification	35
TABLE 9 Reference Doses (RfD, mg kg ⁻¹ day ⁻¹) of Different HMs	38
TABLE 10 Values the Slope Factor for Carcinogen	40
TABLE 11 Risk factors were Used for Calculating HQs and LCRs	41
TABLE 12 AQI Concentration/Breakpoint of PM2.5 [203]	43
TABLE 13 Concentration of HMs in Jubail (3 Locations)	45
TABLE 14 Concentration of HMs in DAMMAM and KHOBAR (6 Locations)	48
TABLE 15 Concentration of HMs in Jeddah	52
TABLE 16 Crustal Background and Local Background Value	54
TABLE 17 Jubail HM Statistic Concentrations	57
TABLE 18 Dammam and Khobar HM Statistic Concentrations	58
TABLE 19 Jeddah HM Statistic Concentrations	60
TABLE 20 Jubail Contamination Factors (Cf) Degree of Contamination (Cd) with respect to (a) the World's Crustal and (b) Local Background	64
TABLE 21 Dammam and Khobar Contamination Factors (Cf) Degree of Contamination (Cd) with respect to (a) the World's Crustal and (b) Local Background	65
TABLE 22 Jeddah Contamination Factors (Cf) Degree of Contamination (Cd) with respect to (a) the World's Crustal and (b) Local Background	67
TABLE 23 Jubail Pollution Load Index with respect to (a) the World's Crustal and (b) Local Background	69
TABLE 24 Enrichment Factor Values for all Cities	71
TABLE 25 All Cities Geo-Accumulation Index Concerning (a) the World's Crustal and (b) Local Background	73
TABLE 26 Jubail Ecological Risk Assessment with respect to (a) the World's Crustal and (b) Local Background	78
TABLE 27 Dammam and Khobar Ecological Risk Assessment with respect to (a) the World's Crustal and (b) Local Background	78
TABLE 28 Jeddah Ecological Risk Assessment with respect to (a) the World's Crustal and (b) Local Background	79
TABLE 29 The Average Daily Dose Children for Jubail, Dammam, Khobar, and Jeddah	83
TABLE 30 The Average Daily Dose Adults for Jubail, Dammam, Khobar, and Jeddah	84
TABLE 31 Jubail Dammam and Khobar and Jeddah Hazard Quotient for Children	88
TABLE 32 Jubail Dammam and Khobar and Jeddah Hazard Quotient for Adults	89
TABLE 33 All Cities Carcinogenic Risk for Children and Adults	95
TABLE 34 PMs Instantaneous Measuring and AQI for Jubail	103
TABLE 35 PMs Instantaneous Measuring and AQI for Dammam	105
TABLE 36 PMs Instantaneous Measuring and AQI for Khobar	107
TABLE 37 PMs Instantaneous Measuring and AQI for Jeddah	109

LIST OF FIGURES

Figure 1 Particulate matters (PM) and their potential health impacts (LAWA, 2021)	18
Figure 2 Eastern Province Map	24
Figure 3 Western Province Map	25
Figure 4 Main step of collecting dust from AC filters.	26
Figure 5 Inductively coupled optical emission spectrometer (ICP-OES)	28
Figure 6 Thermo Scientific™ Personal Data RAM pDR-1500	29
Figure 7 Jubail HMs Relative Contribution	46
Figure 8 Jubail HM Average Conc. for Each Area	46
Figure 9 Dammam and Khobar HMs Relative Contribution	49
Figure 10 Average of HM Conc. for Each Area in Dammam and Khobar	49
Figure 11 Jeddah HM Relative Contribution for Each Area	53
Figure 12 Average of HM Conc. for Each Area in Jeddah	53
Figure 13 All cities HM Average Conc.	61
Figure 14 HMs Relative Contribution for All Cities	61
Figure 15 Jubail Cf (a) Global Crustal	64
Figure 16 Jubail Cr (b) local background	65
Figure 17 Dammam and Khobar Cf (a) Global Crustal	66
Figure 18 Dammam and Khobar Cf (b) Local Background	66
Figure 19 Jeddah Cf (a) global crustal	67
Figure 20 Jeddah Cr (b) local background	68
Figure 21 PLI a and b for all Cities (a) the world's crustal and (b) local background	69
Figure 22 Jubail Enrichment Factor	71
Figure 23 Dammam and Khobar Enrichment Factor	72
Figure 24 Jeddah Enrichment Factor	72
Figure 25 Jubail Geo-Accumulation Index (a) world's crustal	74
Figure 26 Jubail Geo-Accumulation Index (b) local background	74
Figure 27 Dammam and Khobar Geo-Accumulation Index (a) Global Crustal	75
Figure 28 Dammam and Khobar Geo-Accumulation Index (b) Local Background	75
Figure 29 Jeddah Geo-Accumulation Index (a) Global Crustal	75
Figure 30 Jeddah Geo-Accumulation Index (b) Local Background	76
Figure 31 Jubail Ecological Risk (a) Global crustal	79
Figure 32 Jubail Ecological Risk (b) Local background	80
Figure 33 Dammam and Khobar Ecological Risk (a) Global crustal	80
Figure 34 Dammam and Khobar Ecological Risk (b) local background	81
Figure 35 Jeddah Ecological Risk (a) Global crustal	81
Figure 36 Jeddah Ecological Risk (b) local background	82
Figure 37 The potential toxicity risk index for all cities	82
Figure 38 Average Daily Dose for Children	84
Figure 39 Average Daily Dose for Adult	85
Figure 40 HI values for individual HMs for Children	90
Figure 41 HI values for individual HMs for Adults	90
Figure 42 HQ and HI Total Values	91
Figure 43 HQ Individual Relative Contribution for Children	91
Figure 44 HQ Individual Relative Contribution for Adults	92
Figure 45 Relative Contribution for Total HQ	92
Figure 46 LCR values for individual HMs for Children	96
Figure 47 LCR values for individual HMs for Adults	96
Figure 48 CR values for children and adults	97
Figure 49 LCR Individual Relative Contribution for Children	97

Figure 50 LCR individual relative contribution for adults	98
Figure 51 Relative Contribution for CR	98
Figure 52 Individual CR /Total CR	99
Figure 53 All Cities Average AQI for PM 2.5 Indoor and Outdoor	101
Figure 54 All Cities Average AQI for PM 10 Indoor and Outdoor	101
Figure 55 AQI of Jubail	103
Figure 56 AQI of Dammam.	105
Figure 57 AQI of Khobar.	107
Figure 58 AQI of Jeddah.	109

LIST OF ABBREVIATIONS

HMs	Heavy Metals
PMs	Particulate Matters
ICP-OES	Inductively Coupled Plasma Optical Emission Spectroscopy
ER	Ecological Risk
EF	Enrichment factor
I _{geo}	Geo-accumulation index
C _d	Degree of contamination
C _f	Factor of contamination
PLI	Pollution load index
ADD	Average Daily Dose
CR	Carcinogenic risk
AQI	Air Quality Index
Ing	Ingestion
Inh,	Inhalation
dermal	dermal
HQ	Hazard Quotient
LCR	lifetime Carcinogenic risk
CR	Carcinogenic risk
SF	Slop Factor
C	Concentration of HMs in dusts
BW	Average body weight
AT	Average time
IngR	Ingestion rate of dust
EF	Exposure frequency
ED	Exposure duration
ABF	Absorption factor (Dermal)
InhR	Inhalation rate of dust (m ³ /day)
PEF	Particular emission factor (m ³ /kg)
SA	Exposed surface area of skin (cm ²)
C _b	Concentration world's crustal or local background
AF	Skin adherence factor (mg/cm ²)
ppm	parts per million
US EPA	United State Environmental Protection Agency
WHO	World Health Organization
GCC	Gulf Cooperation Council

AQG	Air Quality Guidelines
AC	Air conditioner
ERI	potential toxicity risk index
TRF	factor to be the toxic response
R _f D	Reference Doses
CV	coefficient of variance
SD	standard deviation
PME	Presidency of Meteorology and Environment

ABSTRACT

Name: Mubarak Mufarreh Alenazi
Thesis Title : Assessment of Heavy Metals (HMs) and Particulate Matters (PMs) in
Selected Buildings in Eastern and Western Regions of Saudi Arabia
Major Field : ENVIRONMENTAL SCIENCES
Date of Degree : November 2023

Indoor and outdoor air pollution have been associated with environmental challenges, owing mainly to how they have contributed to a high death rate. Several investigations have been conducted regarding air quality in most Saudi Arabian provinces. Most of these studies focus on the exposure, concentration, and distribution of particulate matter and toxic HMs. Dust-borne PMs and HMs are significant health and environmental hazards. In-depth risk evaluations and ongoing monitoring are essential for educating legislators so they can create and implement pertinent legislation guaranteeing environmental air safety. This study will help raise awareness about buildings' air quality and the potential health risks associated with heavy metals (Chromium (Cr), Zinc (Zn), Copper (Cu), Manganese (Mn), Lead (Pb), Cadmium (Cd), Arsenic (As), Cobalt (Co), Nickel (Ni), Vanadium (V), iron (Fe), Aluminum (Al), Barium (Ba), and Molybdenum (Mo)) and particulate matter (PM₁₀ and PM_{2.5}).

The research methodology included laboratory analysis of heavy metals, instantaneous measurement of particulate matter, and statistical analysis.

Unfortunately, minimal local studies have been carried out that evaluated the efficiency of AC filters in removing sizable particulate matter and heavy metals. Therefore, this study focused on indoor air quality and assessed the effectiveness of AC in filtering out particulate matter and heavy metals. The approach to conducting this study was to select several buildings in the eastern and

western parts of Saudi Arabia and extract parts of the AC filters used in these buildings to be tested in the laboratory for their heavy metal constituents. The Inductively Coupled Plasma/Optical Emission Spectrometry (ICP-EOS) instrument was used to analyze heavy metals. In addition, we will also use Thermal Scientific™ Personal Data RAM PDR-1500 to measure the level of particulate matter concentration inside these buildings. The outcome of this study provided valuable information on the levels of particulate matter and heavy metals present in the selected buildings and how they are affected by the AC filters. The metal concentrations (MHs) in building AC FILTERs throughout four Saudi cities found that Dammam and Khobar had higher amounts than Jeddah and Jubail. According to the ecological risk assessment, Cd presented a significant risk, particularly in Jeddah. For both adults and children, the non-carcinogenic hazards of MH exposure by ingestion, inhalation, and skin contact were below acceptable bounds. Children have more significant cancer risks, highlighting their susceptibility.

ملخص الرسالة

الاسم الكامل: مبارك مفرح العنزي

عنوان الرسالة: تقييم المعادن الثقيلة والجسيمات الدقيقة في مباني مختارة في المنطقة الشرقية والغربية من المملكة العربية السعودية

التخصص: علوم البيئة

تاريخ الدرجة العلمية: ماجستير

لقد ارتبط تلوث الهواء الداخلي والخارجي بالتحديات البيئية، لقد ارتبط تلوث الهواء الداخلي والخارجي بالتحديات البيئية، ويرجع ذلك في الأساس إلى كيفية مساهمته في ارتفاع معدل الوفيات. تم إجراء العديد من التحقيقات فيما يتعلق بجودة الهواء في معظم محافظات المملكة العربية السعودية. تركز معظم هذه الدراسات على التعرض، وتركيز، وتوزيع المواد الجسيمية والمواد السامة. تشكل المعادن الثقيلة، الجسيمات الدقيقة التي يحملها الغبار أخطار صحية وبيئية كبيرة. تعد التقييمات المتعمقة للمخاطر والمراقبة المستمرة ضرورية لتثقيف المشرعين حتى يتمكنوا من إنشاء وتنفيذ التشريعات ذات الصلة التي تضمن السلامة الجوية البيئية. ستساعد هذه الدراسة في رفع مستوى الوعي حول جودة هواء المباني والمخاطر الصحية المحتملة المرتبطة بالمعادن الثقيلة (الكروم، الزنك، النحاس، المنغنيز، الرصاص، الكاديوم، والزرنيخ، والكوبالت، والنيكل، والفناديوم، والحديد، والألمنيوم، والباريوم، والمولبيديوم) والجسيمات الدقيقة.

وتضمنت منهجية البحث التحليل المختبري للمعادن الثقيلة، والقياس اللحظي للجسيمات، والتحليل الإحصائي. ولسوء الحظ، تم إجراء الحد الأدنى من الدراسات المحلية التي قامت بتقييم كفاءة مرشحات مكيف الهواء في إزالة الجسيمات الكبيرة والمعادن الثقيلة. ولذلك، ركزت هذه الدراسة على جودة الهواء الداخلي وتقييم فعالية مكيف الهواء في تصفية الجسيمات والمعادن الثقيلة. كان المنهج في إجراء هذه الدراسة هو اختيار عدة مباني في الأجزاء الشرقية والغربية من المملكة العربية السعودية واستخراج أجزاء من مرشحات مكيف الهواء المستخدمة في هذه المباني ليتم اختبارها في المختبر لمكوناتها المعدنية الثقيلة. تم استخدام أداة قياس طيف الانبعاث البلازمي/البصري المقترنة حثيًا لتحليل المعادن الثقيلة. بالإضافة إلى ذلك، سوف نستخدم أيضًا PDR-1500 لقياس مستوى تركيز الجسيمات داخل هذه المباني. قدمت نتائج هذه الدراسة معلومات قيمة عن مستويات الجسيمات والمعادن الثقيلة الموجودة في المباني المختارة وكيفية تأثرها بمرشحات تكييف الهواء. وجدت تركيزات المعادن الثقيلة في مرشحات مكيف الهواء في أربع مدن سعودية أن الدمام والخبر لديهما كميات أعلى من جدة والجبيل. وفقًا لتقييم

المخاطر البيئية، يمثل الكادميوم خطراً كبيراً، وخاصة في جدة. بالنسبة للبالغين والأطفال على حد سواء، كانت المخاطر غير المسرطنة للتعرض لمهدن الهيموغلوبين عن طريق الابتلاع والاستنشاق وملامسة الجلد أقل من الحدود المقبولة. الأطفال لديهم أخطر أكبر للإصابة بالسرطان، مما يسلط الضوء على قابليتهم للإصابة.

CHAPTER 1

INTRODUCTION

1.1 Background of the Study

Indoor and outdoor air pollution have been associated with environmental challenges, owing mainly to how they have contributed to a high death rate (Derwent & Hjellbrekke, 2019) (Landrigan et al., 2018). Air pollution was found to have contributed to about 6.4 million deaths, which corresponds to 11% of global mortality (Cohen et al., 2017). People in large cities are the most vulnerable due to the large population, toxic dust, and proximity to various pollution sources. The sources of air pollution are mainly natural processes such as weathering, erosion, resuspension, and deposition of soil particles, while anthropogenic activities include traffic, industrial, commercial, and residential emissions.

Dust in city air is mainly composed of emissions from vehicles and their worn parts, particles suspended in the pavement and unpaved shoulder, geologic materials, contaminated soil, and airborne particles (Dytlow & Górka-Kostrubiec, 2021). Hence, the dust usually contains complex chemical compositions or heterogeneous mixtures of air pollutants that emanate from both natural processes and anthropogenic activities. These constituents include micro-aerosols, heavy metals (HMs), polycyclic aromatic hydrocarbons (PAHs), etc. The repeated exposure of both humans and animals to air pollutants such as HMs has led to increased health and environmental issues (Hanfi & Yarmoshenko, 2020). PM is regarded as a massive threat to the sustainability of the environment due to the environmental implications and public health of the

constituent HMs that originate from non-exhaust and exhaust emissions (Moryani et al., 2020). Four risk indicators in dust or PM can be investigated to evaluate the extent of concentration of HMs in PMs or dust (Dytlow & Górka-Kostrubiec, 2021). These risk indicators are enrichment factors, potential ecological risks, sensitivity contamination and geo-accumulation factors, and pollution load index.

Below, we explained the effects of PMs as an air contaminant on crop yield, food productivity, and aquatic bodies.

Impact on soil:

1. **Particle Deposition:** PM released into the atmosphere can deposit itself on the soil's surface. As a result, the soil environment is exposed to pollutants and foreign particles (Saxena et al., 2019).
2. **Imbalance of Nutrients:** PM can change the soil's nutrient composition. Certain particles might include HMs or contaminants that, when applied to agricultural land, could reduce the amount of vital nutrients available for plant growth (Yadav et al., 2020).
3. **Soil deterioration:** Over time, persistent PM deposition may lead to soil deterioration, impacting fertility, structure, and general health. Crop growth may be hampered by this deterioration, which would lower agricultural output (Wu et al., 2020).

Impact on crop

1. **Decline in Photosynthesis:** PM, particularly PM_{2.5}, can obstruct sunlight, decreasing the quantity of light accessible for photosynthesis. This may directly impact Crop productivity and growth, resulting in lower yields.

Some PM particles can accumulate toxic substances or HMs that plant roots can absorb. As these substances build up in them, health risks may arise for humans and animals who consume contaminated crops (Manisalidis et al., 2020).

Impact on water bodies

- 1. Runoff Contamination:** During periods of precipitation, PM may be carried by the wind and land on the ground, resulting in runoff. Runoff from this area may introduce PM and related pollutants into adjacent bodies of water (Muller et al., 2020).
- 2. Disruption of Aquatic Ecosystems:** PM deposition in water bodies can disturb aquatic ecosystems. The particles could impact sedimentation, lowering the water's quality and clarity. Changes in light penetration and nutrient availability may also affect the survival of aquatic plants and organisms (Bashir et al., 2020).
- 3. Effect on Fish and Other Living Things:** Fine particles in the water may negatively impact fish and other aquatic life. Fish with clogged gills have a more challenging time breathing. Furthermore, the health and ability of aquatic organisms to reproduce can be directly impacted by the presence of toxic substances in PM (Lin et al., 2019).

The increasing use and widespread presence of HM toxicants in the environment are sparking ecological concerns. Evidence from a variety of sources suggests that these toxicants interact with many different organelles and processes, both well-defined and poorly understood, to harm biological systems. A decrease in longevity, behavioral abnormalities, developmental problems, and reproductive abnormalities are some organismal manifestations of cellular damage caused by HM exposure (Paithankar et al., 2021).

Several essential organs, including the brain, muscles, nerves, liver, kidneys, and heart, are in danger of injury from high concentrations of HMs. These metals can damage and negatively impact these vital organs, which could result in significant health issues (Das et al., 2023).

In general, several health complications result from exposing humans to HM dust (Du et al., 2013). HMs are, therefore, one of the most significant environmental pollutants, and this is due to their high level of toxicity, ability to persist in the environment, and their inability to biodegrade (Men et al., 2018; Faheem et al., 2018). Aside from that, resuspension of dust contributes significantly to the concentration of PM₁₀ and PM_{2.5}. The dust-containing HMs can penetrate the biological systems through ingestion, inhalation, or dermal contact (Moryani et al., 2020; Du et al., 2013; Jancsek-Turóczi et al., 2013).

Heavy metal (HM) and particulate matter (PM) emissions may rise due to Saudi Arabia's rapid industrialization and urbanization in the eastern and western regions. Industrial processes, transportation, and buildings discharge pollutants into the atmosphere.

Several investigations have been conducted regarding air quality in most Saudi Arabian provinces. Most of these studies focus on the exposure, concentration, and distribution of particulate matter and toxic HMs. Consequently, there have been investigations on the health risks in different functional areas of the country. Some of these functional areas include industrial areas, residential areas, parking areas, and traffic areas. The extent of contamination of HMs is mainly determined by dust storms, industrial activities, meteorological conditions, seasonal changes, and traffic density (Alhrabi et al., 2013; Alghamdi et al., 2020). The health risks were assessed with sensitivity

contamination and geo-accumulation factors, enrichment factors, potential ecological risks, and pollution load index. Apart from the fact that most study results comply with Saudi Arabia's quality standards, the HM concentration in the particulate matter was not significant enough to cause serious health problems in terms of carcinogenic or non-carcinogenic among inhabitants in the study areas. Due to their toxicity, bioaccumulation, and persistence, HMs can hurt the ecosystem. The following list illustrates the effects of heavy metals on the environment.

- 1. Water Contamination:** Industrial discharges, agricultural runoff, and atmospheric deposition are ways that HMs can get into water bodies. After entering the water, they may build up in sediments and harm aquatic life. Over time, fish and other aquatic species may acquire these metals, which could cause biomagnification in the food chain.
- 2. Soil Contamination:** Mining operations, industries, and inappropriate waste disposal cause HMs to pollute soils. This pollution may disturb soil ecosystems and adversely affect plant growth. The possibility of some HMs seeping into groundwater can increase the extent of environmental harm.
- 3. Air Contamination:** Several industrial processes and activities can release HMs into the atmosphere. Once they're in the atmosphere, they can travel great distances before returning to the earth and contaminating the land and water. Furthermore, breathing in airborne particles containing HMs might harm one's health.
- 4. Effects on Plants:** HMs can impede plant growth by altering metabolic processes and nutrient absorption. This may result in reduced agricultural production and general plant health. Some plants, referred to as hyperaccumulators, can absorb and accumulate HMs, which may lead to

the metals entering the food chain when animals or people eat them (Briffa et al., 2020; Masindi & Muedi, 2018).

Several studies have focused on the contamination of PMs and HMs in traffic, industrial, and residential areas. This research, however, aims to comprehensively assess the types and concentration levels of HMs and PMs in the selected residential, suburban, and industrial buildings—sectors within the Western and Eastern provinces of Saudi Arabia. Correlating the levels of air contaminants to their potential sources was investigated in this study. Finally, this research also aims to provide relevant recommendations on ways to curtail the health, ecological, and environmental risks associated with these recalcitrant pollutants. Because of the large petrochemical and industrial plants in these east and west provinces, they were also selected as they both lay on the east and west coasts of Saudi Arabia with more exposure to storms.

1.2 Research Problem Statement

Dust, particulate matter (PMs), and heavy metals (HMs) significantly negatively affect public health and the environment. As such, it is critical to continuously monitor contamination levels and thoroughly investigate the risks to human health and the environment. Policymakers should use this information to help them create and execute relevant laws and regulations related to environmental air safety.

1.3 Significance of the Study

This research is significant because it studies indoor dust in selected buildings in the eastern and western parts of Saudi Arabia, which has never been done before. Also, no studies have considered both HMs and PMs together.

1.4 Research Objectives

This research mainly aims to assess the types and concentration levels of PMs and HMs in dust samples collected from selected buildings located within residential, suburban, and industrial areas in the East and West provinces of Saudi Arabia. In specific, the study aims to:

1. To identify the types and levels of HMs in dust samples collected from specific buildings in residential, suburban, and industrial areas.
2. To investigate the correlation between the types and levels of HMs and their potential sources.
3. To measure the concentration levels of PMs (PM₁₀ and PM_{2.5}) in the indoors of selected buildings.

CHAPTER 2

LITERATURE REVIEW

2.1 Heavy Metals (HMs)

Among other environmental problems, environmental pollution is one of the prime concerns, adversely affecting the healthy functioning of life and ecosystems. Environmental pollution refers to a situation where there is an increase in the concentration of substances at exceeding levels, which can cause adverse effects on the environmental media, such as water, air, soil, etc. For instance, dust consists of particle mixtures, including organic and inorganic compounds, HMs, fungi, bacterial and mold spores, pollen grains, etc. (Ali et al., 2019). Moreover, it causes the suspension of environmental indicators and leads to air pollution.

However, the mixture of many gases and particulate matter in the atmosphere eventually causes environmental problems limiting the health of living organisms and even anthropogenic infrastructure, known as air pollution. Under certain weather conditions, environmental dust can persist in the atmosphere longer (Suryawanshi et al., 2016). Moreover, the environmental contaminants include HMs, which persist longer in the atmosphere and are known for non-biodegradability (Jin et al., 2019).

The specific density of HMs is above 5 gm/cm³ (Jarup, 2003). However, the low concentrations of these metals are essential for the basic metabolic functioning of living organisms. At the same time, exceeding levels above a threshold level can cause deadly environmental and health effects.

Therefore, these are considered high-class environmental pollutants with constant toxicity concerns as no fate for HMs cannot be degraded. They are persistent in the environment and affect the ecology, evolution, nutrition, and the whole environment (Jaishankar et al., 2014). Among different HMs, mercury, lead, cadmium, arsenic, nickel, etc., are responsible for adverse environmental problems (Ali et al., 2019).

Generally, HMs' HM entry routes are stations, mobile natural processes, and anthropogenic sources. These activities comprise soil erosion, geological weathering, smelting and mining, combustion of fossil fuels, industrial and sewage effluents, herbicides, pesticides, etc. (Jaishankar et al., 2014). Additionally, humans can be exposed to HMs via the environment, occupations, and accidents. Therefore, strict monitoring of their introduction and intervention is necessary to minimize and prevent significant exposure.

HM concentration was identified earlier through diverse methods such as principal component analysis and cluster analysis (Jin et al., 2019). One of the suitable tools is principal component analysis, which determines the concentration variations and potential sources from different environmental media. Moreover, cluster analysis is used to investigate the location of the group of samples and ultimately provide enough information about the possible sources of exposure.

In literature, many studies have shown that HMs can have harmful effects because they are small, long-lasting, and adversely affect the environment. This behavior can be recognized in their broader applications, including industrial, agricultural, and consumer products, for instance, nanomaterials, fertilizers, paints, wires, etc. (O'Connor et al., 2018; Zhang et al., 2018). However,

they can accumulate and biomagnify easily in the food chains and webs, ultimately disrupting the ecological system and adversely affecting biodiversity. The air contaminated with HMs can decrease visibility, enhance cloud formation, and eventually transfer heat into the atmosphere, ultimately influencing climate change (Z & Ditri, 2017).

The public health effects of HMs hamper the ecological niche of humans and other living organisms. For instance, arsenic, lead, mercury, and cadmium are highly toxic and carcinogenic with profound health implications (Tao et al., 2014). Human exposure to HMs can lower energy, damage functional organs, and malfunction muscular and neurological systems (Tang et al., 2008). HMs can enter body systems through inhalation, ingestion, and dermal contact. Public health effects of HMs are well pronounced in sensitive populations such as children, pregnant women, women of childbearing age, nursing mothers, etc. (Tan et al., 2016).

2.2 Particulate Matter (PMs)

Particulate matter (PMs) is categorized among the most dangerous air pollutants among all others. The respiratory and cardiovascular systems are the primary targets of its effects, which vary from heart attacks and lung cancer to an escalation in asthma attacks and coughing fits. PM is typically divided into two major categories based on size for regulatory purposes because its composition varies depending on the sources and weather conditions. PM can be categorized into the following classes (Wu et al., 2018; Soberón, 2017)

Coarse Particles: Particles with diameters less than 10 μm and more significant than 2.5 μm can be categorized as PM₁₀.

Fine Particles: Particles with diameters less than 2.5 μm can be categorized as PM_{2.5}.

Ultra-fine Particles: Particles have diameters less than 1.0 μm and can be categorized as PM_{1.0}.

2.3 Global Outlook for PM and Dust Contamination by HMs

Due to its iniquity and environmental implications, HM pollution is one of the leading environmental pollutants. Hence, many countries worldwide have conducted investigations to identify the sources, vulnerable populations, and associated environmental and health hazards, as well as monitoring and prevention strategies.

In 2014, approximately 16.1% of China's soil exceeded the environmental quality standard, and the concentration of the HMs in these soils posed serious threats (The State Council China, 2014). As a result of these findings, the Chinese government published compendium guidelines titled "Soil Pollution Prevention and Control Action Plans" (Hou & Li, 2017). Also, it was discovered that many researchers often need to consider urban recreational centers such as children's playgrounds. Another result revealed that the geological properties of soil cause an elevated concentration of beryllium, vanadium, chromium, manganese, cobalt, nickel, and argon. However, copper and lead were being released from traffic activities in the playground vicinity (Jin et al., 2019).

(Wong & Mak, 1997). show how Cd, Cu, Pb, and Zn concentrations were determined in the soil and dust at seven different fields in Hong Kong. Results of the study reported that the high

concentration of HMs in the collected samples was attributed to commercial and industrial activities. In another study, high zinc, copper, and chromium concentrations were found in ground dust samples in 89 playfields (Yang et al., 2016) in China. The iron was found at elevated levels in the dust of ten kindergartens in Malaysia (Latif et al., 2011). Furthermore, the concentration of other studies' HMs followed the order of lead > zinc > chromium > cadmium (Latif et al., 2014).

Another research work investigated the level of HMs associated with road dust in India to identify the sources and the index of ecological risks (Suryawanshi et al., 2016). The results indicated that the dust samples were significantly contaminated with zinc and lead. Also, potential ecological indices indicated that cadmium was highly contaminated in the road dust, while chromium, copper, nickel, and zinc were moderately contaminated. Summarily, the HMs were highly concentrated in the dust samples collected from industrial environs, while the HMs were moderately concentrated in residential areas.

Moryani and his team also assessed the level of HM concentration in PM_{2.5} of road dust and their respective inhalation and potential health risks at different functional locations in Karachi, Pakistan (Moryani et al., 2020). The mean concentration of HMs from a study was as follows: 0.333 mg/g Copper, 0.427 mg/g Lead, 4.254 mg/g Zinc, 0.062 mg/g Cadmium, 0.390 mg/g Nickel, 0.070 mg/g Antimony, 0.148 mg/g Chromium, whereas the mean concentration values of HMs in Shikarpur were 0.246 mg/g Copper, 0.538 mg/g Lead, 8.351 mg/g Zinc, 0.0578 mg/g Cadmium, 0.132 mg/g Nickel, 0.315 mg/g Antimony, 0.347 mg/g Chromium. The enrichment factor and geo-accumulation index results revealed that the study areas fall within moderate to extreme pollution levels.

The assessment of HMs contamination was done to investigate the sources and concentration of HMs contaminants in street dust. The results showed the mean concentration of HMs present in the dust samples as follows: Zinc > Copper (or Cadmium) > Lead > Nickel > Chromium (Isinkaralar et al., 2023). In another study, the street dust in Lublin, Poland, did not show significant pollution from chromium, nickel, and lead. In contrast, geo-accumulation and enrichment factors indicated moderate levels for copper, cadmium, and zinc. The CA and PCA categorized the sources of the street dust contaminated with HMs into three origins or sources: anthropogenic, natural, and mixed origin (Zgłobicki et al., 2018).

An assessment was done in the Gulf Cooperation Council (GCC) countries for indoor air quality (Patrick et al., 2018). Several published papers after 1986 were reviewed. Different publishers have covered different cities in GCC. Several studies were included in this assessment; therefore, the outcome is a summary of the indoor air quality. Another outcome is a comparison of HMs between Al-Rusayl in Muscat and other locations in Bahrain. HMs were 1293 ng/m³ Pb, 131 ng/m³ Cu, 17ng/m³ Ni, 23 ng/m³ Cr and 464 ng/m³ Zn in Al-Rusayl and Bahrain for first and second locations 517,360 ppm lead, 202,64.4 ppm Zinc, 1.9, 37 ppm, Cadmium 10, 110.2 ppm Nickel and 11, 144.7 ppm Chromium. (Amoatey et al., 2018).

2.4 Assessment of HMs and PMs Pollution in Saudi Arabia

The exponential increase in population, economic growth, intensive project construction, the Industrial Revolution, and traffic density broadly impact air quality in the Kingdom of Saudi

Arabia. Attaining good air quality or meeting ambient air quality standards requires efficient monitoring and assessment approaches. Environmental dust and eroded soils are among the types of samples used to assess PMs and HMs in the environment. Due to the deposition of HMs in the particulate matter, accurate assessment or quantification can be achieved by assessing PMs.

In the past, the traffic volume in Riyadh was the main reason for the presence of lead in the atmosphere (Shobokshy, 1984; Al-Saleh & Taylor, 1994). Dust storms also greatly influence the optical properties of aerosols (Alhrabi et al., 2013; Mohammadi et al., 2018).

In one research conducted in Jeddah, the HM's pollution and health implications were assessed from the classroom PMs at the primary schools in urban, suburban, and industrial areas. For instance, zinc, manganese, and iron were the dominant HMs in the samples studied. Also, the geo-accumulation factor, the contamination factor, and pollution load index values showed increasing order of the HMs in the particles as expressed Cadmium > Lead > Zinc > Arsenic > Copper > Nickel > Manganese > Chromium > Cobalt > Vanadium > iron. However, the enrichment factor value revealed that Zinc, Cadmium, Lead, Arsenic, and Copper are highly enriched. (Alghamdi et al., 2019).

The pollution level and associated human health risks of road dust in six different functional areas such as traffic areas, parking areas, residential areas, mixed residential commercial areas, and suburban areas in Jeddah and rural areas in Hada Al-Sham showed that the geo-accumulation index and pollution load index of HMs in road dust followed the following order Cadmium > Arsenic > Lead > Zinc > Copper > Nickel > Chromium > Vanadium > Manganese > Cobalt > Iron. The

contamination factor values showed that arsenic, lead, and zinc were moderate to heavy, while Cd was highly contaminated by urban road dust. Moreover, Cd, As, Pb, and Cu were highly enriched, while Mn, V, Co, Ni, and Cr were moderately enriched according to the enrichment factor values. In conclusion, the concentration of HMs followed these sequences: traffic areas > parking areas > mixed residential, commercial areas > suburban areas > residential areas > rural areas. (Shabbaj et al., 2018)

The research carried out by Alharbi and his team investigated the concentration of metals and ions in PMs, the effects of seasonal changes and dust storms on their proportion, concentration over weekdays or weekends, and the concentration in industrial or residential areas. Their study revealed that PM was almost three times higher than the country's specified air quality standard. The results showed that metals and ions contributed significantly to the exceeding PM limit. Also, the higher concentration of metals was recorded during summer, on weekdays, and in industrial areas, consequently reflecting the concentration of the recorded particulate matter. (Alharbi et al., 2015)

In another study, the concentration of HMs was assessed at King Fahd Road and King Faisal University Campus in the Eastern Province (El-Sergany & El-Sharkawy, 2011). The results showed that the mean concentration of airborne dust in an ambient environment falls below Saudi Arabia's air quality standards. However, the mean concentration of airborne dust in the street exceeded Saudi Arabia's air quality standards. It was also reported that HM concentration in street airborne dust was significantly higher than in the ambient air. Therefore, the conclusion was that anthropogenic sources, especially motor vehicle movement, largely contribute to the HMs

contamination, and the stoppage of adding lead to gasoline is the main reason for the reduction in lead levels in the Eastern Province of Saudi Arabia.

Recently, the concentration of nine HMs in 22 locations in Riyadh was investigated (Alharbi et al., 2020). The contamination of these contaminants and their ecological and health risks were also carefully evaluated. The study concluded that lead, chromium, zinc, cobalt, copper, and nickel showed similar sensitivity contamination factors, potential ecological risks, and a geo-accumulation index, while the enrichment factor was otherwise. The cancer risk evaluation indicated a significant cancer risk to the inhabitants in the experimental locations. However, about 77% of the sampling locations fall in high ecological risk areas, where almost 41% of these locations fall within high contamination areas, as pointed out by the pollution load index.

2.5 Air Quality Guidelines

The World Health Organization's Air Quality Guidelines (AQG) comprise evidence-based recommendations for limiting specific air pollutants. These guidelines are designed to aid countries in maintaining air quality levels that protect public health. Initially published in 1987, the most recent revisions were implemented in 2021. To ensure the ongoing relevance of these Air Quality Guidelines and their ability to support diverse policy approaches for managing air quality worldwide, especially considering the numerous new health studies published in the interim, the WHO consistently updates them (WHO, 2021). Table 1 shows the Saudi Arabia Air Quality Guidelines.

TABLE 1 Saudi Arabia Air Quality Guidelines Levels (Mofarrah et al., 2010)

Pollutant	Standard	Measurement Period
Inhalable PM	340 $\mu\text{g}/\text{m}^3$	24 Hour Average
	80 $\mu\text{g}/\text{mm}^3$	Annual average
PM ₁₀ (US NAAQS)	150 $\mu\text{g}/\text{m}^3$	24 Hour
PM _{2.5} (US NAAQS)	35 $\mu\text{g}/\text{m}^3$	24 Hour
PM _{2.5} (US NAAQS)	15 $\mu\text{g}/\text{mm}^3$	Annual

2.6 Potential Health and Environmental Effects of PMs and HMs

The health impacts of the PM must be addressed based on high concern. PMs can enter and deposit in human airways through three primary mechanisms.

1. Impaction– coarse particles (PM₁₀) primarily deposit in the nasal cavity, pharyngeal and laryngeal passage, trachea, and bronchi.
2. Sedimentation – fine particles (PM_{2.5}) primarily deposit in the respiratory bronchioles and alveoli
3. Diffusion – ultrafine tends to diffuse into respiratory surfaces and eventually deposit there (US-EPA, 2023).
4. Interception – deposition of fibers or elongated particles on the surface of the airway passage.

The transportation and deposition of particulate matter depend on several factors, including breathing rates, particle size, characteristics, and the nature of particles (US-EPA, 2023).

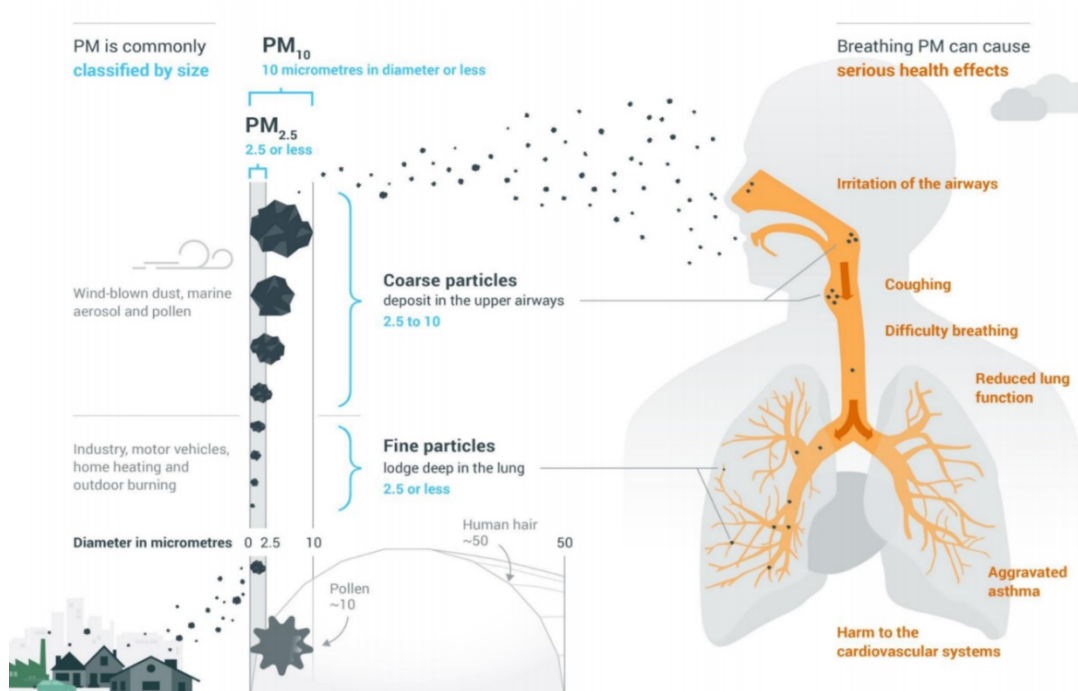


Figure 1 Particulate matters (PM) and their potential health impacts (LAWA, 2021)

PMs are tiny liquid or solid particles that can cause serious health problems if inhaled. PM₁₀ particles can pass through the lungs and even enter the bloodstream. PM_{2.5}, or smaller particles, are considerably more dangerous to your health (Manisalidis et al., 2020).

A study was conducted on the concentration of various indoor pollutants, including PM₁₀ and PM_{2.5} as well as CO₂, in various parts of the house during the COVID-19 period. The study showed that the peak concentrations of PMs were in the kitchen, bedroom, and hall, with concentrations ranging from approximately 40,000 to 81,000µm. CO₂ concentration reached 700µm during sleep hours. The recorded concentration is highly hazardous to human health (Algarni et al., 2021).

Another study investigated the effect of PM_{2.5} with PAHs and microplastics (MPs) on human health. The results showed that MP spread is highly controlled by weather and atmospheric

patterns. PM_{2.5}-bound MPs highly possess the risk of cancer during the winter season (Akhbarizadeh et al., 2021).

Moreover, there was an evaluation of the potential health risks due to exposure to PM₁₉ and PM_{2.5}. The case study focused on the death rate due to unnatural causes such as circulatory, cerebrovascular, respiratory, and lung disease. The results showed that PM_{2.5} and PM₁₀ are highly related to higher mortality rates from the abovementioned diseases. The mortality rates showed approximately a 1.08/10µgm³ increase in PM_{2.5} concentrations and a 1.04/10µgm³ increase in PM₁₀ concentration (Chen & Hoek, 2020). Also, air pollution, especially PM, CO₂, NO_x, and O₃, showed that PM_{2.5} can adversely affect the central nervous system. PM_{2.5} serves as a potent neurotoxicant due to its biological characteristics and can worsen neurological disorders such as autism spectrum disorder, neurodegenerative diseases, etc. (Costa et al., 2020).

PMs, especially dust and fine particles, are released due to both natural and human activities. Sandstorms, volcanic eruptions, soil erosion, and rock weathering are examples of natural occurrences of PMs. Conversely, industrial processes, burning fossil fuels, automobile emissions, smelting, and related activities are the sources of human-induced PM (Masindi & Muedi, 2018). Particles are carried by wind across incredible distances before settling on land or in bodies of water. The effects of this settling are contingent upon the chemical makeup of the particles. This process can cause lakes and streams to become more acidic, changing the nutrient balance in coastal waters and large river basins. It might also cause the soil to deplete nutrients, harming crops and delicate forests. The total effect affects many life forms and reaches into the diversity of ecosystems. Moreover, this particle settling exacerbates the environmental problems caused by

long-range particle transport, adding to the negative impacts of acid rain (EPA, 2016). Undoubtedly, the harmful consequences of air pollution, precisely PM, are beyond the atmosphere and can substantially influence soil and water ecosystems.

The health of humans is at risk from dust-containing HMs since these harmful compounds can enter the body through the skin, food, or breathing. The health of those who reside in the impacted areas may suffer from this exposure over time. Some essential organs, such as the kidneys, are susceptible to acute poisoning from cadmium, which may result in renal failure. The kidneys, neurological system, and reproductive system can all suffer significant harm from lead, which is especially dangerous for children's growing brains. The symptoms of metal fume fever, which includes chills, muscle aches, and coughing, can be brought on by exposure to copper (Jaishankar et al., 2014).

Exposure to nickel can cause skin rashes and dermatitis, among other health problems, and can put the body's vital organs in danger. As crucial as zinc is as a trace element, excessive amounts above a certain point can be hazardous and upset other organs' regular equilibrium (Qadeer et al., 2020).

The literature revealed that a high intake of HMs can be highly harmful to human health because they can damage DNA molecules and produce reactive oxygen species (ROS), which can cause cancer. Specific organs may suffer damage due to HMs entering the human body. In a study, the kidneys of Wister rats exposed to 1 mg/kg of mercury showed apparent alterations, including acute poisoning (Balali-Mood et al., 2021). According to a different study, oral mercury intake in rats caused diarrhea.

Moreover, studies found that guinea pigs exposed to lead concentrations between 0.1 and 0.4M had higher serum endothelium, serum total protein levels, and lung infections. These results emphasize the detrimental impacts that HMs can have on different organ systems and draw attention to the possible health hazards that come with an excess of these metals in the body (Das et al., 2023).

Since HMs damage the entire ecosystem when they enter the food chain, their presence in soils is a significant hazard. Although organic pollutants can biodegradation, the coexistence of HMs impedes this process, creating a dual pollution problem for the ecosystem. The hazards posed by HMs have an impact on people, animals, plants, and ecosystems through a variety of channels, including direct ingestion, plant absorption, contaminating food chains, drinking contaminated water, and changing the pH, porosity, color, and natural chemistry of soil, which in turn affects the general quality of soil (Musilova et al., 2016).

CHAPTER 3

RESEARCH METHODOLOGY

3.1 Study Area Description

Saudi Arabia is one of the largest countries, featuring approximately 35 million people and an area of around 2 million square kilometers (GMI, 2023). An increase in oil production activities has led to high government expenditures on supporting multiple plans. Consequently, there have been increased agricultural activities, significant industrial developments, and population increases in different cities. Jubail, Dammam, and Jeddah cities are among the most populated Saudi Arabian areas, with various physical and climatic features, as shown in Figure 2.

Jubail City is located in the Arabian Gulf, Eastern Saudi Arabia, at 27.39° N and 49.70° E coordinates. It occupies an area of approximately 100-kilometer square and has around 68500 populations (Worldometer, 2022). It is the home of one of the largest global petrochemical organizations and hosts multiple infrastructures, such as about 172000 industrial and workshop firms. There are also multiple fertilizer, gas, oil, and plastic manufacturers. It has excellent and dry winters and long and arid summers. It experiences little rain of about 5 mm and has high temperatures of up to 45 degrees Celsius (WeatherSpark, 2022), as shown in Figure 3.

In addition, Dammam is the largest Eastern Province Saudi Arabian metropolitan area situated at 26.42° N, 50.08° E coordinates. It entails a population of about 1.3 million and an area of

approximately 3-kilometer square (WeatherSpark, 2022). Moreover, together with Dhahran and Khobar cities, they form an industrial complex and larger metropolitan area. It also has year-round cool, windy, dry winters and long, hot, arid, and humid summers. It experiences minimal annual rainfall at 5mm and high temperatures of up to 43 degrees Celsius (WeatherSpark, 2022), as shown in Figure 3.

Furthermore, Jeddah is a major city in the Western region of Saudi Arabia with 29.21°N, 39.7°E coordinates. It is also located on the Red Sea's East coastline and has a vast population of about 4 million, thus containing approximately 14% of the Saudi Arabian population. Its strategic location along the Red Sea coastline makes it the most significant port. It is also boasted as the primary gateway to the Holy City of Mecca (Azam & Ali, 2019). Consequently, it is regarded as an international trading and economic city, and its status as the Holy City of Mecca gateway has boosted and attracted tourism, among other economic activities. The city is a hot desert with temperatures of up to 45 degrees Celsius and experiences minimal annual rains at about 60mm (Alqurashi & Kumar, 2019), as shown in Figure 3.

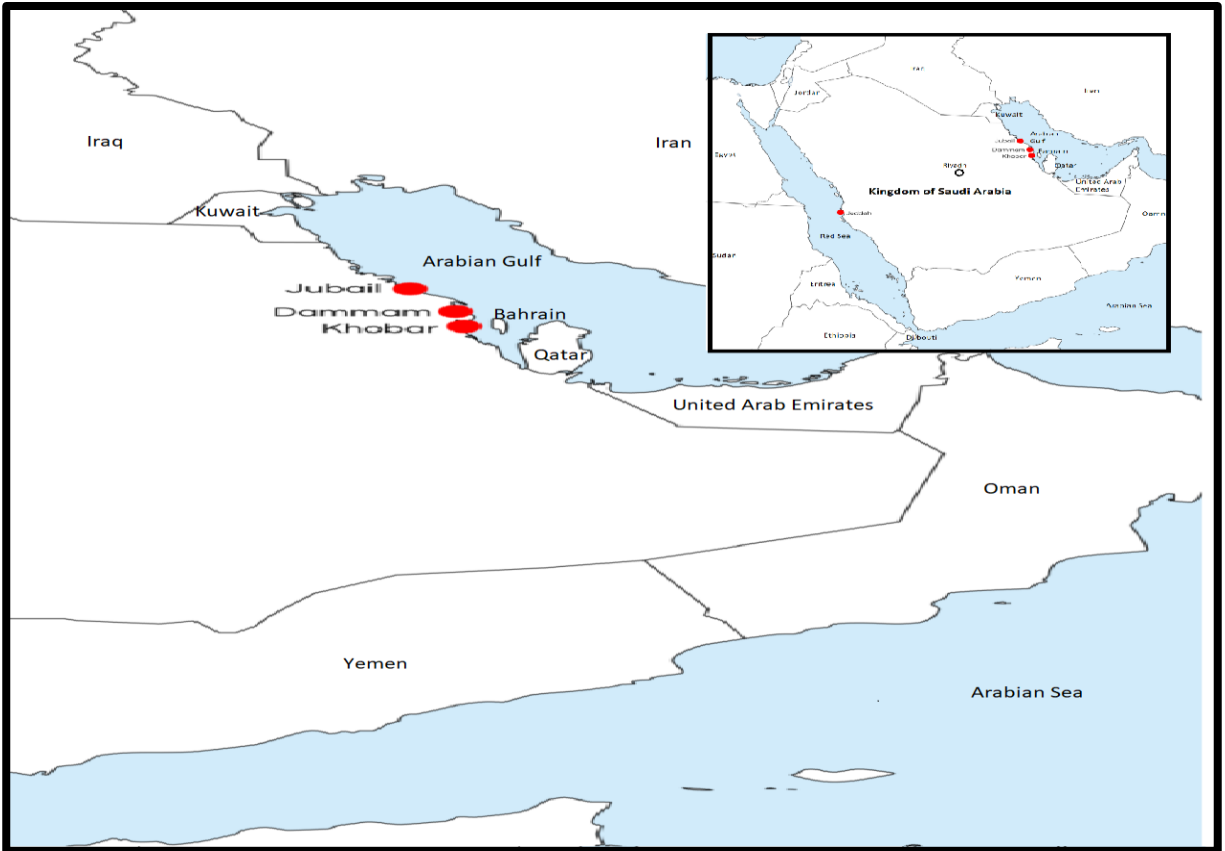


Figure 2 Eastern Province Map

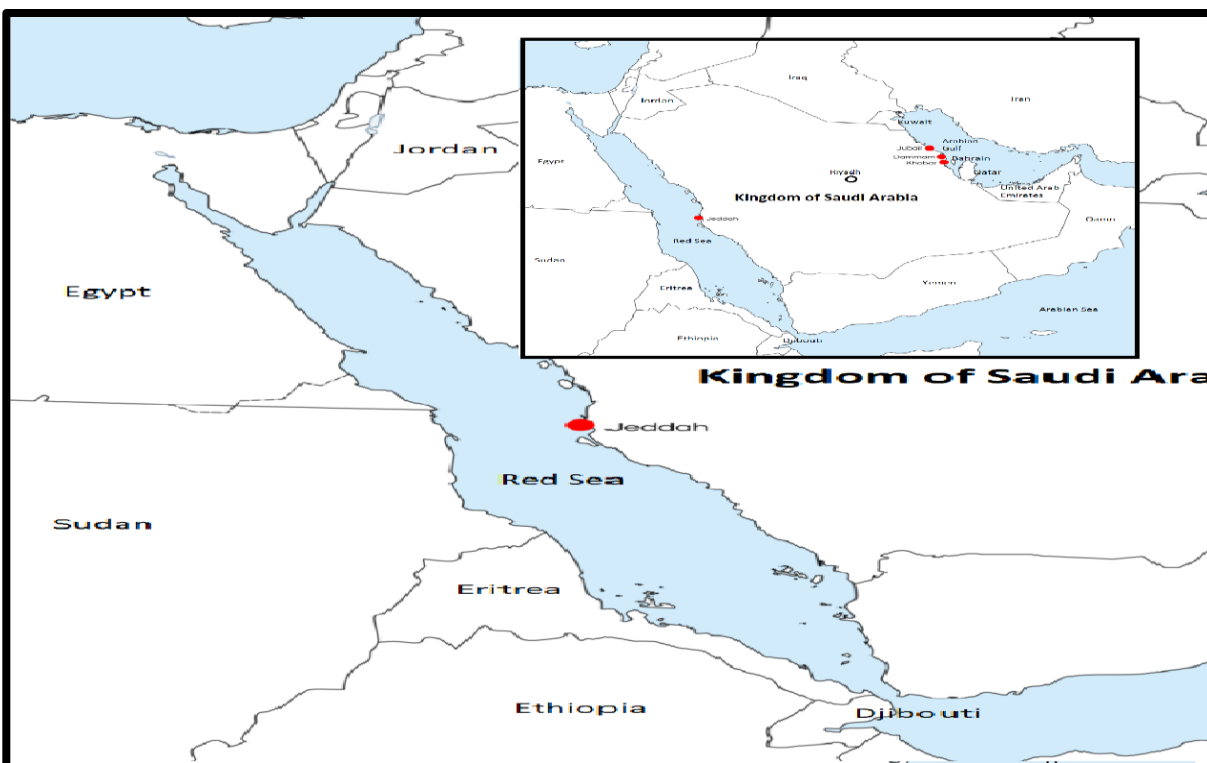


Figure 3 Western Province Map

3.2 Dust Collection

Dust samples were started from Aug 2020 till June 2021 from the indoor environment of the selected buildings with tools, a zipper bag, a paintbrush, plastic gloves, clean white paper, and a marker were used for collecting dust from the AC filter. By following the below steps:

- The air conditioning (AC) filters were removed.
- A small brush was used to sweep the dust from the AC filter into white paper.
- The collected dust was transferred into a zipper plastic bag and closed firmly.
- The procedure was carried out separately for the other two AC filters in the selected building. As a result, the dust samples for three AC units in each building were kept in a different or separate zipper bag.
- The date, time, building address, and sample number were recorded in the sample bag and the working sample sheet.

- This procedure was carried out for three (3) selected buildings in each residential, suburban, and industrial area. Each sample was labeled accordingly before being transferred to the analytical laboratory for further investigation. Quality control and assurance of the dust samples will be carefully monitored.



Figure 4 Main step of collecting dust from AC filters.

3.3 Sample Digestion

A modified method, USEPA 3050 B (US-EPA, 1996), was adopted to digest the sample. Approximately 0.2 mg of the sample (AC filter) was digested in an HCl/HNO₃ ratio 3/1 solution, about 5 ml. This was carried out in a polypropylene digestion tube, which was approximately 50 ml, and temperatures were maintained at 95 degrees Celsius for a few hours. Hydrogen peroxide 3 ml with a concentration of 30% was added portion-wise and heated for thirty minutes. The resulting content was then filtered, and a solution of HNO₃ with a concentration of 1% was added

to it to increase its volume to 50 ml. *Red fuming nitric acid* is a visually striking liquid that can be pale yellow to reddish-brown. It also releases a pungent stench and red-brown fumes. Its tremendous toxicity makes inhalation extremely harmful. It damages tissues and metals when it comes into contact with them. Negative health impacts may arise from short-term exposure to high concentrations or long-term exposure to low quantities.

These symptoms come on instantly and might linger for hours or even days. Around 1 ppm is the very low threshold at which the odor is discernible. Despite being widely employed in many industries, red-fuming nitric acid presents serious risks. It is extremely caustic to materials like metals, mucous membranes, and skin. To reduce health risks, handling red-fuming nitric acid requires careful safety measures (BYJUS, 2023).

3.4 ICP-OES An Analyzing

To analyze HMS, the USEPA method 6010 (US-EPA, 2007) was adopted, and this was conducted on an Inductively Coupled Plasma/Optical Emission Spectrometry ICP-OES (type Perkin Elmer DV 8000 Dual View) as shown in Figure 4. The standards used in calibration were adopted from the CPI mixed standards, which range from a concentration of 10 to 1000 ug/l. A further dilution of the samples was then conducted using nitric acid, which was 1% in concentration, to ensure that the analyte concentration did not exceed the range used in the calibration. To ensure that the quality issue was addressed in a batch of 20 samples, two samples with a concentration of 10% were duplicated, and one sample with a concentration of 5% was spiked and then analyzed. The difference in percentage for the duplicate samples was less than 10%, while recoveries for the spiked samples ranged between 92-106%. For this analysis to be validated, a NIST CRM 2702

was digested, and an analysis was conducted using the samples. For the NIST CRM, the recovery ranged from 88-104%.

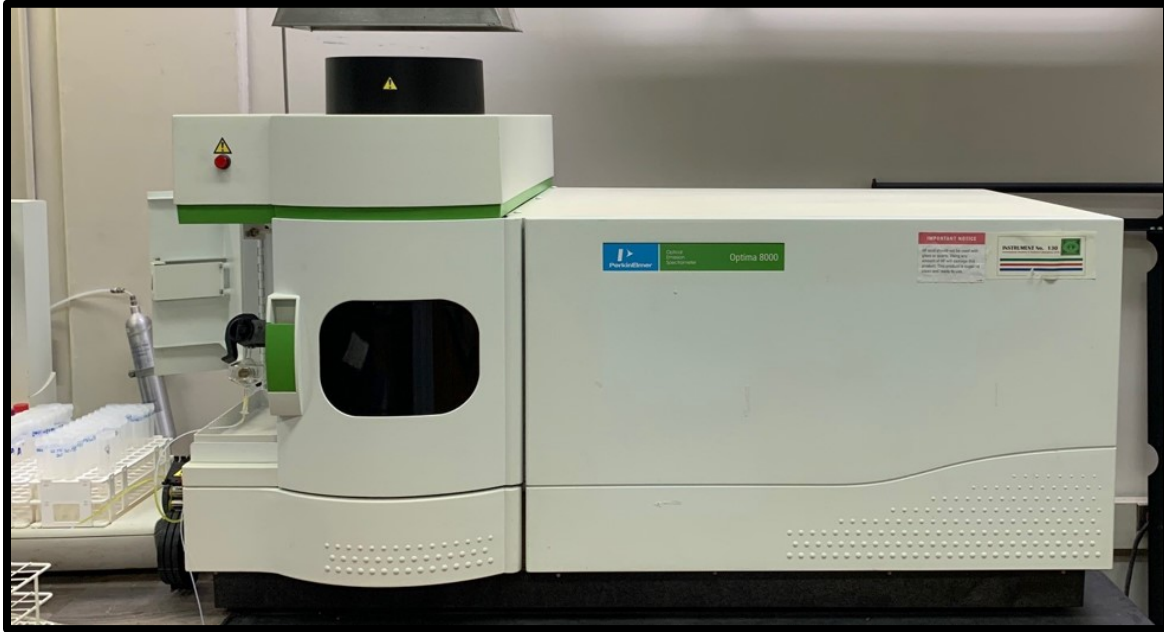


Figure 5 Inductively coupled optical emission spectrometer (ICP-OES)

3.5 PMs Measurement

PM measurements were done in selected city buildings using A portable PM device. **Thermo Scientific™ Personal Data RAM pDR-1500** (Figure 5) measured PM₁₀ and PM_{2.5}.

The concentration levels of PMs were measured directly inside the selected buildings over a 10-minute period and recorded accordingly. RAM pDR—1500 can measure the total PM₁₀ and PM_{2.5} in ug/m³ in blue and red cyclones, respectively.

- Install the proper cyclone (red or blue cyclones).
- Start-up. Press and hold the ON/OFF key for 4 seconds.
- Press run to start the air pump.
- The device will start showing a reading.

- Write down the readings of PM₁₀ and PM_{2.5} in ug/m³ after until stabilized.
- Calibration was performed from time to time to make sure the device was reporting accurate measurements. The calibration was carried out by installing a calibration tube accompanying the device from the inlet to the air outlet.
- Configure the calibration according to the device's mode.
- Press run.
- Calibration will start.



Figure 6 Thermo Scientific™ Personal Data RAM pDR-1500

3.6 HMs Characterizing

Different contamination indices, such as an Enrichment factor (EF), Contamination factor (C_f), Contamination degree (C_d), Geo-accumulation, index (I_{geo}), risk assessment of Potential ecological and index (ER) of Pollution load, were used to figure out how contaminated the HMs related with AC filters of building.

3.6.1 Enrichment Factor (EF)

The factors of enrichment, also known as EFs, measure how much HMs are caused by humans. They are used to differentiate between HMs that come from humans and those that come from nature (Okedeyi et al., 2014; Li et al., 2017). Equation 1 was used to figure out enrichment factors for HMs in Ac filters of building:

$$EF = \frac{(C_n / C_{ref})_{sample}}{(B_n / B_{ref})_{background}} \dots \dots \dots \text{eq. (1)}$$

C_n and B_n are target HM concentrations in sample Ac filters and the background, respectively. C_{ref} & B_{ref} are reference HM concentrations in the sample Ac filters and the background, respectively. Conventional tracer parts such as Ti, Zr, Al, Mn, and Fe are mainly used as reference elements within the method of calculating EFs for HMs to separate human-made sources from natural ones (Neto et al., 2006; Mediolla et al., 2018). Here, Fe was Considered as an element reference for calculating EF because it occurs naturally in large amounts, has a negligible effect from human activities, and is less reactive with other elements (Adimalla et al., 2020; Jiang et al., 2020). The composition of the continental crust (Taylor, 1964) and background values of soil (Shabbaj et al., 2018) are used to determine the number of HMs in the background. Table 2 shows six pollution levels based on how much HMs are enriched (Na et al., 2018).

TABLE 2 Enrichment Factor (EF) Classifications

Classification values	Classification
<1	No enrichment
1–2	Light enrichment
2–5	Moderate enrichment
5–20	Significant enrichment
20–40	Strong enrichment
>40	Extreme enrichment

3.6.2 Geo-accumulation Index (I_{geo})

Comparing calculated HMs in Ac filters towards I_{geo} level in the world's crustal and local background (Lu et al., 2009; Xiao et al., 2021) measures the HMs' pollution in terms of several enrichment classes (Zhang et al., 2017). Table 2 shows the pollution caused by HMs in several calcifications. Equation 2 was used to figure out I_{geo} for building dust:

$$I_{geo} = \log_{2 \times} \left(\frac{C_n}{1.5B_n} \right) \dots\dots\dots \text{eq. (2)}$$

C_n represents the evaluated HMs concentration in Ac filters, and B_n is the geochemical (background) of the earth's crust (world's crustal) and local background values. Background HMs values depend on the crust composition for continental (Taylor, 1964) and the values of the related soil in the area (Shabbaj et al., 2018). To reduce fluctuations like a given individual HM and for anthropogenic impacts, the constant 1.5 was used in equation No.2 (Lu et al., 2009).

TABLE 3 Geo-Accumulation Index (I_{geo}) Classifications

Classification values	Classification
$I_{geo} \leq 0$	Uncontaminated
$0 < I_{geo} \leq 1$	Uncontaminated to moderately contaminated
$1 < I_{geo} \leq 2$	Moderately contaminated
$2 < I_{geo} \leq 3$	Moderately to heavily contaminated
$3 < I_{geo} \leq 4$	Heavily contaminated
$4 < I_{geo} \leq 5$	Heavily to extremely contaminated
$I_{geo} > 5$	Extremely contaminated

3.6.3 Degree and Factor of Contamination (C_d, C_f)

Degree and factor for contamination are utilized to figure out how contaminated HMs are in the dust. The index of C_f was calculated by dividing the element value of the Ac filter sample by the concentration of that element in the background (Rastmanesh et al., 2018) (Eq. 3)

$$C_f = \frac{(C_{n \text{ Sample}})}{(C_{n \text{ Background}})} \dots \dots \dots \text{eq. (3)}$$

C_d was worked out using Eq. 4, which considers the total C_f for HMs in Ac filter samples.

$$C_d = \sum C_f \dots \dots \dots \text{eq. (4)}$$

Tables 4 and 5 show a list of the four types of C_f and C_d. (Zhang et al., 2017; Liu et al., 2019)

TABLE 4 Contamination Factor (Cf) Classification

Classification values	Classification
$C_f < 1$	Low contamination
$C_f = (1-3)$	Moderate contamination
$C_f = (3-6)$	Considerable contamination
$C_f = (>6)$	Very high contamination

TABLE 5 Contamination Degree (Cd) Classification

Classification values	Classification
$C_d < 8$	Low contamination degree
$8 < C_d \leq 16$	Moderate contamination degree
$16 < C_d \leq 32$	Moderate to strong contamination degree
$C_d > 32$	Very strong contamination degree

3.6.4 Pollution Load Index (PLI)

PLI, also known as the pollution load index, is utilized to evaluate the contamination of several HMs. It can present the movement of pollution over time by comparing different regions. It can be calculated using Eq. 5 (Gope et al., 2018; Wahab et al., 2020).

$$PLI = (C_{f1} \times C_{f2} \times \dots \times C_n)^{\left(\frac{1}{n}\right)} \dots \dots \dots \text{eq. (5)}$$

CF represents the factor OF contamination calculated using Eq. 3, and n shows the quantity of HMs dignified in the Ac filters examples. Table 6 has a list of the standards for each PLI category (Tomlinson et al., 1980; Wang et al., 2012; Olujimi et al., 2015; Mohammadi et al., 2018).

TABLE 6 Pollution Load Index (PLI) Classification

Classification values	Classification
$PLI < 1$	No load pollution
$1 \leq PLI < 2$	Slight load pollution
$2 \leq PLI < 3$	Moderate load pollution
$3 \leq PLI$	Heavy load pollution

3.6.5 Potential Risk assessment of ecological

Using the index of potential ecological risk (Hankinson et al., 1980), the risk of potential ecological risk to the environment can be estimated (Yi et al., 2011). This index is often used to measure contamination when a large variety of components are involved (Mazurek et al., 2023; Odediran et al., 2021). Using Eq. 6 (Yuan et al., 2014), you can figure out the factor of possible ecological risk represented as ER for a specific element.

$$ER = \frac{C_n}{C_b} TRF \quad ER = \frac{C_n}{C_b} TRF \quad \dots \dots \dots \text{eq. (6)}$$

$$ERI = \sum ER \quad \dots \dots \dots \text{eq. (7)}$$

Where Represents target elements concentration AC filters samples, C_b is the world's (crustal and local background) value of the specific HMs, TRF factor to be the toxic response for (As, Cd, Co, Cr, Cu, Mn, Ni Pb and Zn 10, 30, 5, 2, 5, 1,5,5 and 1 respectively) (Hankinson et al., 1980; Odediran et al., 2021; Guo et al., 2010)". The summation of ER values of individual HMs gives the potential toxicity risk index (ERI). It is used to evaluate the contamination that all the identified HMs produce in the Ac filter samples (Equation (7). Tables 7 and 8 show the classification of ER and ERI (Mohammadi et al., 2018; Zhang et al., 2017).

TABLE 7 Ecological Risk (ER) Classification

Classification values	Classification
$ER < 40$	Lower potential ER
$40 \leq ER < 80$	Moderate level of potential ER
$80 \leq ER < 160$	Considerable potential ER
$160 \leq ER < 320$	Very high potential ER
$ER \geq 320$	Dangerous

TABLE 8 Ecological Risk (ERI) Classification

Classification values	Classification
$ERI < 150$	Lower potential ER
$150 \leq ERI < 300$	Moderate level of potential ER
$300 \leq ERI < 600$	Considerable potential ER
$ERI \geq 600$	Very high potential ER

3.7 Risk Assessment of Human Health

The evaluation models of health risk (Alghamdi et al., 2019) are utilized to determine if children and adults exposed to HMs from the AC filters of buildings are at risk of getting cancer or not. During the usage in these buildings, individuals are exposed to HMs in 3 primary ways: by putting their hands in their mouths, breathing through their noses and mouths, or touching their skin. Total non-cancerous or cancerous risks to the health of this element are found by adding up the estimated risks from these three ways of being exposed to it. Based on models which are set up by (Alghamdi et al., 2019).

3.7.1 Daily Average Dose

The ADD, which represents the daily average dose, especially for both children and adults, revealed to HMs in AC FILTERS of building through ingestion ADD_{ing}, inhalation ADD_{inh}, and skin ADD_{dermal} as calculated in (Eq. 8, 9 and 10).

$$ADD_{ing} = \frac{(C \times IngR \times EF \times ED)}{(BW \times AT)} \times 10^{-6} \dots\dots\dots \text{eq. (7)}$$

$$ADD_{inh} = \frac{(C \times InhR \times EF \times ED)}{(PEF \times BW \times AT)} \dots\dots\dots \text{eq. (8)}$$

$$ADD_{dermal} = \frac{(C \times SA \times AF \times ABF \times EF \times ED)}{(BW \times AT)} \times 10^{-6} \dots\dots\dots \text{eq. (9)}$$

3.7.2 Non-carcinogenic Risk

Just after figuring out ADD, the hazard quotient (HQ) in (eq. 10–13) and index of hazard were utilized to determine the non-carcinogenic and potential risks of HMs in building AC Filters (Eq. 13).

$$HQ_{ing} = \frac{ADD_{ing}}{RfD} \dots\dots\dots \text{eq. (10)}$$

$$HQ_{inh} = \frac{ADD_{inh}}{RfD} \dots\dots\dots \text{eq. (11)}$$

$$HQ_{dermal} = \frac{ADD_{dermal}}{RfD} \dots\dots\dots \text{eq. (12)}$$

$$HI = HQ_{ing} + HQ_{inh} + HQ_{dermal} \dots\dots\dots \text{eq. (13)}$$

The HQ, HI, and CR methods were used to determine the health risks of being exposed to the elements in the dust of roads. The carcinogenic dangers assist in determining values that show how likely it is that a person will get cancer if they are exposed to a cancer-causing contaminant for

their whole lives. You can use the following equations to determine how likely a person will be exposed to carcinogenic and non-carcinogenic risks (Lopes & Eduardo, 2005). Exposure factors for both children and adults are described in detail, where ADD_{inh}, ADD_{ing}, and ADD_{dermal} represent the daily dose when the drug is taken by mouth, inhaled, or put on the skin, respectively. There is a full explanation of the values of sources of exposure for both children and adults, in which RfD represents the reference dose in milligrams per kilogram per day as shown in Table 9 (US-EPA, 1993), which is an estimate of the highest risk that people can be exposed to everyday, taking into account the most sensitive group (children), throughout a lifetime. The risk factor for a single route is HQ. HI is the hazard index, which measures the non-carcinogenic risk from each route of exposure. It is the total of HQ for each route of exposure.

When HQ and HI are always less than 1, there is not much non-carcinogenic risk, but there is a chance of non-carcinogenic risk whenever HQ and HI are more than 1 (US-EPA, 2011; Zhang et al., 2019).

TABLE 9 Reference Doses (RfD, mg kg⁻¹ day⁻¹) of Different HMs

Element	RfD _{ing}	RfD _{inh}	RfD _{dermal}
Al	1.00E+00	5.02E-01	1.00E+00
As	3.00E-04	3.01E-04	1.23E-04
Ba	7.00E-02	1.43E-04	4.90E-03
Co	2.00E-02	5.71E-06	1.60E-02
Cr	4.00E-02	2.86E-05	5.00E-05
Cu	4.00E-02	4.02E-02	1.20E-02
Mn	4.70E-02	1.43E-05	1.84E-03
Ni	2.00E-02	2.06E-02	5.40E-03
Pb	3.50E-03	3.52E-03	5.25E-04
V	7.00E-03	7.00E-03	7.00E-05
Zn	3.00E-01	3.00E-01	6.00E-02
Fe	8.4	2.20E-04	7.00E-02
Cd	0.001	1.00E-03	1.00E-05
References	(Ali et al., 2017; Shabbaj et al., 2018; Li et al., 2017; Alghamdi et al., 2019)		

3.7.3 Carcinogenic Risk

The LCR_{inh} , LCR_{ing} , and LCR_{dermal} are cancer risks of gradual lifetime from inhalation, ingestion, and skin contact, respectively. Here, C stands for the number of HMs ($mg\ kg^{-1}$) that are in AC Filters in the building. Table 10 shows the SF value, which represents the slope factor for carcinogens for each pathway and element. BW represents the weight of the body (kg). AT represents how long most people live (years). AT represents how long most people live (years). EF is the number of times you are exposed ($days/year$). ED represents the time of exposure (years). $InhR$ represents the total amount of air breathed in m^3/day . $IngR$ represents the amount eaten in mg/day . SA stands for "skin surface exposure." AF stands for the skin adhesion factor. ABF is the factor of skin absorption. PEF represents a factor of particle emission in m^3/kg . Table 11 has all the information about the values of exposure factors for both children and adults. Eq. 14 and 15 (US-EPA, 1989; Mediolla et al., 2018) determine the cancer risk of incremental lifetime represented as LCR and the cancer risk CR .

$$LCR = ADD \times SF \dots\dots\dots eq. (14)$$

$$CR = LCR_{inh} + LCR_{ing} + LCR_{dermal} \dots\dots\dots eq. (15)$$

The values of LCR and CR between 1×10^{-6} & 1×10^{-4} may be considered acceptable. All the values above 1×10^{-4} are probably unacceptable, possibly for very high risk. The values less than 1×10^{-6} show that there is no significant health risk (Wei et al., 2015; Islam et al., 2020).

TABLE 10 Values the Slope Factor for Carcinogen

HMs	SF _{Ing.}	SF _{Inh.}	SF _{Dermal}	References
Cr	0.5	42	20	(Zheng et al., 2015; Kamunda et al., 2016; Liu et al., 2016; Adimalla, 2020)
Ni	1.7	0.84	42.5	(Lu et al., 2014; Xinwei et al., 2014; Adimalla, 2020)
Cd	0.38	0.38	6.1	(Xinwei et al., 2014; Kamunda et al., 2016)
Pb	0.01	0.04	0.01	(Pavilionis et al., 154; Kamunda et al., 2016 Bello et al., 2017; Johnbull et al., 2019)
Co	-	9.8	-	(Xinwei et al., 2014; Zheng et al., 2015; Bello et al., 2017)
As	1.5	1.5	7.5	(Xinwei et al., 2014; Liu et al., 2016; Pavilionis et al., 2017)

TABLE 11 Risk factors were Used for Calculating HQs and LCRs

Factor	Description	Value		References
		Children	Adults	
C	Concentration of HMs in dusts (mg/kg)	-	-	Present study
BW	Average body weight (kg)	15	70	(Hu et al., 2011; Lu et al., 2010; US-EPA, 1989)
AT	Average time (non-carcinogenic effects) (days)	2190	8760	(US-EPA, 2004)
AT	Average time (carcinogenic effects) (days)	25550	25550	(US-EPA, 2004)
IngR	Ingestion rate of dust (mg/day)	200	100	(US-EPA, 2011; Gope et al., 2017)
EF	Exposure frequency (days/year)	38.02	38.02	(Peng et al., 2011; (Zheng et al., 2010; Adelaide Airport, 2022
ED	Exposure duration (years)	6	24	(US-EPA, 2002; US-EPA, 2001a; US-EPA, 2001b)
ABF	Absorption factor (Dermal)	0.001	0.001	(Wei et al., 2015; US-EPA, 2001a; US-EPA, 2001b)
InhR	Inhalation rate of dust (m ³ /day)	7.63	12.8	(Li et al., 2011; US-EPA, 2002)
PEF	Particular emission factor (m ³ /kg)	1.36x10 ⁹	1.36x10 ⁹	(US-EPA, 2001a; US-EPA, 2001b)
SA	Exposed surface area of skin (cm ²)	1600	4350	(Zheng et al., 2010; Adelaide Airport, 2022)
AF	Skin adherence factor (mg/cm ²)	0.2	0.7	(US-EPA, 2011)

3.8 Health Risk Analysis of PMs

The Air Quality Index (AQI) is a metric used to assess air pollution and its potential health effects, focusing on the short-term health implications following exposure to polluted air. The Environmental Protection Agency (EPA) has identified five primary air pollutants, ground-level ozone, particulate matter, carbon monoxide, sulfur dioxide, and nitrogen dioxide, as critical components in calculating the AQI. The air mentioned above pollutants are used to determine the

Air Quality Index, which can be measured in parts per million (ppm) (Kalia & Ansari, 2020). Table 12 describes the Air Quality Index per guidelines provided by the US EPA.

The Air Quality Index of PM_{2.5} and PM₁₀ was calculated using the standard formula by AirNow US EPA (AirNow, 2016), which is given below.

$$AQI = \frac{(AQI_{Hi}) - (AQI_{Lo})}{(Conc_{Hi}) - (Conc_{Lo})} \times ((Conc_i) - (Conc_{Lo})) + (AQI_{Lo})$$

While

Conc_i = Input Concentration for a given pollutant

Conc_{Lo} = The Concentration breakpoint that is less than or equal to Conc_i

Conc_{Hi} = The Concentration breakpoint that is greater than or equal to Conc_i

AQI_{Lo} = The AQI value/breakpoint corresponding to Conc_{Lo}

AQI_{Hi} = The AQI value/breakpoint corresponding to Conc_{Hi}

The US EPA gave AQI Concentration and breakpoints that are given below.

TABLE 12 AQI Concentration/Breakpoint of PM_{2.5} [203]

Air Quality	PM _{2.5}				PM ₁₀			
	Conc _{Lo} (µg/m ³)	Conc _{Hi} (µg/m ³)	AQI _{Lo}	AQI _{Hi}	Conc _{Lo} (µg/m ³)	Conc _{Hi} (µg/m ³)	AQI _{Lo}	AQI _{Hi}
Good	0.0	12.0	0	50	0	54	0	50
Moderate	12.1	35.4	51	100	55	154	51	100
Unhealthy for Sensitive Groups	35.5	55.4	101	150	155	254	101	150
Unhealthy	55.5	150.4	151	200	255	354	151	200
Very Unhealthy	150.5	250.4	201	300	355	424	201	300
Hazardous	250.5	500.4	301	500	425	604	301	500

The results of the calculated AQI were further compared with standards given by WHO.

CHAPTER 4

RESULTS AND DISCUSSION

4.1 Concentration of HMs in Jubail

As shown in Table 13, the concentration of certain HMs in the (AC) filters of buildings in different areas exceeded the world's crustal background value (Taylor, 1964) in Table 16. Specifically for Zn, Cu, Pb, As, and Cd. HMs mean concentrations were significantly higher in residential areas (10.6, 2.3, 2.2, 1.7, and 4.2 times), industrial areas (12.2, 3.6, 4.4, 2.2, and 6.7 times), and suburban areas (9.9, 2.8, 5.7, 2.8, 5.5 times) compared to world's crustal background values respectively. Moreover, comparing HMs mean levels Cu, Zn, Pb, Ni, As, and Cd with local background values in Saudi Arabia, HMs the concentration was found to be much higher in all three areas 6.3, 9.2, 1.8, 1.5, 1.3 and 2.1 times in residential area, and Zn, Cu, Cr, Pb, Ni, As, Co and Cd were 10.6, 9.9, 1.2, 3.7, 2.3, 2.1, 1.0 and 3.3 times in industrial areas. Finally, Zn, Cu, Cr, Pb, Ni, As, Co, and Cd were 8.5, 7.7, 1.2, 4.6, 2.1, 2.1, 1.2, and 2.7 times in suburban areas than the values identified in rural areas in Saudi Arabia (Shabbaj et al., 2018).

Figure 6 presents the relative contribution (percentage, which is the average of specific element over the total average of all HMs) to determine the order of the mean concentrations of the HMs in the AC filter in each area as follows: suburban Fe > Al > Zn > Mn > Ba > Cu > Pb > Cr > Ni > V > Co > As > Cd, industrial Fe > Al > Zn > Mn > Ba > Cu > Pb > Ni > Cr > V > As > Co > Cd and residential Fe > Al > Zn > Mn > Cu > Ba > Cr > Ni > Pb > V > Co > As > Cd. Figure 7 compares

HMs in each area in Jubail except Fe, Al, and Mn, which are considered earth crustal components (Al-Awadhi et al., 2016; Albar et al., 2020). Still, the concentrations of Fe and Al are higher in every sector. The mean average in increasing sequence is 1075 residential, 1351 suburban, and 1581 industrial.

TABLE 13 Concentration of HMs in Jubail (3 Locations)

AREA	As	Cd	Co	Cr	Cu	Mn	Ni	Pb	V	Zn	Fe	Al	Ba
Residential	4.8	0.9	3.3	36.9	131.7	366.9	34.1	26.6	19.6	768.1	7957.0	3453.5	78.5
	2.4	0.7	3.4	34.5	128.2	366.9	33.9	27.3	20.7	794.0	8120.0	3787.5	86.7
	2.2	1.0	3.2	33.5	120.0	370.0	32.4	28.9	19.7	670.2	7831.0	3368.5	77.8
Ave. Residential	3.1	0.8	3.3	35.0	126.6	367.9	33.5	27.6	20.0	744.1	7969.4	3536.5	81.0
Industrial	4.5	1.7	4.1	51.2	185.7	478.0	45.5	60.8	32.5	918.3	11896.0	5014.5	286.7
	4.8	1.5	3.9	51.9	273.6	432.7	55.8	78.3	26.6	1025.1	12966.0	4736.5	446.4
	5.4	0.8	6.4	47.1	140.0	344.5	52.0	27.5	40.8	625.2	11116.0	8102.5	240.6
Ave. Industrial	5.0	1.3	4.9	50.0	199.7	418.4	51.1	55.6	33.3	856.2	11992.7	5951.2	324.6
Suburban	4.2	1.4	4.1	51.2	268.0	465.7	55.3	80.0	28.3	1065.1	13316.0	4932.5	436.1
	4.7	0.9	5.0	42.3	95.3	270.7	38.7	33.8	30.6	648.7	8973.0	6564.5	262.1
	6.0	1.0	8.1	57.3	105.6	378.7	45.5	97.6	38.1	362.2	15006.0	11005.5	175.2
Ave. Suburban	5.0	1.1	5.8	50.3	156.3	371.7	46.5	70.4	32.3	692.0	12431.7	7500.9	291.1

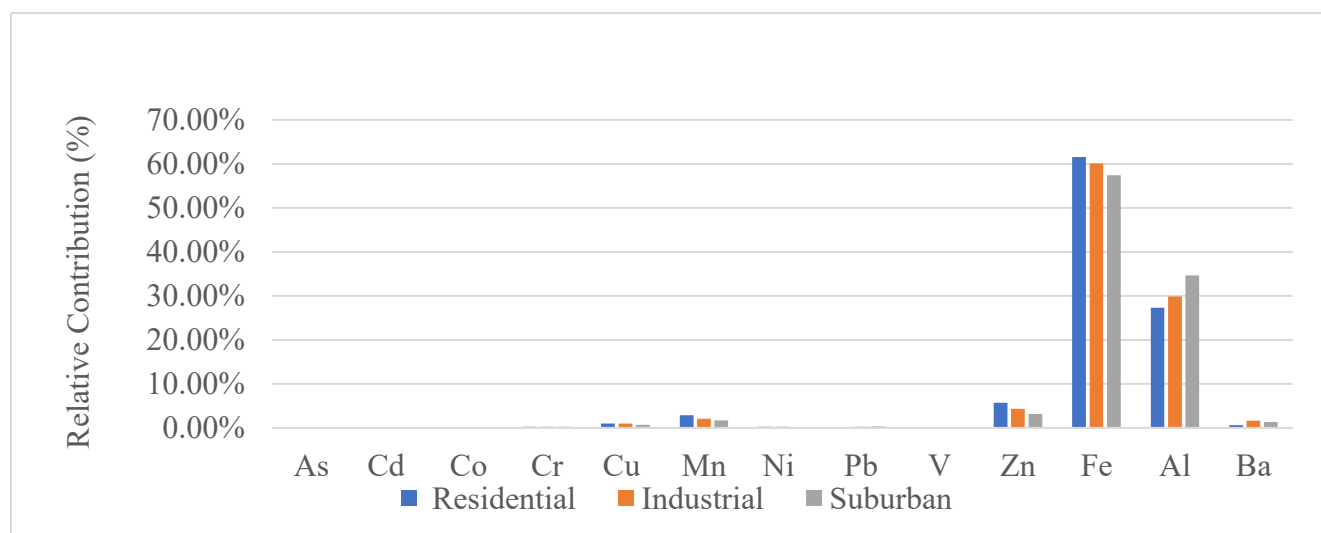


Figure 7 Jubail HMs Relative Contribution

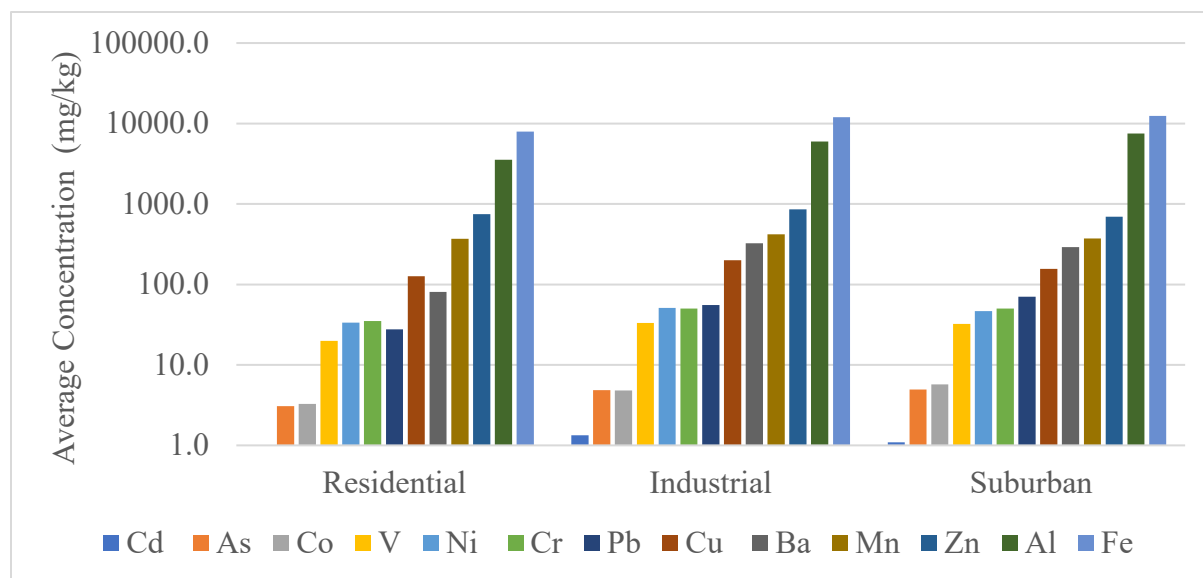


Figure 8 Jubail HM Average Conc. for Each Area

4.2 Concentration of HMs in Dammam and Khobar

As shown in Table 14, the concentration of HMs in the air conditioning (AC) filters of buildings in different areas was found to exceed the world's crustal background value (Taylor, 1964) in Table 16, specifically for Zn, Cu, Pb, As, Ba, and Cd. HMs mean of concentration levels were significantly higher in industrial areas (11.4, 4.5, 5.0, 3.0, 1.17, and 6.0), residential areas Zn, Cu, Pb, As, and Cd (11.3, 3.4, 4.4, 2.4 and 6.4) and suburban areas (3.5, 3.6, 2.2 and 5.8) times compared to world's crustal background values respectively. Moreover, comparing HMs mean levels Cu, Zn Cr, Pb, Ni, As, Co and Cd were 12.2, 9.8, 1.5, 4.1, 2.6, 2.4, 1.6 and 3.0 times in industrial area, Zn, Cu, Cr, Pb, Ni, As, Co, and Cd 9.7, 9.4, 1.1, 3.6, 1.9, 1.9, 1.4 and 3.2 times in residential areas, and Zn, Cu, Cr, Pb, Ni, As, Co, and Cd 11.3, 9.5, 1.1, 3.0, 2.0, 1.7, 1.2 and 2.9 times in suburban areas than the values crustal in rural areas in Saudi Arabia (Shabbaj et al., 2018).

Figure 8 presents the relative contribution (percentage which is the average of specific element over the total average of all HMs) to determine the order of the mean concentrations of the HMs in the AC filter in each area as follows: Fe > Al > Zn > Mn > Cu > Ba > Cr > Ni > Pb > V > Co > As > Cd or residential, Fe > Al > Zn > Mn > Ba > Cu > Pb > Cr > Ni > V > Co > As > Cd for both industrial and suburban as showing in Table 14.

TABLE 14 Concentration of HMs in DAMMAM and KHOBAR (6 Locations)

AREA	As	Cd	Co	Cr	Cu	Mn	Ni	Pb	V	Zn	Fe	Al	Ba
Residential	5.1	1.4	6.0	45.9	223.4	303.1	45.8	56.6	37.6	777.5	11736.0	8110.5	443.2
	3.5	0.9	7.0	49.5	212.5	305.5	53.1	31.6	35.3	648.6	11546.0	8505.5	366.4
	6.7	1.1	8.7	59.8	109.3	401.8	46.1	123.1	38.1	365.0	15806.0	11305.5	174.4
	4.0	1.8	5.6	41.9	147.9	248.5	45.4	45.7	34.3	1062.1	10176.0	7263.5	331.8
	3.1	1.2	7.7	42.8	247.3	230.6	37.0	33.8	30.3	928.1	9560.0	7699.5	375.7
	3.2	1.2	4.0	36.1	193.0	143.3	29.1	39.6	17.2	949.1	6611.0	4063.5	214.8
Ave. Residential	4.3	1.3	6.5	46.0	188.9	272.1	42.8	55.1	32.2	788.4	10905.9	7824.7	317.7
Industrial	7.6	1.0	7.1	49.0	234.9	301.6	52.5	32.7	33.2	467.7	11536.0	8180.5	273.4
	5.4	0.9	7.2	50.2	235.2	311.1	54.2	35.3	39.1	463.3	11586.0	8146.5	298.3
	6.4	1.0	6.6	48.7	247.9	290.8	48.6	30.9	33.0	459.5	11266.0	7553.5	284.8
	5.0	1.0	7.0	48.7	185.3	277.4	55.4	34.1	35.8	500.6	10956.0	8133.5	341.3
	2.4	1.7	8.5	99.0	340.5	252.0	68.4	171.9	18.6	1672.1	17356.0	5137.5	955.5
	5.7	1.6	8.8	70.5	230.7	239.9	64.2	72.4	29.8	1211.1	11736.0	6633.5	817.9
Ave. Industrial	5.4	1.2	7.5	61.0	245.7	278.8	57.2	62.9	31.6	795.7	12406.0	7297.5	495.2
Suburban	4.4	1.4	6.2	45.3	227.5	301.9	42.9	57.1	39.7	754.6	11316.0	7651.5	429.6
	4.8	1.5	6.3	49.5	235.3	315.8	45.6	57.5	43.8	784.5	12156.0	8473.5	501.1
	5.7	1.4	6.2	46.7	222.5	311.0	44.9	55.4	38.8	733.2	11806.0	8178.5	446.7
	3.0	1.1	4.5	39.3	139.3	191.8	39.1	40.3	24.2	1499.1	7719.0	5587.5	280.4
	2.7	0.8	5.6	44.5	157.9	231.9	46.3	30.8	28.5	798.8	8851.0	6877.5	291.6
	3.2	0.8	5.6	43.1	164.9	228.9	46.4	27.9	30.8	907.3	8767.0	6941.5	254.2
Ave. Suburban	4.0	1.2	5.7	44.7	191.2	263.5	44.2	44.8	34.3	912.9	10102.5	7285.0	367.3

Figure 9 compares HMs in each area in Dammam and Khobar except Fe, Al, and Mn, which are considered earth crustal components (Al-Awadhi et al., 2016; Albar et al., 2020). The mean average in increasing sequence is 1483 residential, 1650 suburban, and 1763 Industrial.

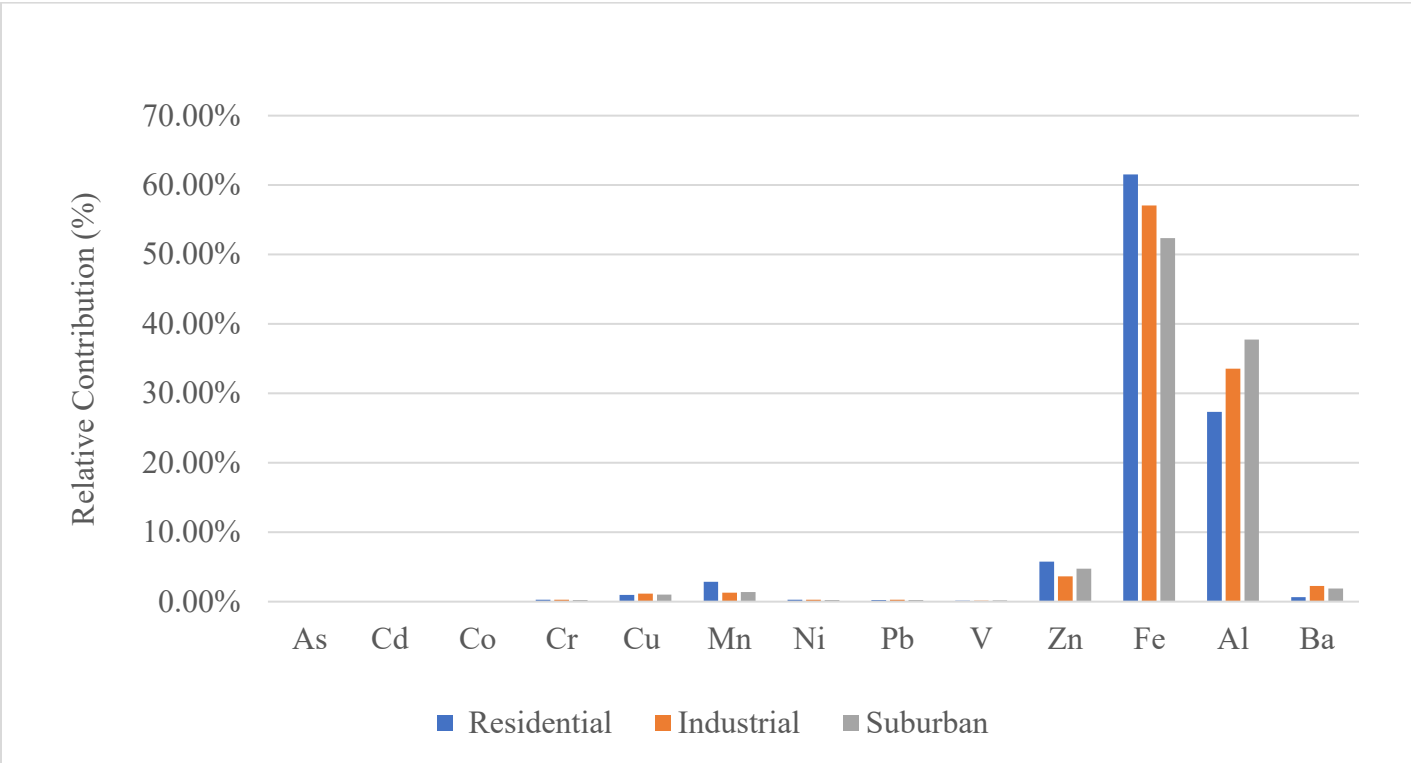


Figure 9 Dammam and Khobar HMs Relative Contribution

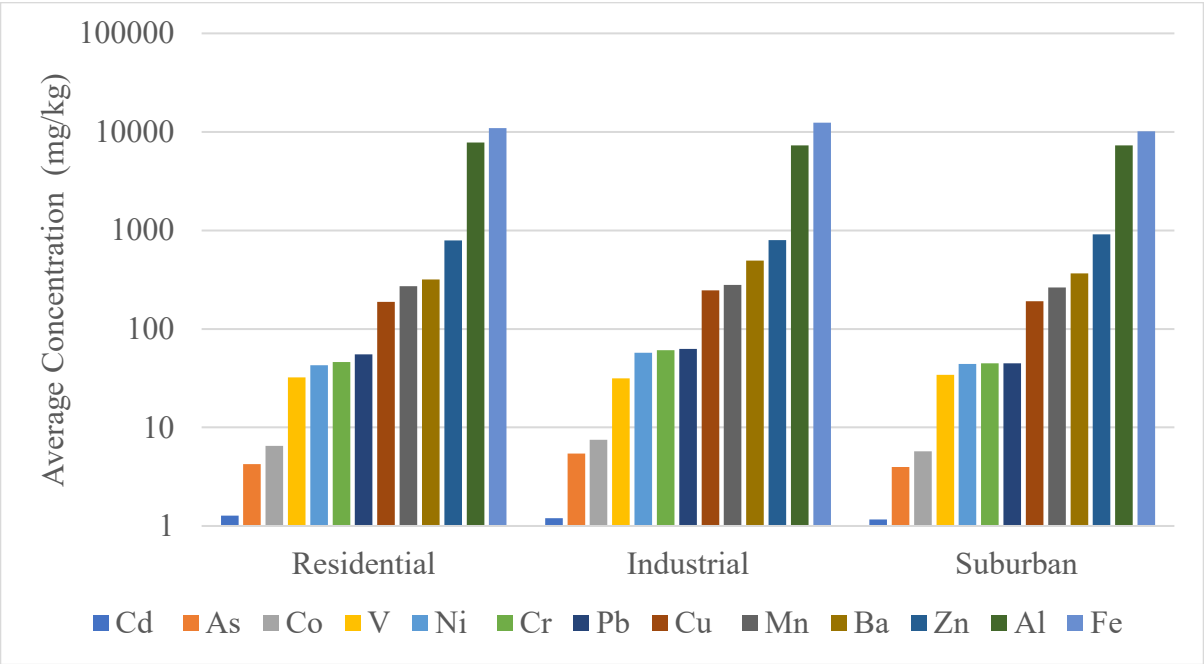


Figure 10 Average of HM Conc. for Each Area in Dammam and Khobar

4.3 Concentration of HMs in Jeddah

As shown in Table 15, the concentration of HMs in the air conditioning (AC) filters of buildings in different areas was found to exceed the world's crustal background value (Taylor, 1964) in Table 16, specifically for Zn, Cu, Pb, As, Cr, Ba, and Cd. HMs mean concentrations were significantly higher in industrial area (17.4, 4.7, 11.0, 2.1, 2.1, 2.1, and 7.3), residential areas Zn, Cu, Pb, As, Cr and Cd (10.61, 4.1, 5.6, 1.6, and 5.8) and suburban areas Zn, Cu, Pb, As, and Cd 11.3, 3.1, 12.3, 2.7, and 8.6 compared to world's crustal background values respectively. They were, moreover, comparing HMs mean level Cu, Cu Zn, Pb, Ni, As, Co, Cr, Fe and Cd 12.7, 15.1, 9.1, 3.1 1.7, 3.0, 5.2, 1.1 and 3.6 in the industrial area, Zn, Cu, Pb, Ni, As, Co, Cr, V and Cd 9.2, 11.2, 4.4, 1.9, 1.3, 1.6, 1.0, 1.7 and 2.9 in residential areas and Zn, Cu, Pb, Ni, As, Co, Cr, V, Fe and Cd 9.8, 8.5, 10.1, 2.4, 2.0, 2.7 1.4, 2.4 and 4.3) suburban areas than the values crustal in rural areas in Saudi Arabia (Shabbaj et al., 2018).

Figure 10 presents the relative contribution (percentage which is the average of specific element over the total average of all HMs) to determine the order of the mean concentrations of the HMs in the AC filter in each area as follows: industrial $Fe > Al > Zn > Ba > Mn > Cu > Cr > Pb > Ni > V > Co > As > Cd$, residential $Fe > Al > Zn > Mn > Cu > Ba > Pb > V > Cr > Ni > Co > As > Cd$ and suburban $Fe > Al > Zn > Mn > Cu > Pb > Ba > V > Cr > Ni > Co > As > Cd$. Figure 11 compares HMs in each area in Jeddah except Fe, Al, and Mn, which are considered earth crustal components (Al-Awadhi et al., 2016; Albar et al., 2020). The mean average in increasing sequence is 1305 res, 1474 suburban, and 2864 Industrial.

TABLE 15 Concentration of HMs in Jeddah

AREA	As	Cd	Co	Cr	Cu	Mn	Ni	Pb	V	Zn	Fe	Al	Ba
Residential	2.1	1.0	6.1	37.7	288.2	225.2	41.5	59.1	52.5	657.3	9073.0	6429.5	111.5
	3.2	1.1	7.0	42.1	304.5	243.9	45.2	58.0	51.6	604.6	10216.0	7631.5	104.3
	2.8	1.3	7.4	47.0	219.6	250.6	46.2	45.9	46.7	688.8	10966.0	8047.5	104.7
	3.4	1.1	9.2	47.0	173.2	362.9	41.2	70.7	62.4	1130.1	14116.0	10555.5	157.7
	3.1	1.2	8.0	39.0	134.2	289.9	38.6	100.5	59.9	632.6	11916.0	8391.5	122.9
Ave. Residential	2.9	1.1	7.6	42.6	223.9	274.5	42.5	66.8	54.6	742.7	11257.4	8211.1	120.2
Industrial	5.4	1.7	9.4	67.7	289.9	341.4	55.9	83.0	55.4	1104.1	17736.0	11125.5	481.4
	3.2	1.2	9.7	121.6	237.1	314.0	80.7	85.0	44.5	1360.1	16186.0	10105.5	424.6
	3.5	1.5	7.5	41.6	177.6	245.2	38.8	82.3	41.1	656.8	11176.0	7272.5	319.0
	4.0	1.8	24.6	668.8	275.0	520.9	74.7	255.6	65.7	1200.1	29246.0	11695.5	1413.0
	3.0	1.2	18.1	172.9	298.4	438.1	91.1	183.2	48.6	1774.1	24726.0	9644.5	1853.0
Ave. Industrial	3.8	1.5	13.9	214.5	255.6	371.9	68.2	137.8	51.0	1219.0	19814.0	9968.7	898.2
Suburban	4.2	2.1	11.0	53.1	145.6	400.1	47.9	129.7	80.6	738.6	16196.0	11815.5	109.3
	5.8	1.9	12.5	60.2	164.9	461.0	54.7	298.3	90.2	764.8	20126.0	15315.5	134.5
	4.6	1.7	13.4	64.2	176.0	452.2	65.7	144.0	95.4	849.0	19566.0	14345.5	130.3
	5.1	1.4	13.5	66.4	147.0	530.8	51.2	88.5	80.8	969.0	21056.0	11125.5	206.7
	3.3	1.5	10.7	47.1	222.7	422.8	41.9	108.3	76.3	638.2	16146.0	10105.5	135.9
Ave. Suburban	4.6	1.7	12.2	58.2	171.2	453.4	52.3	153.8	84.6	791.9	18618.0	12541.5	143.3

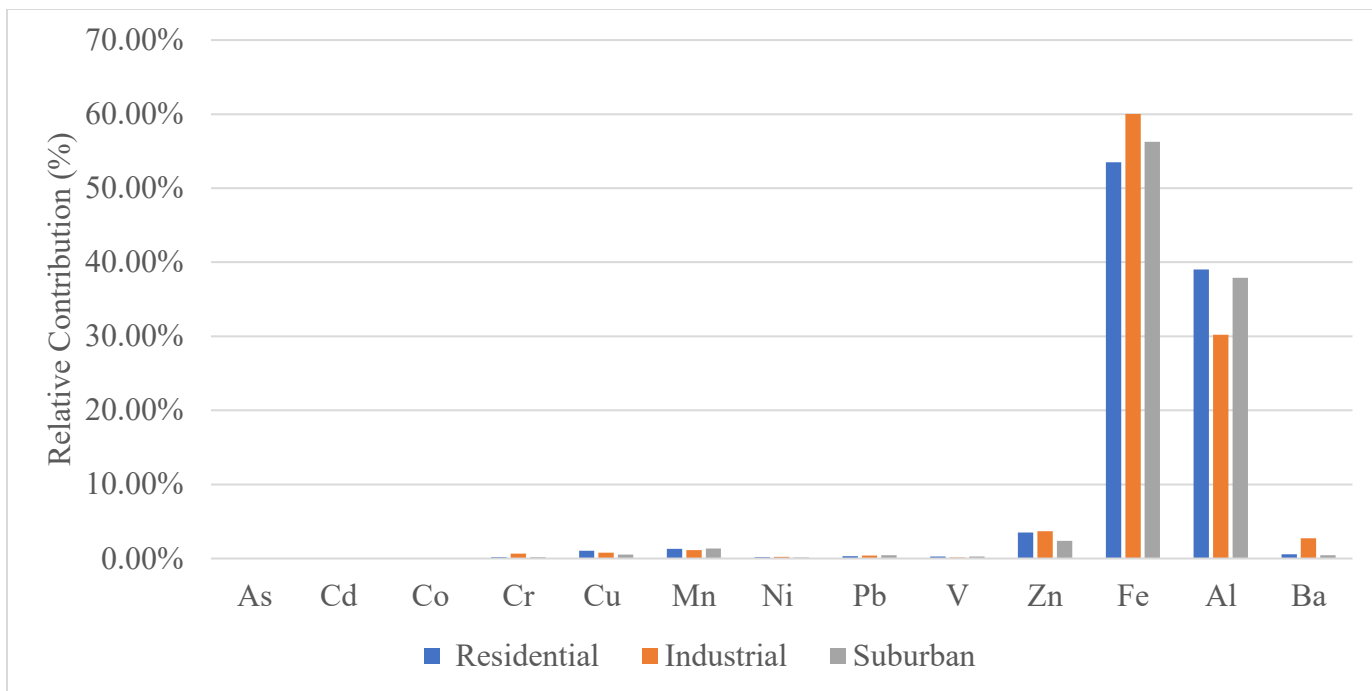


Figure 11 Jeddah HM Relative Contribution for Each Area

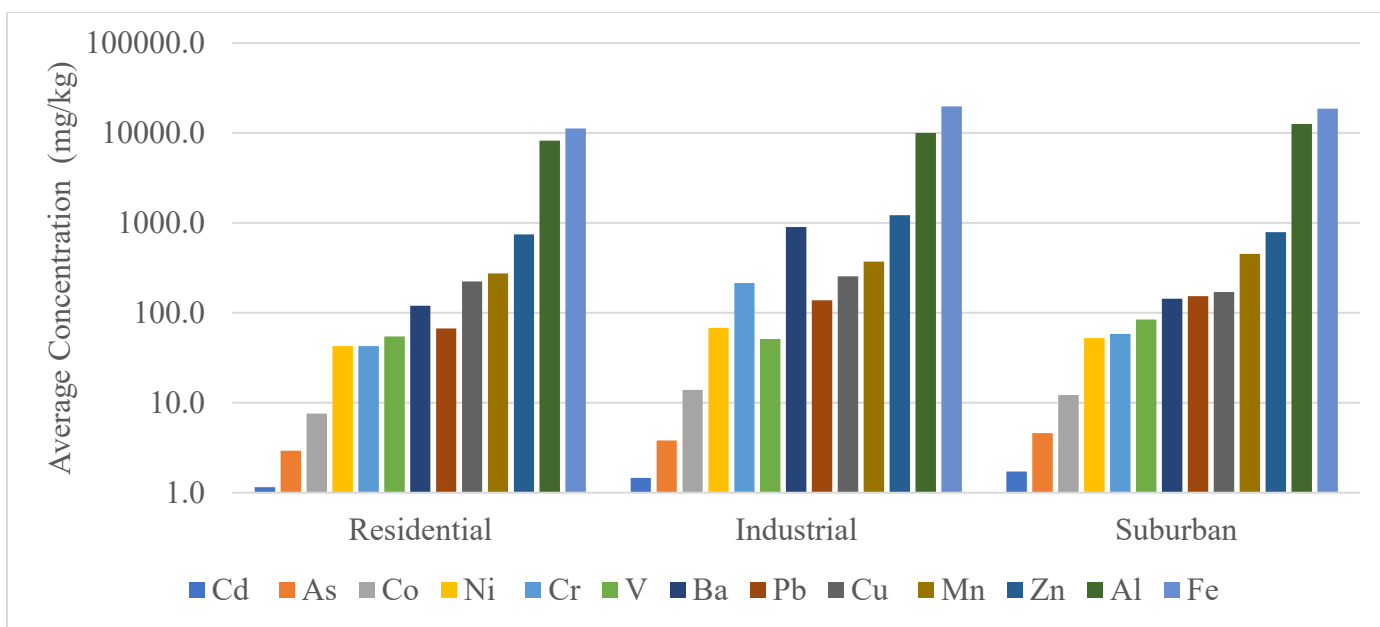


Figure 12 Average of HM Conc. for Each Area in Jeddah

TABLE 16 Crustal Background and Local Background Value

HM	C_n crustal	C_n soil
	mg/kg	mg/kg
As	1.8	2.3
Cd	0.2	0.4
Co	25.0	4.6
Cr	100.0	41.0
Cu	55.0	20.2
Mn	950.0	520.0
Ni	75.0	22.0
Pb	12.5	15.2
V	135.0	34.9
Zn	70.0	81.0
Fe	56300.0	18500.00
Al	82300.0	-
Ba	425	

4.4 Descriptive Statistics of HM Concentrations

Tables 17, 18, and 19 display the descriptive statistics of HM concentrations in the air conditioner [AC] filters collected from various buildings in Jeddah, Dammam, Khobar, and Jubail. The study observed the coefficient of variance [CV] and the standard deviation [SD] differences for HMs derived from the three cities. The results from the CV values were categorized into four groups.

CV values below 20 % were termed low, while those between 21% and 50% were considered moderate. On the other hand, the values spanning between 51% and 100% were categorized as high, while those over 100% were marked as highly high. Within this study, low CV values propose a uniform dispersal and prevalence of some pollution types. At the same time, moderate to high numbers designate the diverse distribution of HMs and the diversity of pollutant sources. It was shown that Ba and Cr have higher variability in the AC filters in Jeddah, and Pb was in the AC filters of Jeddah, Jubail, Dammam, and Khobar. At the same time, Cr and Mn in Jubail were variably low. Moderate variability is characteristic in the remaining HMs of the involved buildings in these cities.

Figure 12 presents the relative contribution to determine the order of the mean concentrations of the HMs in the AC filter in each city as follows: Jubail $Fe > Al > Zn > Mn > Ba > Cu > Pb > Cr > Ni > V > Co > As > Cd$, Dammam and Khobar $Fe > Al > Zn > Ba > Mn > Cu > Pb > Cr > Ni > V > Co > As > Cd$ and Jeddah $Fe > Al > Zn > Ba > Mn > Cu > Pb > Cr > V > Ni > Co > As > Cd$. Figure 13 compares HMs in each city in Jeddah except Fe, Al, and Mn, which are considered earth crustal components (Al-Awadhi et al., 2016; Albar et al., 2020). The mean average in increasing sequence is 1213 Jubail, 1389 Jeddah, 1567 Dammam, and Khobar.

Table 17 shows the statistics of concentration results of HMs in Jubail City for three areas: residential, industrial, and suburban. The average HM concentrations obtained from AC filters in different buildings surpassed the world's crustal disposition values [Taylor] for Cu, Zn, As, Cd, and Pb. The mean concentration levels were 2.9, 10.9, 2.4, 5.4, and 4.1 times higher in Jubail than in the world's crustal numbers.

When the results were matched with the local background values, the values of the mean concentration of Cr, Cd, As, Pb, Cu, Ni, and Zn in Jubail surpassed the local background values found in rural Saudi Arabia. The mean concentration values for As, Cd, Ni, Cr, Pb, Cu, and Zn were 1.9, 2.7, 2.0, 1.1, 3.4, 8.0, and 9.4 times in Jubail, compared to the concentrations in the local background, respectively. It can be deduced from the findings that HMs in AC filters in the studied buildings were heavily influenced by anthropogenic sources and accumulated in diverse regions (Shabbaj et al., 2018).

TABLE 17 Jubail HM Statistic Concentrations

parameters	As	Cd	Co	Cr	Cu	Mn	Ni	Pb	V	Zn	Fe	Al	Ba
Minimum	2.2	0.7	3.2	33.5	95.3	270.7	32.4	26.6	19.6	362.2	7831.0	3368.5	77.7
Maximum	6.0	1.7	8.1	57.3	273.6	478.0	55.7	97.5	40.8	1065.1	15006.0	11005.5	446.4
Median	4.6	1.0	4.1	47.1	131.7	370.0	45.5	33.8	28.3	768.1	11116.0	4932.5	240.6
Arithmetical Mean	4.3	1.1	4.6	45.1	160.9	386.0	43.7	51.2	28.5	764.1	10797.9	5662.8	232.2
Geometrical Mean	4.1	1.0	4.4	44.3	150.2	381.1	42.8	44.8	27.6	731.8	10503.1	5248.4	190.2
Standard Deviation	1.3	0.3	1.7	8.6	67.3	64.3	9.3	28.1	7.8	219.8	2679.3	2519.5	142.9
Standard Error	0.4	0.1	0.6	2.9	22.4	21.4	3.1	9.4	2.6	73.3	893.1	839.8	47.6
Coefficient of Variation	29.4	32.1	36.1	19.1	41.8	16.7	21.3	55.0	27.3	28.8	24.8	44.5	61.5
95% Confidence	5.2	1.4	6.1	47.9	227.0	395.5	47.9	82.6	33.9	925.2	12419.1	8226.1	398.2

Table 18 shows the statistics of concentration results of HMs in Dammam and Khobar Cities for three areas: residential, industrial, and suburban. The average HM concentrations obtained from AC filters in different buildings surpassed the world's crustal disposition values [Taylor] for Cu, Zn, As, Cd, and Pb. The mean concentration levels were 3.8, 11.9, 2.5, 6.1, and 4.3 times higher in Dammam and Khobar compared to the world's crustal numbers, respectively.

When the results were matched with the local values of background, the values of the mean concentration of Co, Cr, Cd, As, Pb, Cu, Ni, and Zn in Dammam and Khobar surpassed the local background values found in rural Saudi Arabia. The mean concentration values for Cd, Co, As, Ni, Pb, Cr, Cu, and Zn were 3.0, 1.4, 2.0, 2.2, 3.6, 1.2, 10.3, and 10.3 times higher than the concentrations in the local background, respectively. It can be deduced from the findings that HMs

in AC filters in the studied buildings were heavily influenced by anthropogenic sources and accumulated in diverse regions (Shabbaj et al., 2018).

TABLE 18 Dammam and Khobar HM Statistic Concentrations

Parameters	As	Cd	Co	Cr	Cu	Mn	Ni	Pb	V	Zn	Fe	Al	Ba
Minimum	2.4	0.8	4.0	36.1	109. 3	143. 3	29. 1	27.9	17. 2	365.0	6611.0	4063.5	174.4
Maximum	7.6	1.8	8.8	99.0	340. 5	401. 8	68. 4	171. 9	43. 8	1672. 1	17356. 0	11305. 5	955.5
Median	4.6	1.2	6.4	47.7	222. 9	284. 1	46. 2	40.0	33. 8	781.0	11426. 0	7675.5	336.6
Arithmetical Mean	4.5	1.2	6.6	50.6	208. 6	271. 5	48. 1	54.3	32. 7	832.3	11138. 2	7469.0	393.4
Geometrical Mean	4.3	1.2	6.4	49.2	202. 0	265. 2	47. 2	47.1	31. 8	765.8	10871. 9	7303.7	358.1
Standard Deviation	1.5	0.3	1.3	14.3	52.8	57.5	9.2	37.1	7.2	357.0	2540.4	1556.0	199.9
Standard Error	0.4	0.1	0.3	3.4	12.5	13.6	2.2	8.7	1.7	84.2	598.8	366.8	47.1
Coefficient of Variation	0.3	25. 8	20. 0	28.2	25.3	21.2	19. 1	68.3	21. 9	42.9	22.8	20.8	50.8
95% Confidence	3.8	0.9	4.6	39.4	156. 3	192. 2	33. 0	63.9	23. 4	769.0	8065.5	5261.8	394.5

Table 19 shows the statistics of concentration results of HMs in Jeddah City for three areas: residential, industrial, and suburban. The average HM concentrations obtained from AC filters in different buildings surpassed the world's crustal disposition values [Taylor] for Cu, Zn, As, Cd, and Pb. The mean concentration levels in Jeddah were 3.9, 13.1, 2.1, 7.2, and 9.6 times higher than the world's crustal numbers, respectively.

When the results were matched with the local values of background, the values of the mean concentration of Cd, V, Co, As, Ni, Pb, Cr, Cu, and Zn were 3.6, 1.8, 2.4, 1.6, 2.5, 7.9, 2.7, 10.7, and 11.3 times in Jeddah higher compared to the concentrations in the local background, respectively. It can be deduced from the findings that HMs in AC filters in the studied buildings were heavily influenced by anthropogenic sources and accumulated in diverse regions (Shabbaj et al., 2018).

TABLE 19 Jeddah HM Statistic Concentrations

Parameters	As	Cd	Co	Cr	Cu	Mn	Ni	Pb	V	Zn	Fe	Al	Ba
Minimum	2.1	1.0	6.1	37.7	134. 2	225. 2	38. 6	45.9	41. 1	604.6	9073. 0	6429 .5	104. 3
Maximum	5.8	2.1	24. 6	668. 8	304. 5	530. 8	91. 1	298. 3	95. 4	1774. 1	29246 .0	1531 5.5	1853 .0
Median	3.4	1.4	9.7	53.1	219. 6	362. 9	47. 9	88.5	59. 9	764.8	16186 .0	1010 5.5	135. 9
Arithmetical Mean	3.8	1.4	11. 2	105. 1	216. 9	366. 6	54. 4	119. 5	63. 4	917.9	16563 .2	1024 0.4	387. 3
Geometrical Mean	3.6	1.4	10. 4	68.5	208. 7	352. 7	52. 3	103. 3	61. 3	869.1	15690 .5	9959 .9	226. 8
Standard Deviation	1.0	0.3	4.9	160. 1	61.6	103. 1	16. 4	73.6	17. 3	337.8	5704. 2	2501 .8	526. 2
Standard Error	0.3	0.1	1.3	41.3	15.9	26.6	4.2	19.0	4.5	87.2	1472. 8	646. 0	135. 9
Coefficient of Variation	27. 7	22. 5	43. 3	152. 4	28.4	28.1	30. 2	61.6	27. 3	36.8	34.4	24.4	135. 9
95% Confidence	3.3	1.2	11. 6	235. 5	188. 4	317. 2	48. 3	147. 7	54. 3	882.4	15490 .2	8441 .9	797. 3

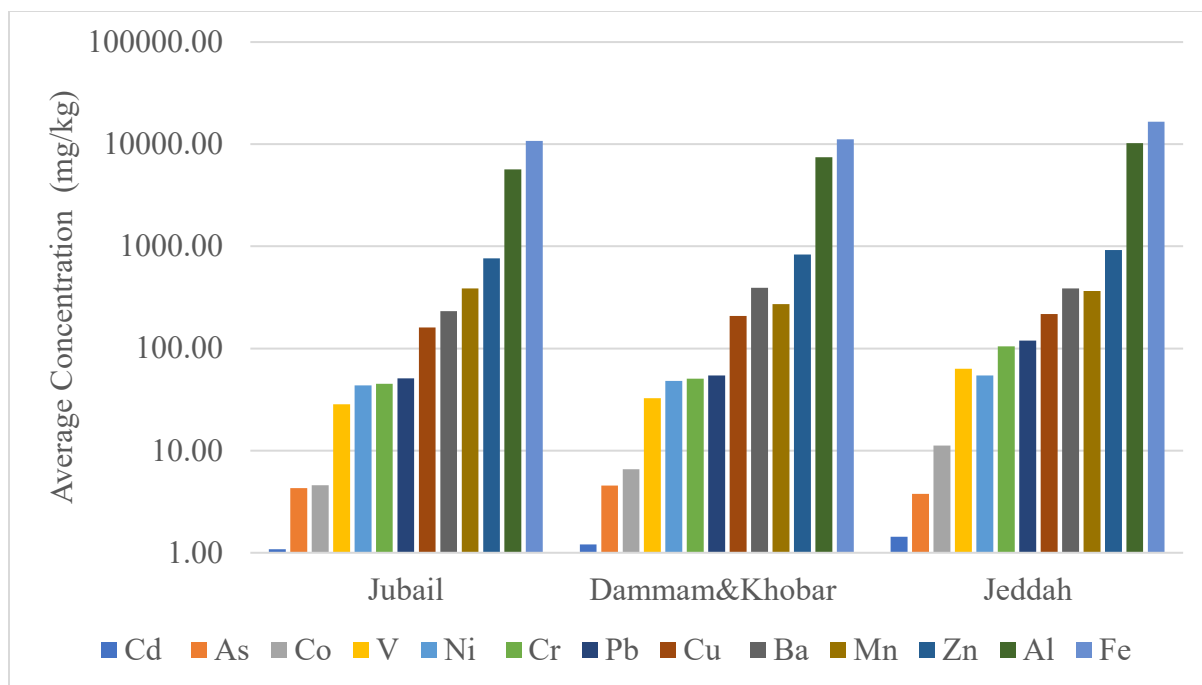


Figure 13 All cities HM Average Conc.

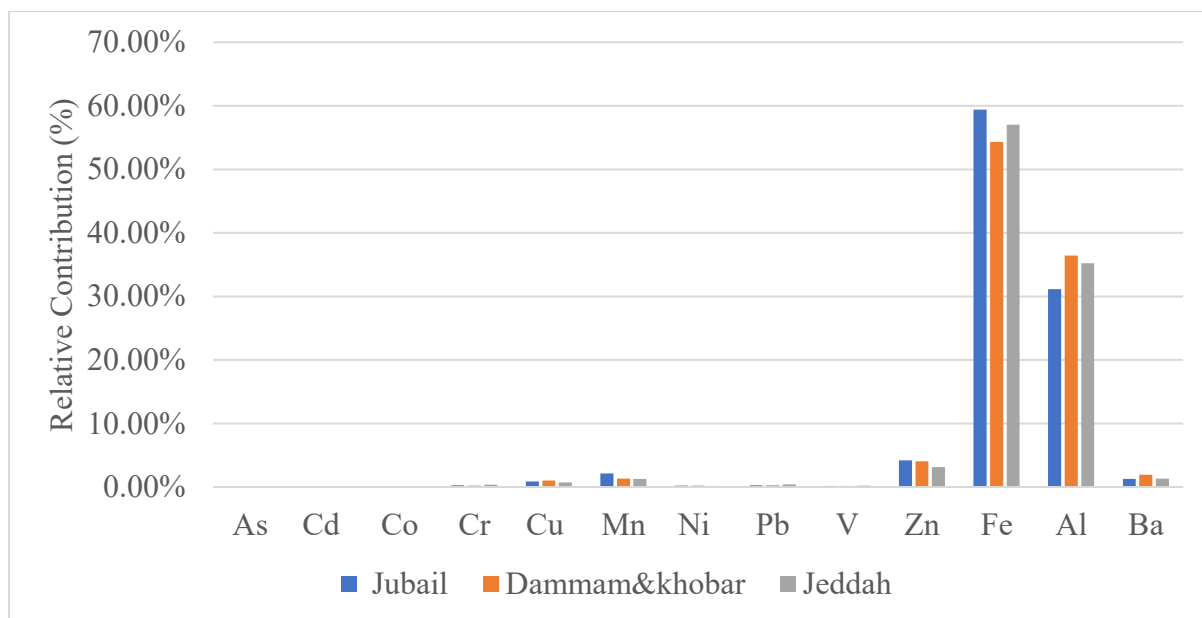


Figure 14 HMs Relative Contribution for All Cities

4.5 HMs Pollution Characteristics

Ecosystems may suffer significantly as a result of heavy metal contamination. It can damage aquatic life, upend microbial populations in soil, and harm plant development. Long-term ecological harm can result from some heavy metals' propensity to linger in the environment.

4.5.1 Contamination Factors (C_f) Degree of Contamination (C_d)

The HMs contamination factors in the AC filter of Jeddah (Table 22), Dammam, Khobar (Table 21), and Jubail (Table 20) are based on the local background as well as the global crustal. These factors vary from low to high contamination, depending on the criteria used to classify the C_f . The C_f values that were calculated for Mn and Fe in the Jeddah, Dammam, Khobar, and Jubail, those calculated in both Dammam, Khobar, and Jubail Cr, Ni, Co, and V, and in both Dammam, Khobar and Jubail (based in the local background and global crustal)) Moreover, V in Jeddah (based on local background) was found to be less than one, implying low contamination and their origination from suspended soil dust.

The contamination factors C_f of As in Dammam, Khobar and Jeddah and Cu and As in Jubail and Ni, Cr, Co, Cd, and As in Jubail, Ni, Cr, Co, Cd, As in Dammam and Khobar and V, Ni, Cr, Co, and As in Jeddah were found to be between one and three, and this is a sign of moderate contamination. However, the contamination values of Pb and Cd in Jubail, Pb and Cu in Dammam and Khobar, and Cu in Jeddah ranged between three and six, indicating considerable contamination. The contamination values of Zn in Jeddah, Dammam, Khobar, and Jubail and Cd in Jeddah, Dammam, and Khobar were found to be higher than six, indicating high contamination. Generally, the results of contamination factors revealed that the HMs C_f in the AC filter of distinct

Jeddah, Dammam, Khobar, and Jubail had a considerable variation and with the highest values of Pb, Cd, Cu, and Zn Table 20, 21 and 22. On average, the concentration of As, Cd, Pb, Cu, and Zn were 1.9, 2.7, 3.4, 8.0, 9.4 times Jubail, As, Cd, Pb, Cu, and Zn 2, 3.0, 3.6, 10.3, 10.3 times Dammam and Khobar, and Cd, Pb, Cu, Zn and V 3.6, 7.9, 10.7, 11.3 and 1.8 times Jeddah higher compared to those in the local background (Figure 15,17 and 19) respectively. This confirms that anthropogenic activities influenced As, Zn, Pb, Cu, V, and Cd pollution. On average, the concentration of As, Cd, Pb, Cu, and Zn were 2.4, 5.4, 4.1, 2.9, 10.9 times Jubail As, Cd, Pb, Cu, and Zn 2.5, 6.1, 4.3, 3.8, 11.9 times Dammam and Khobar, and As, Cd, Cr, Pb, Cu, and Zn 2.1, 7.2, 1.1, 9.6, 3.94, and 13.1 times Jeddah higher compared to those in the world's crustal (Figure 14, 16 and 18) respectively. This confirms that anthropogenic activities influenced As, Zn, Pb, Cu, Cr, and Cd pollution.

Tables 20, 21, and 22 show the HMs - Cd values in the Jeddah, Dammam, Khobar, and Jubail AC filters. The degree of contamination varied from moderate to firm to solid contamination based on the Cd's classification criteria. In both Dammam, Khobar, and Jeddah, there were very high degrees of pollution, while in Dammam, Khobar, and Jubail, moderate to strong Cd was noticed. The values for the degree of contamination were 31.6 and 28.3 Jubail, 36.1 and 31.7 Jeddah, based on the local background and the world's crustal, respectively. The presence of a very high Cd of indoor dust in Jeddah compared to that of Jubail, Dammam, and Khobar through HMs may result from high traffic density. High traffic density is one of the sources of these metals, especially in the areas around Jeddah than in the areas around Jubail, Dammam, and Khobar.

TABLE 20 Jubail Contamination Factors (Cf) Degree of Contamination (Cd) with respect to (a) the World's Crustal and (b) Local Background

City	HM	C _f a	C _f b	C _d a	C _d b
Jubail	As	2.4	1.9	28.3	31.6
	Cd	5.4	2.7		
	Co	0.2	1.0		
	Cr	0.5	1.1		
	Cu	2.9	8.0		
	Mn	0.4	0.7		
	Ni	0.6	2.0		
	Pb	4.1	3.4		
	V	0.2	0.8		
	Zn	10.9	9.4		
	Fe	0.2	0.6		
	Ba	0.6	-		

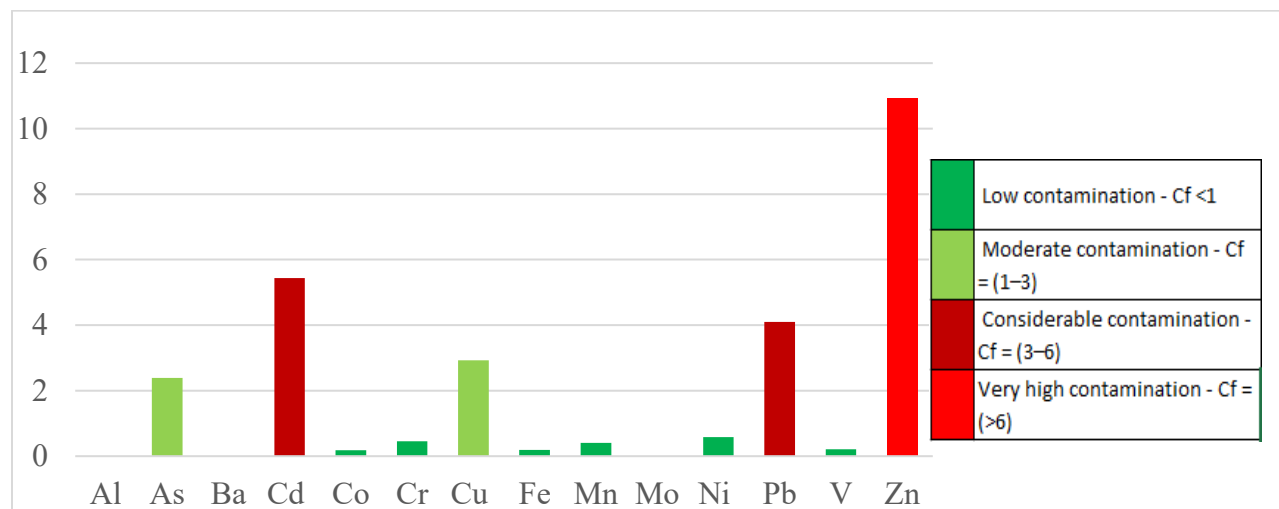


Figure 15 Jubail Cf (a) Global Crustal

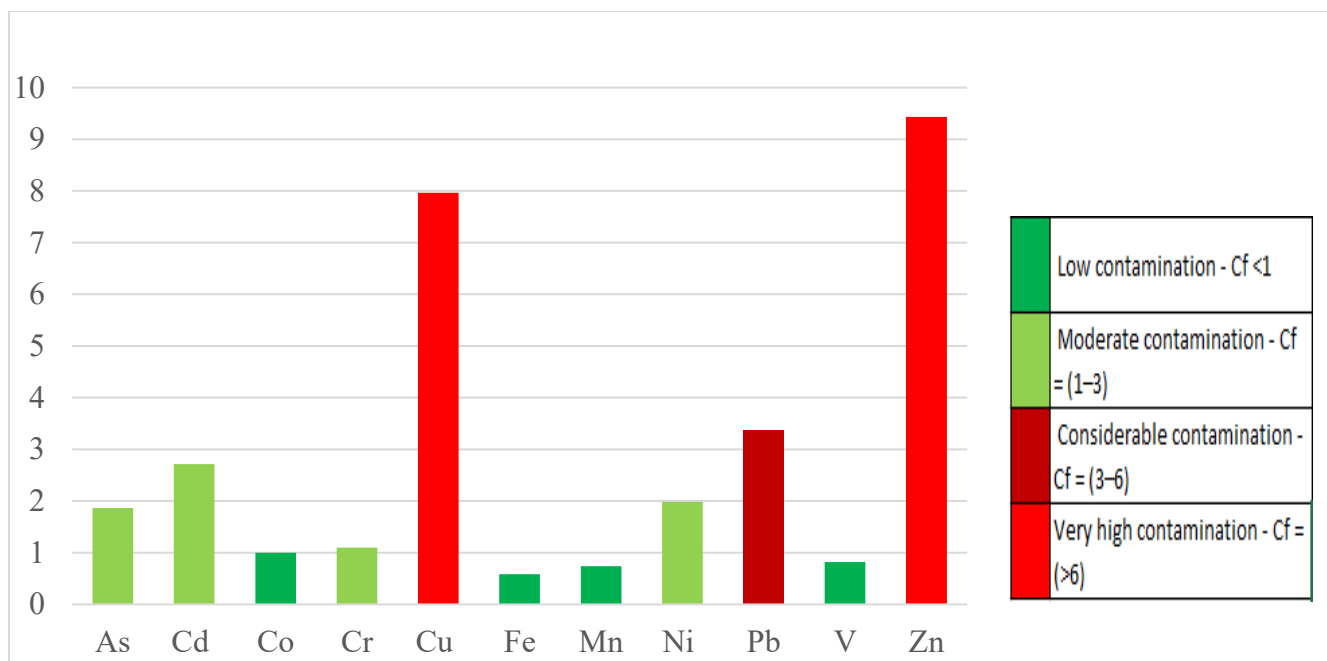


Figure 16 Jubail Cr (b) local background

TABLE 21 Dammam and Khobar Contamination Factors (Cf) Degree of Contamination (Cd) with respect to (a) the World's Crustal and (b) Local Background

City	HM	C _f a	C _f b	C _d a	C _d b
Dammam and Khobar	As	2.5	2.0	31.7	36.1
	Cd	6.1	3.0		
	Co	0.3	1.4		
	Cr	0.5	1.2		
	Cu	3.8	10.3		
	Mn	0.3	0.5		
	Ni	0.6	2.2		
	Pb	4.3	3.6		
	V	0.2	0.9		
	Zn	11.9	10.3		
	Fe	0.2	0.6		
	Ba	0.9	-		

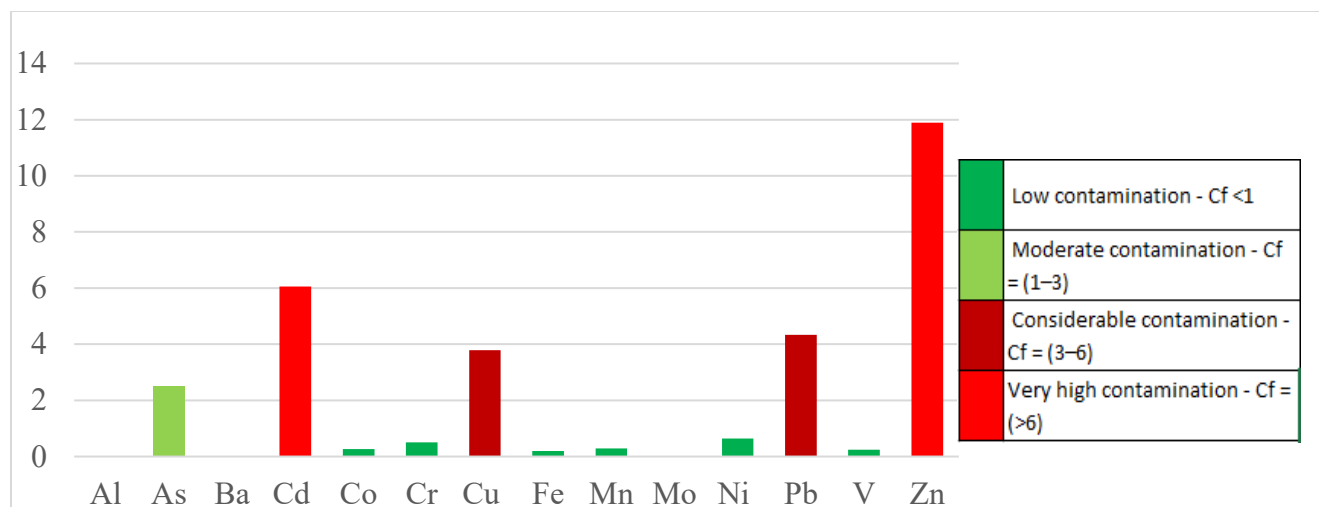


Figure 17 Dammam and Khobar Cf (a) Global Crustal

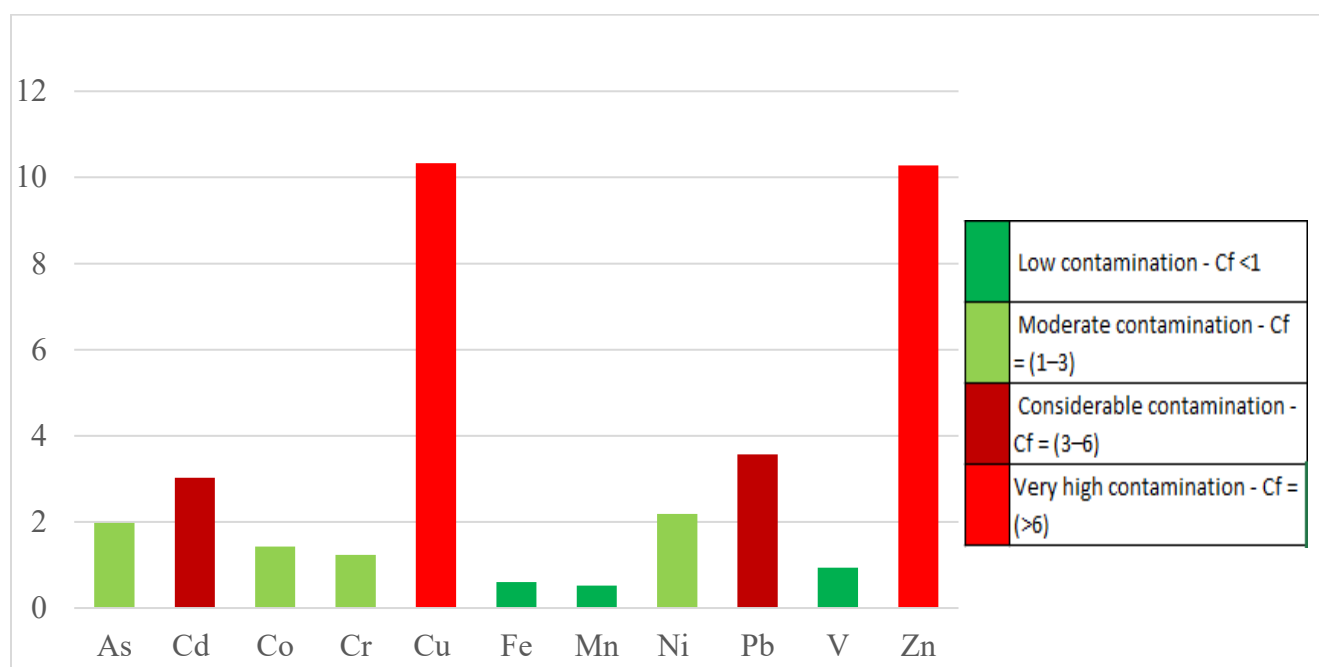


Figure 18 Dammam and Khobar Cf (b) Local Background

TABLE 22 Jeddah Contamination Factors (Cf) Degree of Contamination (Cd) with respect to (a) the World's Crustal and (b) Local Background

City	HM	C _f a	C _f b	C _d a	C _d b
Jeddah	As	2.1	1.6	40.2	46.1
	Cd	7.2	3.6		
	Co	0.5	2.4		
	Cr	1.1	2.6		
	Cu	3.9	10.7		
	Mn	0.4	0.7		
	Ni	0.7	2.5		
	Pb	9.6	7.9		
	V	0.5	1.8		
	Zn	13.1	11.3		
	Fe	0.3	0.9		
	Ba	0.9	-		

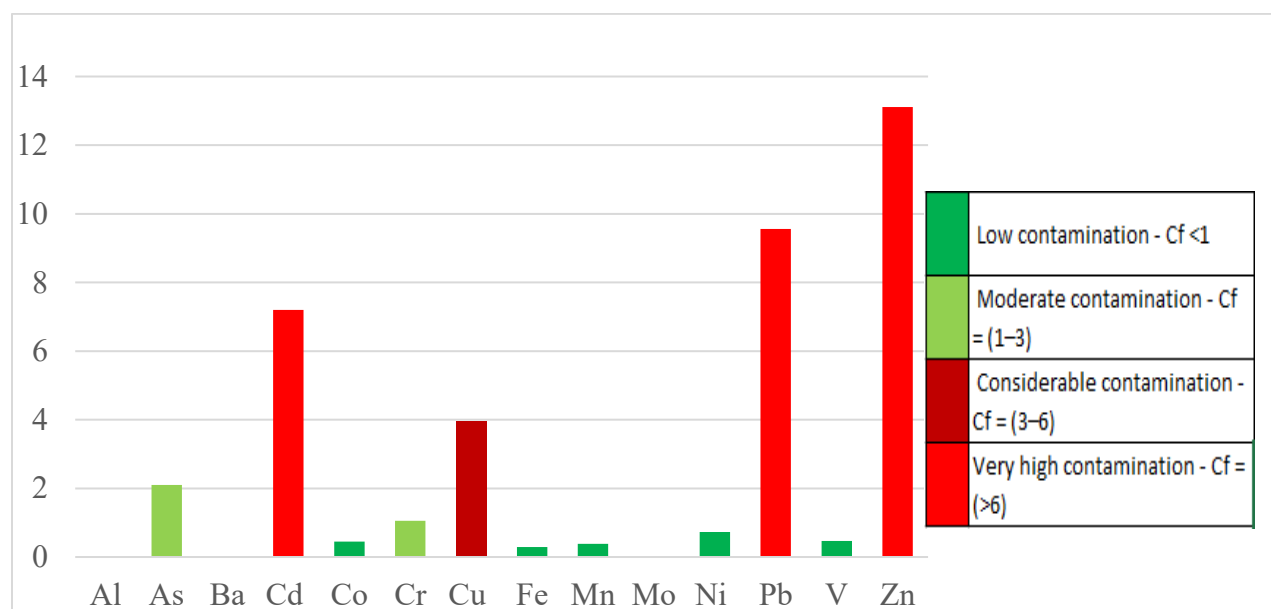


Figure 19 Jeddah Cf (a) global crustal

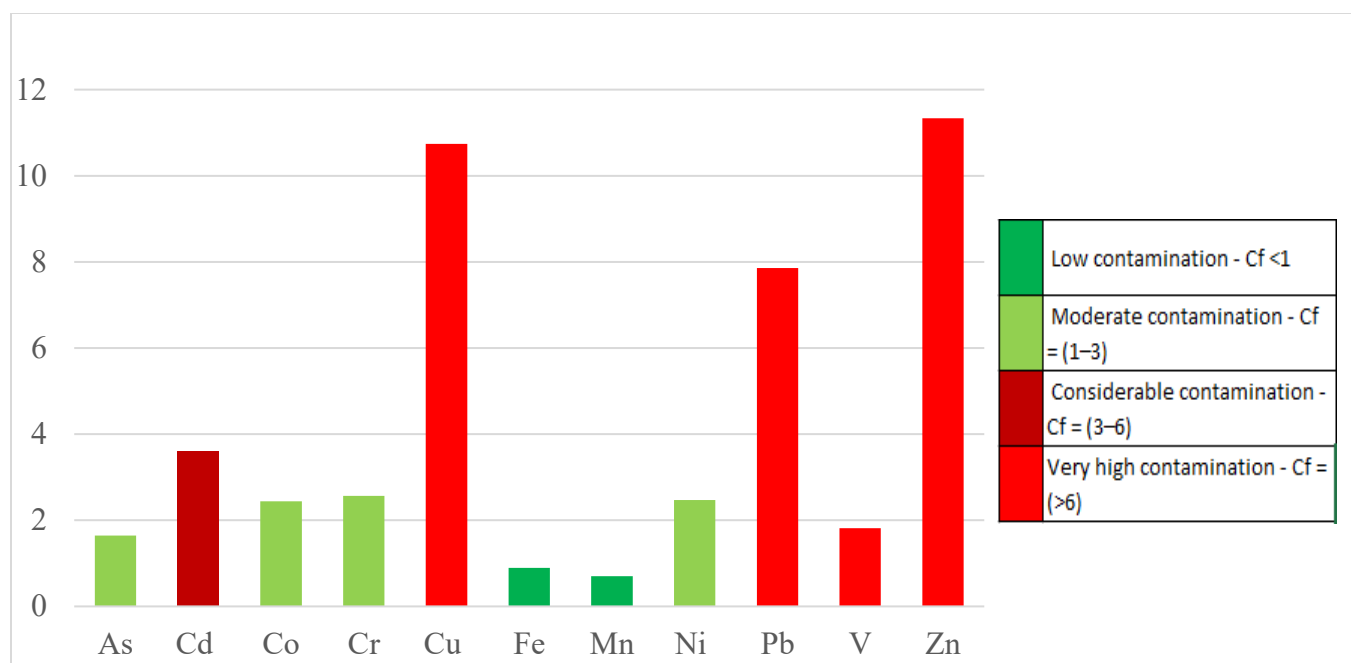


Figure 20 Jeddah Cr(b) local background

4.5.2 Pollution Load Index (PLI)

A calculation was made on the pollution load index to evaluate the impact of HM's accumulated contamination load. The calculated HMs PLI in the Jubail, Dammam, Khobar, and Jeddah AC filters are graphically represented in Figure 20 and recorded in Table 23. Depending on PLI's classification criteria, as indicated in Table 6, the value of the pollution load index in the AC filter composed of all the buildings indicated the occurrence of HM cumulative pollution load. The results indicated high values of PLI in Jeddah, Dammam, Khobar, and Jubail, which had the lowest PLI values. The values of the pollution load index were Jubail (1.0 and 1.8), Dammam and Khobar (1.1 and 1.9), and Jeddah (1.5 and 2.4). This was centered on the local background and the world's crust. According to data from the local background, the uppermost PLI of HMs was in Dammam Kho, bar, and Jeddah buildings, with slight pollution concerning the global crust. Based on the world's crustal and local background, the PLI values in Jubail indicated slight pollution. To sum up, the highest values of HMs PLI in Jeddah, Dammam, and Khobar buildings result from the

effects of high traffic emissions. According to past studies, vehicle emissions are the leading cause of HMs in interior dust (Alghamdi et al., 2019; Doyi et al., 2019; Al-Rajhi et al., 1996).

TABLE 23 Jubail Pollution Load Index with respect to (a) the World's Crustal and (b) Local Background

City	PLI a	PLI b
Jubail	1.0	1.8
Dammam and Khobar	1.1	1.9
Jeddah	1.5	2.4

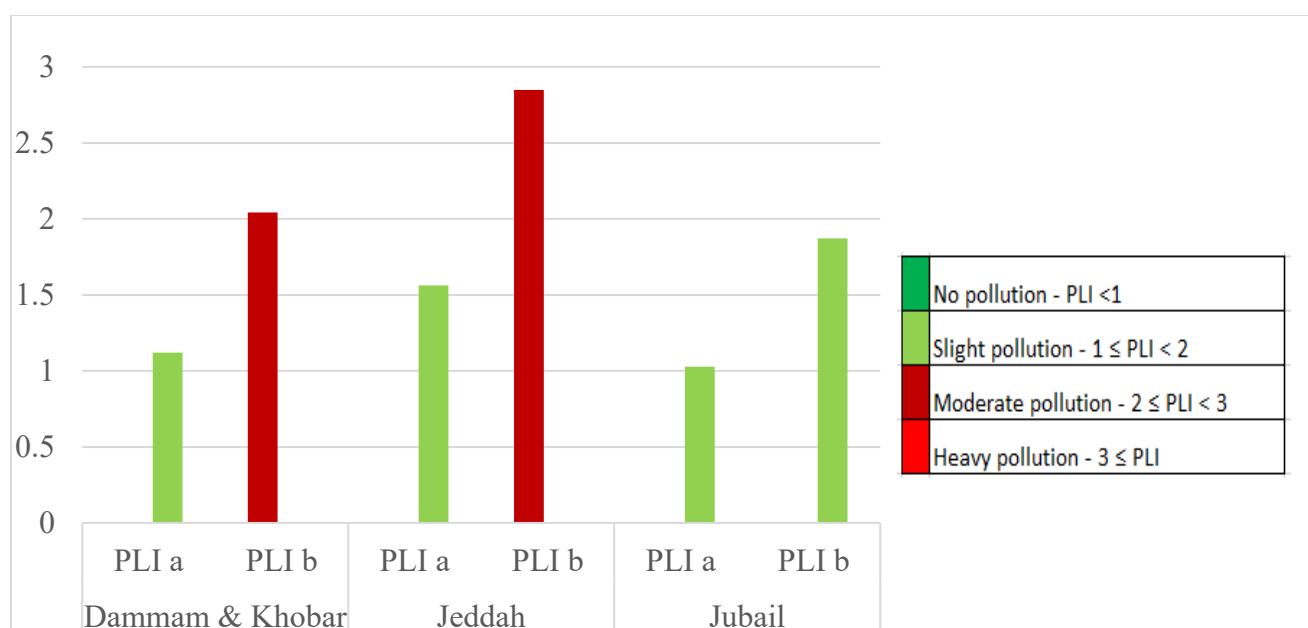


Figure 21 PLI a and b for all Cities (a) the world's crustal and (b) local background

4.5.3 Enrichment Factor (EF)

Figures 21, 22, and 23 represent enrichment factors calculated for the measured HMs in the Jeddah, Dammam, Khobar, and Jubail AC filters. There was a variation in the degree of enrichment, i.e., from moderate to extreme. This is with the adopted enrichment factor values classification criteria, as shown in Table 24. An increasing trend was displayed by the mean of HMs enrichment factors as shown in Figure 25, 26 and 27: Co < Fe < V < Mn < Cr < Ni < As < Cu < Pb < Cd < Zn in Jubail, Fe < V < Co < Mn < Cr < Ni < As < Cu < Pb < Cd < Zn in Dammam and Khobar, and Fe < Mn <

Co < V < Ni < As < Cr < Cu < Cd < P < Zn in Jeddah. Based on the HMs EF values calculated in the AC filter of Jubail, Dammam, Khobar, and Jeddah and the criteria used in the classification, the enrichment factors values, which ranged from two to five, moderate enrichment, were V, Fe, and Co in Jubail, Dammam, Khobar, and Jeddah, and Mn in Dammam, Khobar and Jeddah.

The enrichment factor values ranging from 5 to 20 were found for Mn in Jubail, As in Jeddah and Jubail, and Ni and Cr in Jubail, Dammam, Khobar, and Jeddah. This suggested significant enrichment. The enrichment factor values ranging from 20 to 40 were Cu in Jeddah and As in Dammam and Khobar, indicating a solid enrichment. Enrichment factor values above 40 were found for Cu in Jubail, Dammam, and Khobar, and Cd, Pb, and Zn in Jubail, Dammam, Khobar, and Jeddah, and this suggested extreme enrichment. According to these results, the seven HMs- Zn, Ni, Pb, Cu, Cr, Cd, and As in the AC filter of Jubail, Dammam, Khobar, and Jeddah enrichment levels varied from enormously to significantly enriched and this was an indication that the accumulation and origin of the HMs in the AC filters of the buildings composed of Dammam, Khobar and Jeddah and this was an indication that exterior anthropogenic sources almost had a complete influence. Zn, Pb, Ni, Cu, Cr, Cd, and As, which are examples of anthropogenic HMs, are usually released from tire wear and tear, greasing oil, combustion of fossil fuel, and traffic emissions (Alghamdi et al., 2019 Zhao et al., 2019; El-Mubarak et al., 2016; Shen et al., 2023; Tan et al., 2016; Albar et al., 2020).

Furthermore, the process of corrosion, such as the wearing down of railings, lamps, street safety barriers, batteries, walls, and wares, especially after being affected by weather conditions, may increase the presence of HMs such as Zn, Cu, Cr, and Cd in residential dust (Rehman et al., 2020;

Al-Rajhi et al., 1996; Zhao et al., 2021). Although Saudi Arabia phased out Pb in 2011 (Aburas et al., 2011), it was highly enriched in the collected samples of AC filters from all three cities' buildings. This is an indication that lead contamination can continue to persist in a local environment as a part of the street dust produced during its lengthy half-life (Alghamdi et al., 2019; Shabbaj et al., 2018; Khodeir et al., 2012; Lim et al., 2017). Moreover, it can also be re-suspended (Nematollahi et al., 2021; Wang et al., 2020).

TABLE 24 Enrichment Factor Values for all Cities

City	As	Cd	Co	Cr	Cu	Mn	Ni	Pb	V	Zn	Fe	Ba
Jubail	12.4	79.0	2.7	6.6	42.5	5.9	8.5	59.5	3.1	158.6	2.8	7.9
Dammam & Khobar	27.8	66.7	2.9	5.6	41.8	3.1	7.1	47.8	2.7	131.0	2.2	10.2
Jeddah	7.1	57.9	3.6	8.4	31.7	3.1	5.8	76.8	3.8	105.4	2.4	7.3

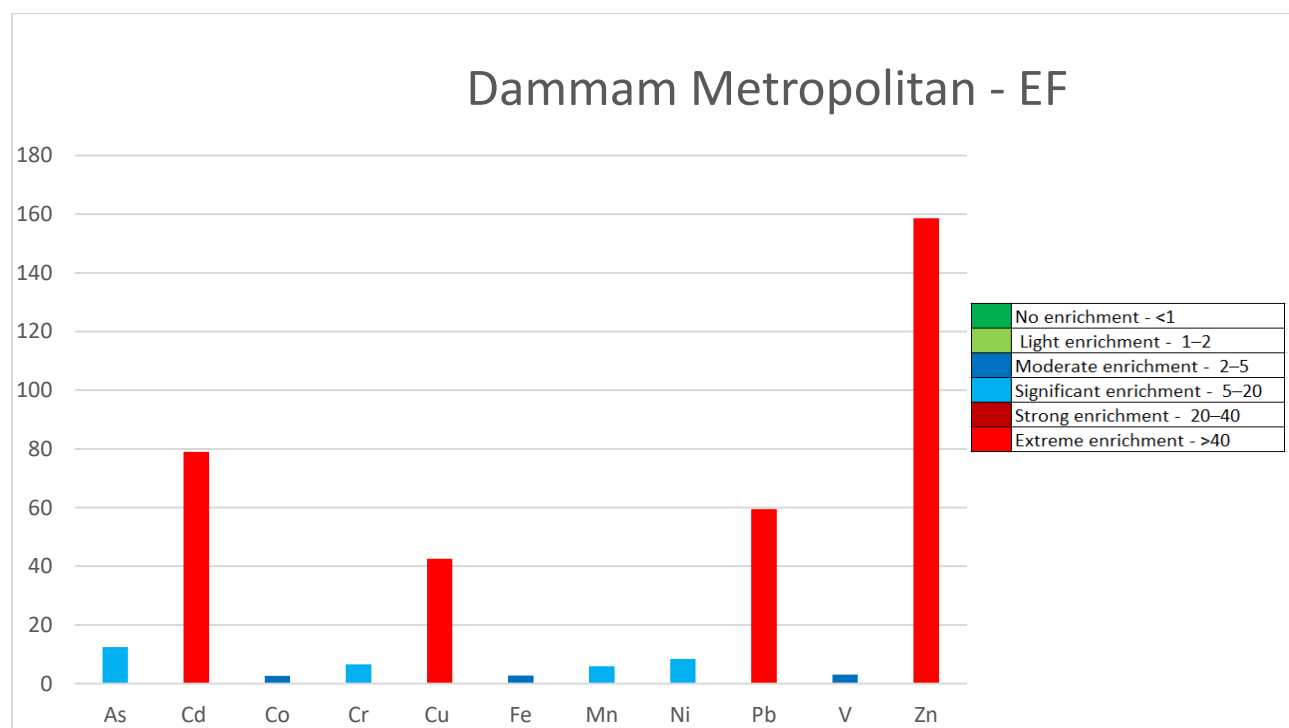


Figure 22 Jubail Enrichment Factor

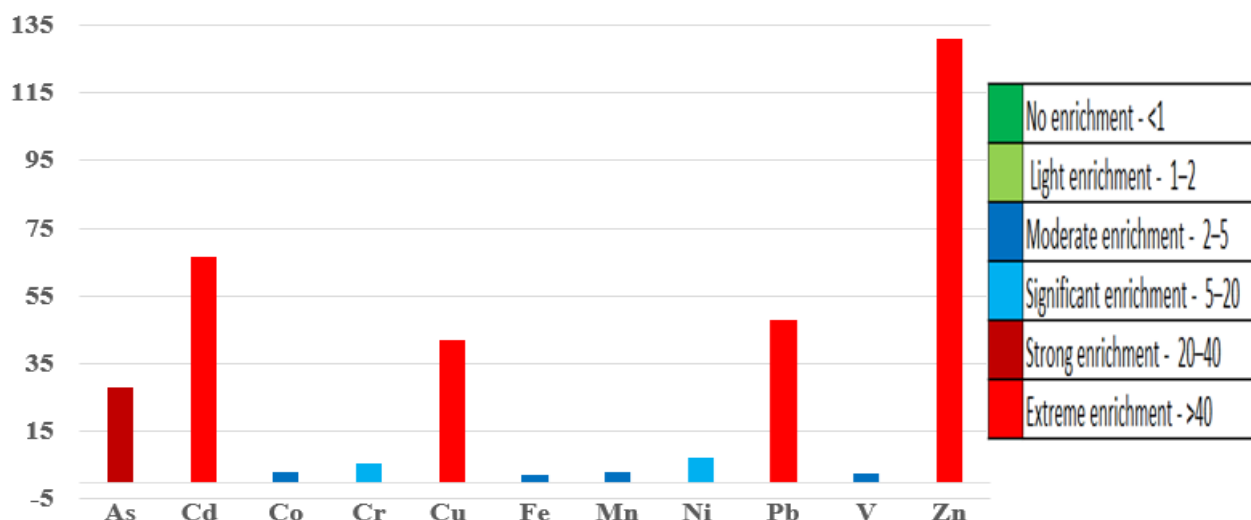


Figure 23 Dammam and Khobar Enrichment Factor

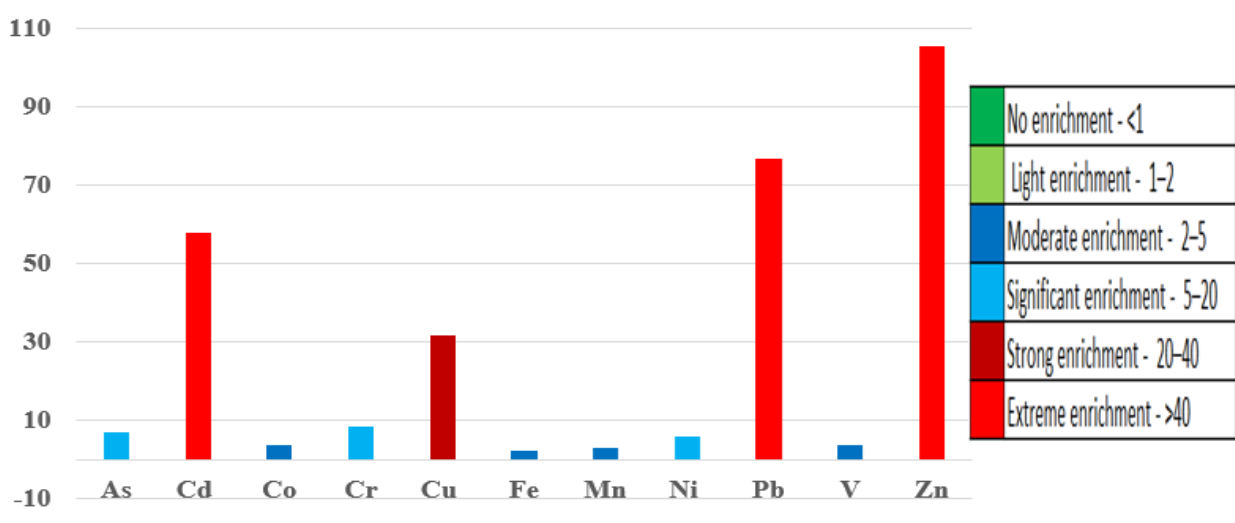


Figure 24 Jeddah Enrichment Factor

4.5.4 Geo – Accumulation Index (Igeo)

Table 25 and Figures 24 to 29 represent the HMs Igeo values in the Jubail, Dammam, Khobar, and Jeddah AC filters. These values are calculated and then interpreted, and this is based on the local background Figures 25, 27, and 29 and the world's crustal Figures 24, 26, and 28. Zn, Pb, Cu, and Cd had the highest Igeo values, while V, Ni, Mn, Fe, Cr, and Co displayed the lowest values. This criterion is based on the Igeo values. Based on the classifications in Table 2, the AC filter was

found to be unpolluted by Mn and Fe in Jeddah, Dammam, Khobar, and Jubail, V, Cr, and Co in Dammam, Khobar and Jubail, V, Ni, Cr, and Co in Jeddah, and Ni in Dammam, Khobar and Jubail. This was based on the local background of Figures 25, 27, and 29 and the world's crustal data in Figures 24, 26, and 28. The AC filter was found to range from moderately contaminated to uncontaminated by As in Jeddah, Dammam, Khobar, and Jubail, Cu in Jubail, Ni and Cd in Dammam and Khobar and Jubail, and V, Ni, Cr, and Co in Jeddah. It was also moderately contaminated by Pb and Cd in Jubail, Pb, Cu, and Cd in Dammam and Khobar, Cu in Jeddah, Pb in Jubail, Dammam and Khobar, and Cd in Jeddah. It was also found to be polluted moderately by Zn in Dammam, Khobar, and Jubail and heavily to moderately contaminated in Jeddah. The resulting high Igeo values for Pb, Cu, Cd, and Zn in the AC FILTER of all the distinct buildings studied resulted from the increased outdoor emissions of these elements. These elements' sources include exterior anthropogenic sources and the indoor dust found in buildings. Increased levels of metal pollution are brought not only by rapidly increasing socio-economical activities such as traffic density but also by inadequate protocols for the disposal of spent products, which include tires, fuel, grease, oil, and paint (Aiman et al., 2016 Chen et al., 2005).

TABLE 25 All Cities Geo-Accumulation Index Concerning (a) the World's Crustal and (b) Local Background

HM		As	Cd	Co	Cr	Cu	Mn	Ni	Pb	V	Zn	Fe	Ba
Jubail	Igeo a	0.67	1.86	-3.03	-1.73	0.96	-1.88	-1.36	1.45	-2.83	2.86	-2.97	-1.46
	Igeo b	0.32	0.86	-0.59	-0.45	2.41	-1.01	0.40	1.17	-0.88	2.65	-1.36	-
Dammam and Khobar	Igeo a	0.75	2.01	-2.51	-1.57	1.34	-2.39	-1.23	1.53	-2.63	2.99	-2.92	-0.70
	Igeo b	0.40	1.01	-0.07	-0.28	2.78	-1.52	0.54	1.25	-0.68	2.78	-1.32	-

Jeddah	Igeo a	0.48	2.26	-1.74	-0.51	1.39	-1.96	-1.05	2.67	-1.67	3.13	-2.35	-0.72
	Igeo b	0.13	1.26	0.70	0.77	2.84	-1.09	0.72	2.39	0.28	2.92	-0.74	-

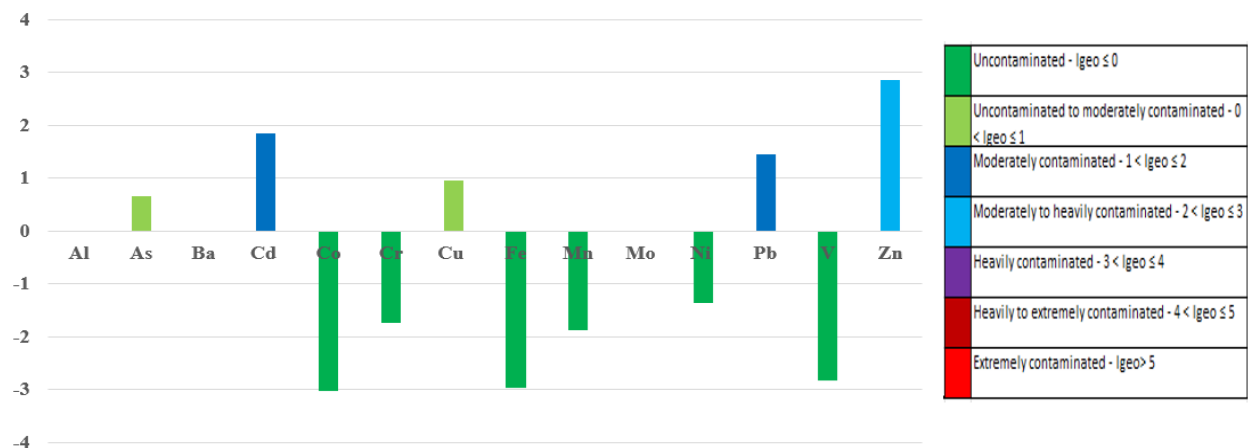


Figure 25 Jubail Geo-Accumulation Index (a) world's crustal

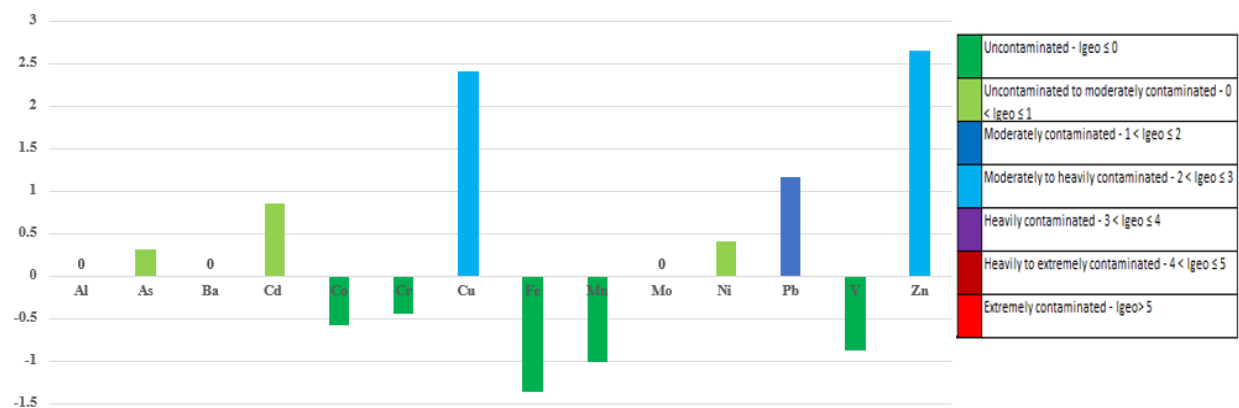


Figure 26 Jubail Geo-Accumulation Index (b) local background

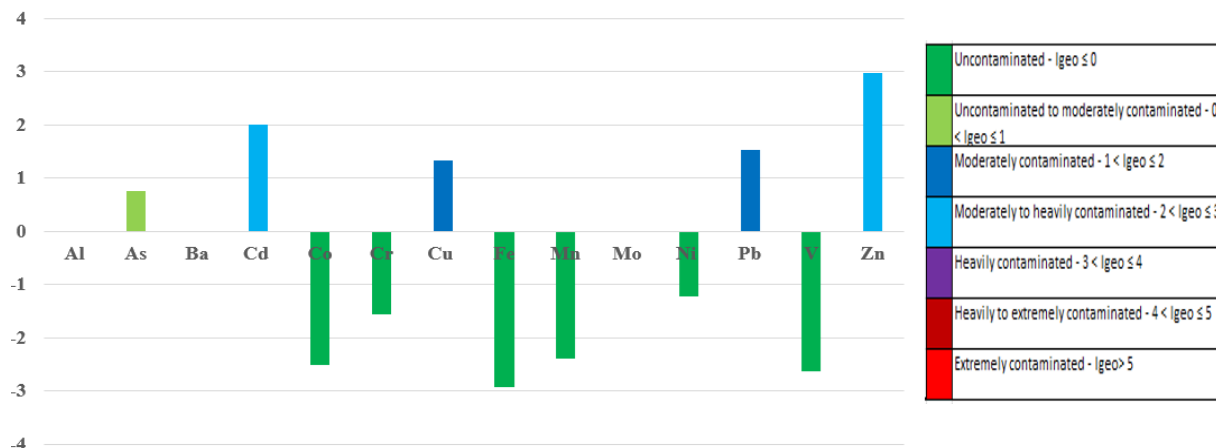


Figure 27 Damman and Khobar Geo-Accumulation Index (a) Global Crustal

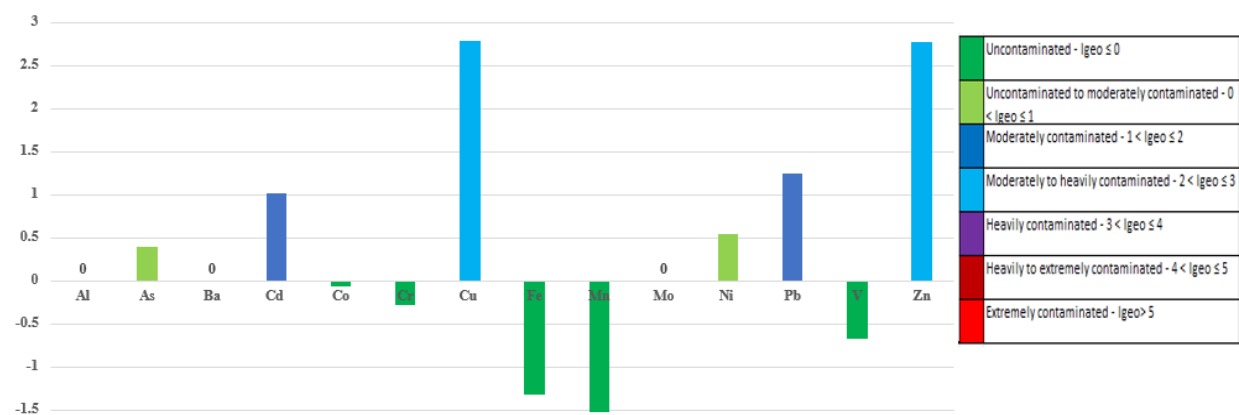


Figure 28 Damman and Khobar Geo-Accumulation Index (b) Local Background

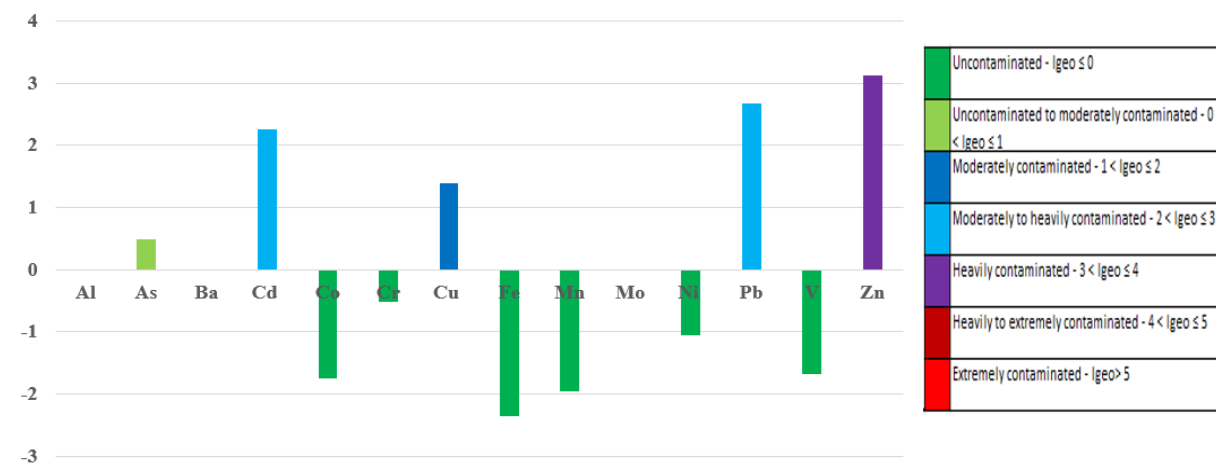


Figure 29 Jeddah Geo-Accumulation Index (a) Global Crustal

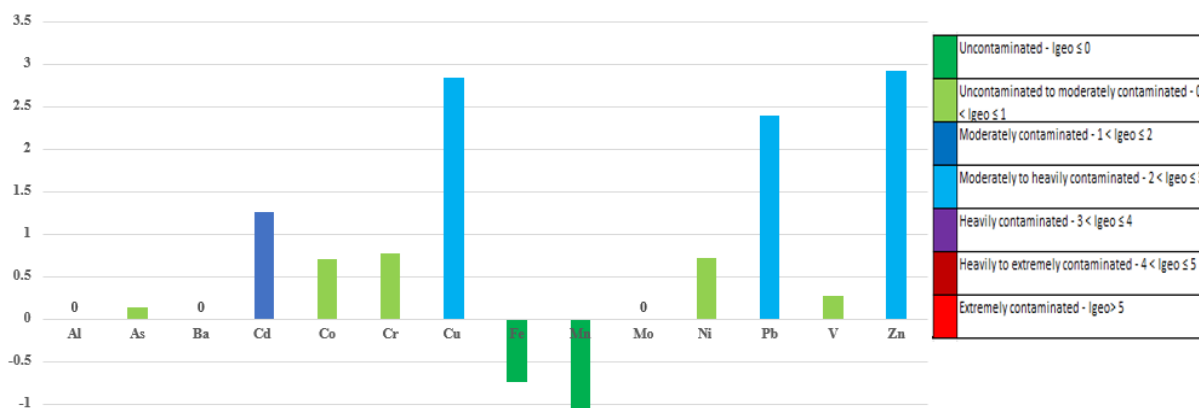


Figure 30 Jeddah Geo-Accumulation Index (b) Local Background

4.5.5 Ecological Risk Assessment (ER)

Tables 26, 27, and 28 show the calculated possible environmental risk factors for Zn, Pb, Ni, Mn, Cu, Cr, Cd, and As in the AC filter of Jubail, Dammam, Khobar, and Jeddah. The pattern displayed by the ecological risk values in ascending order was $Mn < Cr < Co < Ni < Zn < Cu < Pb < As$, and Cd in Jubail, Dammam and Khobar, and $Mn, < Cr < Co < Ni < Zn < Cu < As < Pb$ and Cd in Jeddah. Ecological risk values were high at 163.1., 181.7, and 216.1 for Cd, 21.0, 25.3, and 23.9 for As, and 47.8, 21.7, and 20.5 for Pb in Jubail, Dammam, Khobar, and Jeddah based on the world's crustal figure 30,32,34. Figures 31, 33, and 35 show the classification criteria for ER. Depending on this classification, Zn, Ni, Mn, Cu, Cr, Co, and As in Jubail, Dammam, Khobar, and Jeddah and Pb in Jubail, Dammam and Khobar represented lower ecological risks of less than 40. The ecological risk values for Pb in Jeddah ranged between $40 < ER < 80$. This was an indication of moderate risks in the environment. Cd, on the other hand, represented a higher risk to the ecology.

Furthermore, the highest ecological risk values were 108.0, 90.83, and 81.53 for Cd, 53.69, 51.63, 39.82 for Cu, and 39.30, 17.85, and 16.84 for Pb in Jeddah, Dammam, Khobar, and Jubail

respectively with comparing to the local background in Figure 31, 33 and 35. According to the criteria used to classify ecological risk values as shown in Tables 26, 27, and 28, Zn, Ni, Mn, Pb, Cr, Co, and As in Jubail, Dammam, Khobar, and Jeddah and Cu in Jubail indicated a lower ecological risk of less than 40. Cu in Dammam, Khobar, and Jeddah registered values ranging from $40 < ER < 80$, indicating moderate risk to the environment. Cd, on the other hand, registered a higher risk to the ecology.

According to the potential toxicity risk index, the higher ERI values were found in Jeddah, Dammam, and Khobar, then Jubail at 325.0, 265.3, and 238.1, respectively, based on the world's crustal. Only Jeddah exceeds 300 of the ERI classification, a considerable potential ecological risk. Although there is a moderate level of potential ecological risk for Jubail, Dammam, and Khobar, the lowest value was observed in Jubail. Concerning local background, ERI values in Figure 36 were 259.2, 184.2, and 163.5 for Jeddah, Jubail, Dammam, and Khobar, respectively, less than 300, which is a moderate level of potential ecological risk.

TABLE 26 Jubail Ecological Risk Assessment with respect to (a) the World's Crustal and (b) Local Background

City	HM	ER a	ER b	TRF	ERI a	ERI b
Jubail	As	23.86	18.67	10.00	237.15	179.16
	Cd	163.06	81.53	30.00		
	Cr	0.90	2.20	2.00		
	Cu	14.63	39.82	5.00		
	Mn	0.41	0.74	1.00		
	Ni	2.91	9.93	5.00		
	Pb	20.47	16.84	5.00		
	Zn	10.92	9.43	1.00		

TABLE 27 Dammam and Khobar Ecological Risk Assessment with respect to (a) the World's Crustal and (b) Local Background

City	HM	ER a	ER b	ERI a	ERI b
Dammam and Khobar	As	25.27	19.78	265.30	163.51
	Cd	181.65	90.83		
	Co	1.32	7.15		
	Cr	1.01	2.47		
	Cu	18.96	51.63		
	Mn	0.29	0.52		
	Ni	3.20	10.92		
	Pb	21.70	17.85		
	Zn	11.89	10.28		

TABLE 28 Jeddah Ecological Risk Assessment with respect to (a) the World's Crustal and (b) Local Background

City	HM	ER a	ER b	ERI a	ERI b
Jeddah	As	20.99	16.43	326.04	259.15
	Cd	216.08	108.04		
	Co	2.24	12.19		
	Cr	2.10	5.13		
	Cu	19.72	53.69		
	Mn	0.39	0.70		
	Ni	3.62	12.35		
	Pb	47.78	39.30		
	Zn	13.11	11.33		

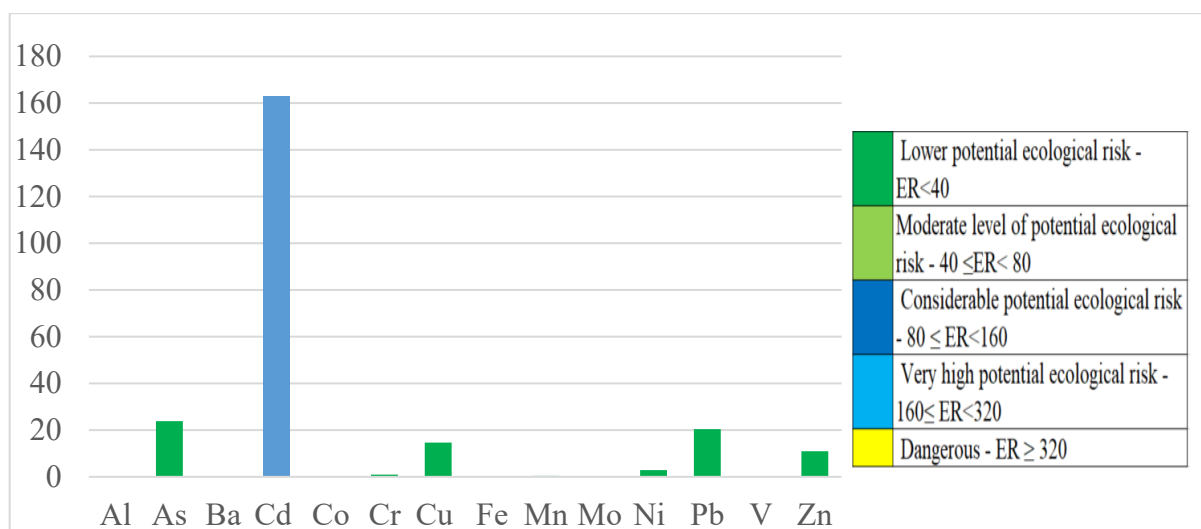


Figure 31 Jubail Ecological Risk (a) Global crustal

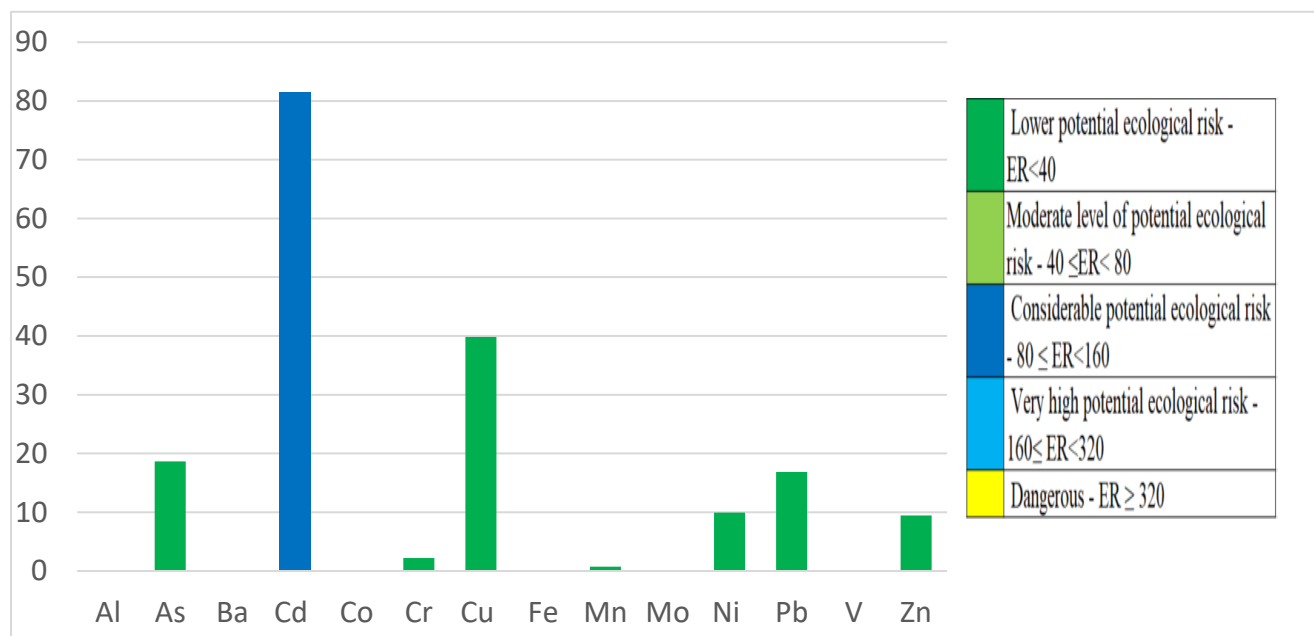


Figure 32 Jubail Ecological Risk (b) Local background

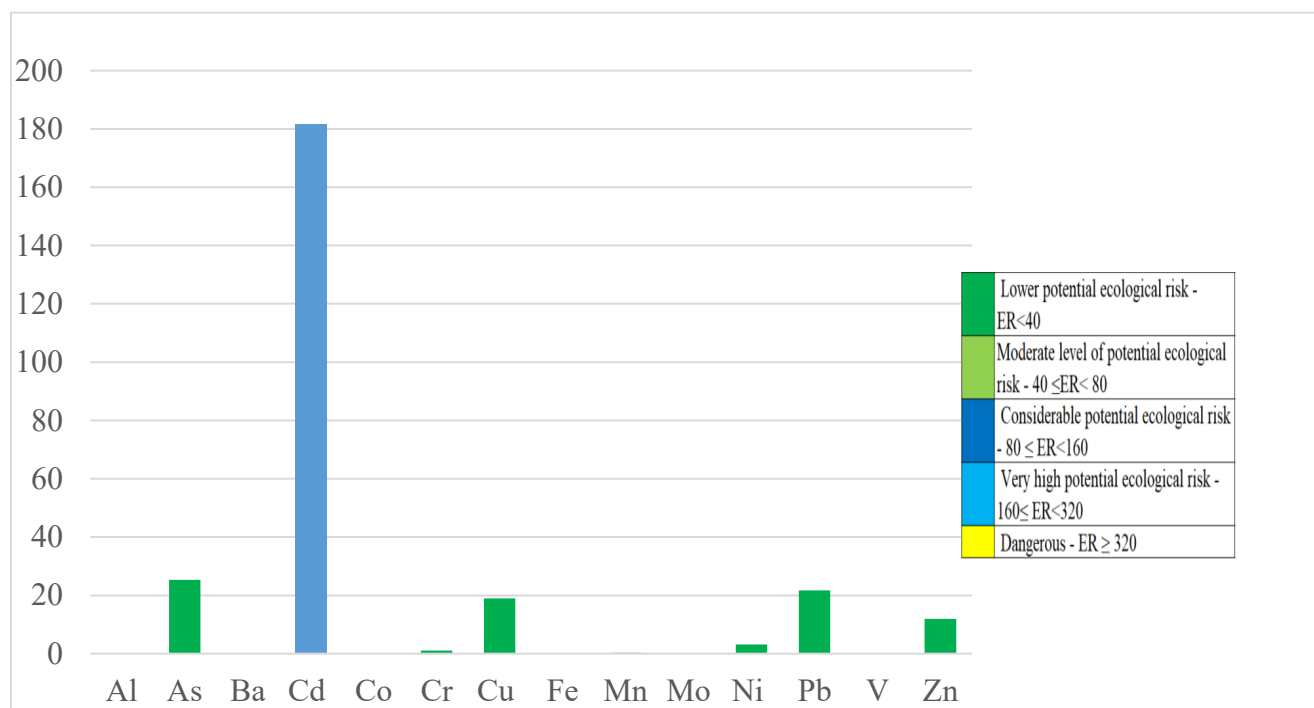


Figure 33 Dammam and Khobar Ecological Risk (a) Global crustal

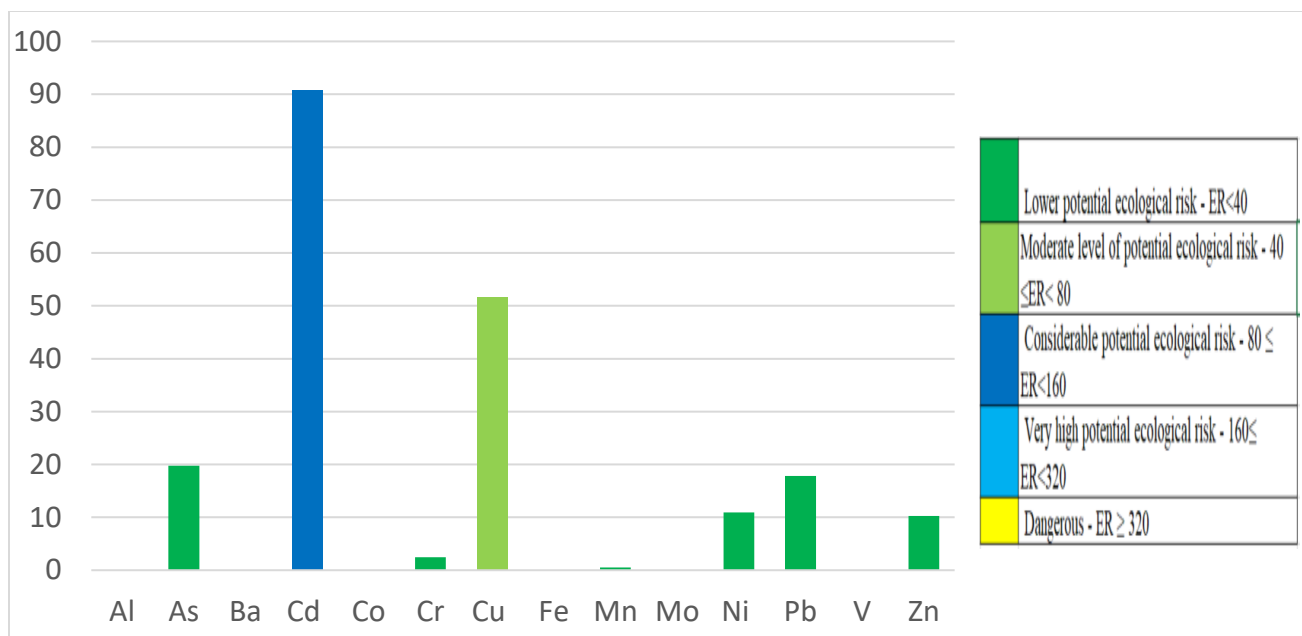


Figure 34 Damman and Khobar Ecological Risk (b) local background

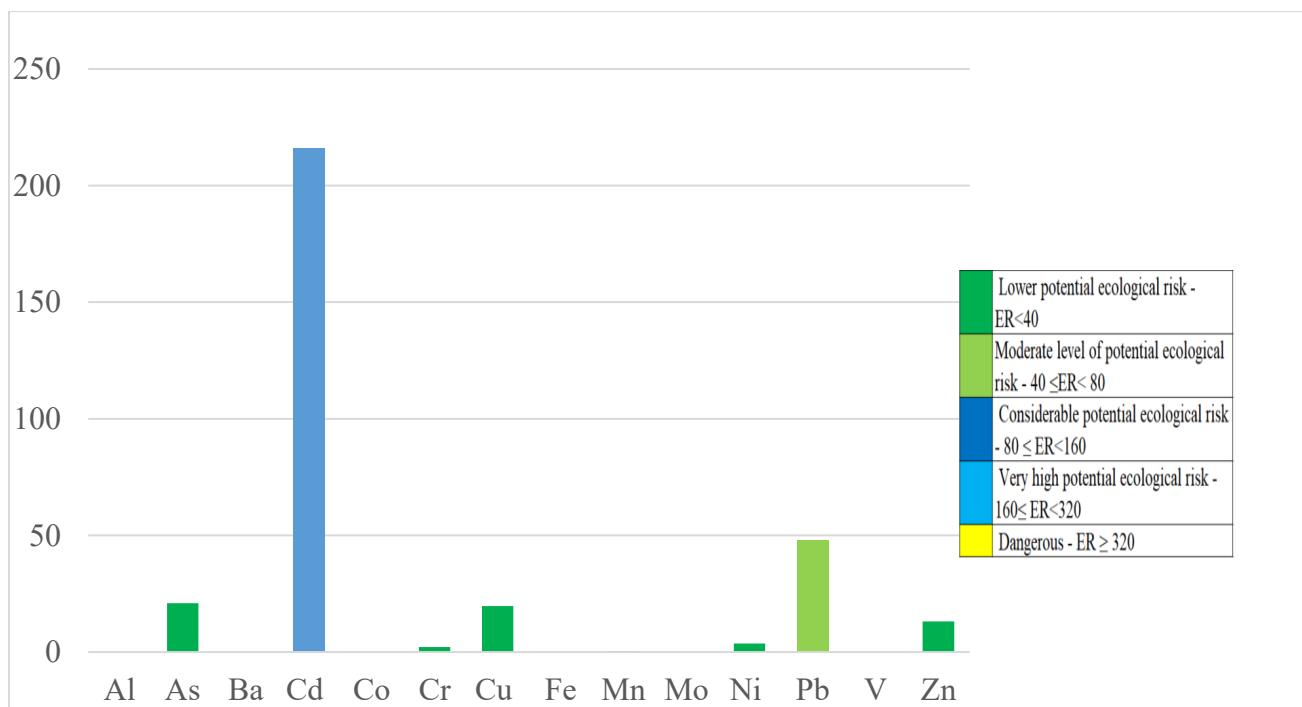


Figure 35 Jeddah Ecological Risk (a) Global crustal

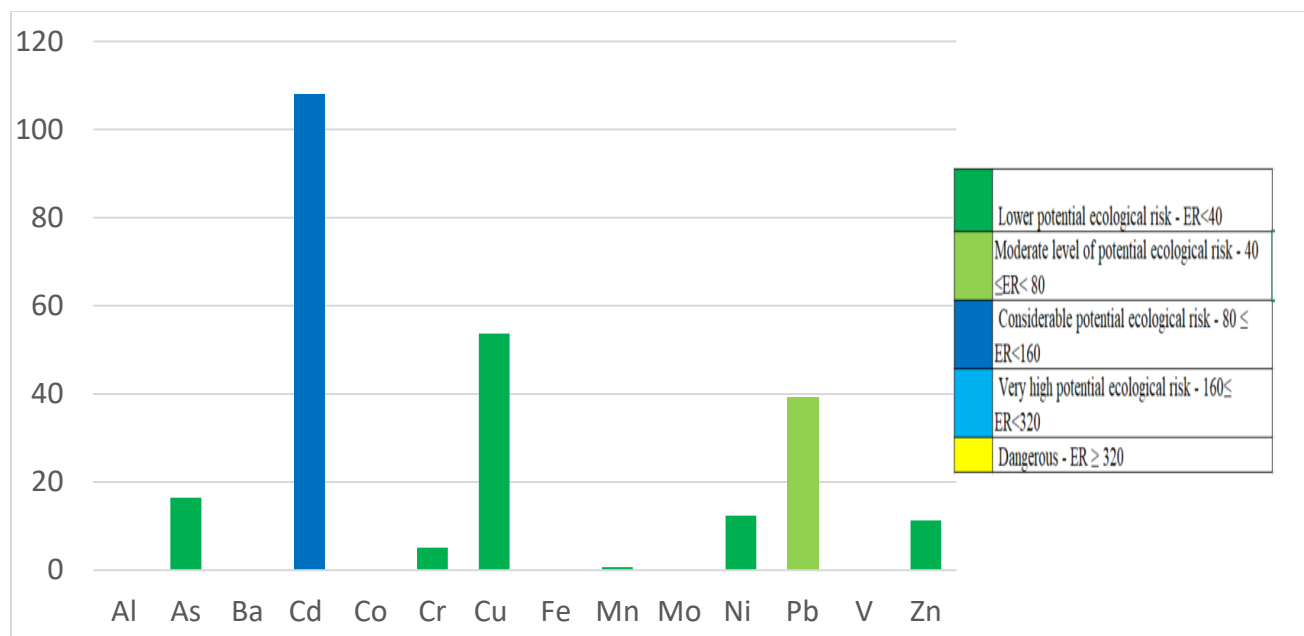


Figure 36 Jeddah Ecological Risk (b) local background

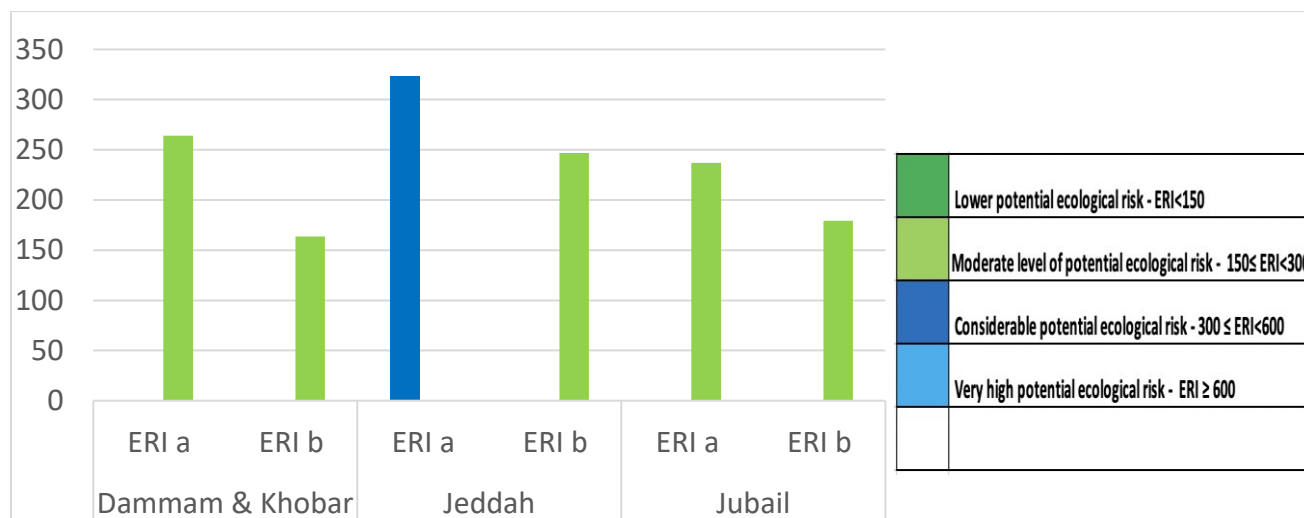


Figure 37 The potential toxicity risk index for all cities

4.6 Risk assessment of human health

The methodical process of risk assessment for human health entails identifying possible dangers and estimating the possibility and impact of adverse health outcomes linked to exposure to certain chemicals, activities, or environmental factors. The objective is to offer a scientific foundation for risk management, decision-making, and public health protection.

4.6.1 Average daily dose

Tables 29 and 30 represent the ADD (average daily dose) of non-carcinogenic elements in road dust. This has been represented using three distinct exposure pathways. A similar trend was revealed in both children and adults, $ADD_{inh} < ADD_{dermal} < ADD_{ing}$. The situation corresponds to what was revealed by past studies (Izhar et al., 2016; Na et al., 2018). The ingestion exposure pathway is around one time higher than the other two exposure pathways. The average daily dose of dust in the AC filters revealed a maximum dose in three elements, Zn, Al, and Fe, and a minimum dose in Co, As, and Cd. The calculations revealed that the average daily dose for children in Figure 37 was higher than that of adults in Figure 38 by 9.07 times. This is an indication that adults are exposed to fewer elements than children.

TABLE 29 The Average Daily Dose Children for Jubail, Dammam, Khobar, and Jeddah

City	Jubail			Dammam and Khobar			Jeddah		
HM	Adding	ADD _{inh}	ADD _{dermal}	Adding	ADD _{inh}	ADD _{dermal}	Adding	ADD _{inh}	ADD _{dermal}
As	5.96E-06	1.67E-10	9.54E-09	6.32E-06	1.77E-10	1.01E-08	5.25E-06	1.47E-10	8.40E-09
Cd	1.51E-06	4.24E-11	2.42E-09	1.68E-06	4.72E-11	2.69E-09	2.00E-06	5.61E-11	3.20E-09
Co	6.39E-06	1.79E-10	1.02E-08	9.14E-06	2.56E-10	1.46E-08	1.56E-05	4.37E-10	2.49E-08
Cr	6.26E-05	1.76E-09	1.00E-07	7.03E-05	1.97E-09	1.12E-07	1.46E-04	4.09E-09	2.34E-07
Cu	2.23E-04	6.27E-09	3.57E-07	2.90E-04	8.13E-09	4.64E-07	3.01E-04	8.45E-09	4.82E-07
Mn	5.36E-04	1.50E-08	8.58E-07	3.77E-04	1.06E-08	6.03E-07	5.09E-04	1.43E-08	8.15E-07
Ni	6.07E-05	1.70E-09	9.71E-08	6.67E-05	1.87E-09	1.07E-07	7.55E-05	2.12E-09	1.21E-07
Pb	7.11E-05	1.99E-09	1.14E-07	7.54E-05	2.11E-09	1.21E-07	1.66E-04	4.65E-09	2.65E-07
V	3.96E-05	1.11E-09	6.34E-08	4.54E-05	1.27E-09	7.26E-08	8.81E-05	2.47E-09	1.41E-07
Zn	1.06E-03	2.98E-08	1.70E-06	1.16E-03	3.24E-08	1.85E-06	1.27E-03	3.58E-08	2.04E-06
Fe	1.50E-02	4.21E-07	2.40E-05	1.55E-02	4.34E-07	2.48E-05	2.30E-02	6.45E-07	3.68E-05
Al	7.86E-03	2.21E-07	1.26E-05	1.04E-02	2.91E-07	1.66E-05	1.42E-02	3.99E-07	2.28E-05
Ba	3.23E-04	9.05E-09	5.16E-07	5.46E-04	1.53E-08	8.74E-07	5.38E-04	1.51E-08	8.61E-07

TABLE 30 The Average Daily Dose Adults for Jubail, Dammam, Khobar, and Jeddah

City	Jubail			Dammam and Khobar			Jeddah		
HM	Adding	ADD _{inh}	ADD _{dermal}	Adding	ADD _{inh}	ADD _{dermal}	Adding	ADD _{inh}	ADD _{dermal}
As	6.39E-07	6.01E-11	1.95E-08	6.77E-07	6.37E-11	2.06E-08	5.62E-07	5.29E-11	1.71E-08
Cd	1.62E-07	1.52E-11	4.93E-09	1.80E-07	1.70E-11	5.49E-09	2.14E-07	2.02E-11	6.53E-09
Co	6.84E-07	6.44E-11	2.08E-08	9.79E-07	9.22E-11	2.98E-08	1.67E-06	1.57E-10	5.08E-08
Cr	6.71E-06	6.32E-10	2.04E-07	7.53E-06	7.08E-10	2.29E-07	1.56E-05	1.47E-09	4.76E-07
Cu	2.39E-05	2.25E-09	7.29E-07	3.10E-05	2.92E-09	9.45E-07	3.23E-05	3.04E-09	9.83E-07
Mn	5.74E-05	5.41E-09	1.75E-06	4.04E-05	3.80E-09	1.23E-06	5.46E-05	5.13E-09	1.66E-06
Ni	6.50E-06	6.12E-10	1.98E-07	7.15E-06	6.73E-10	2.18E-07	8.09E-06	7.61E-10	2.46E-07
Pb	7.62E-06	7.17E-10	2.32E-07	8.07E-06	7.60E-10	2.46E-07	1.78E-05	1.67E-09	5.41E-07
V	4.24E-06	3.99E-10	1.29E-07	4.86E-06	4.58E-10	1.48E-07	9.44E-06	8.88E-10	2.87E-07
Zn	1.14E-04	1.07E-08	3.46E-06	1.24E-04	1.17E-08	3.77E-06	1.37E-04	1.29E-08	4.16E-06
Fe	1.61E-03	1.51E-07	4.89E-05	1.66E-03	1.56E-07	5.05E-05	2.46E-03	2.32E-07	7.51E-05
Al	8.43E-04	7.93E-08	2.57E-05	1.11E-03	1.05E-07	3.38E-05	1.52E-03	1.43E-07	4.64E-05
Ba	3.46E-05	3.25E-09	1.05E-06	5.85E-05	5.51E-09	1.78E-06	5.76E-05	5.42E-09	1.75E-06

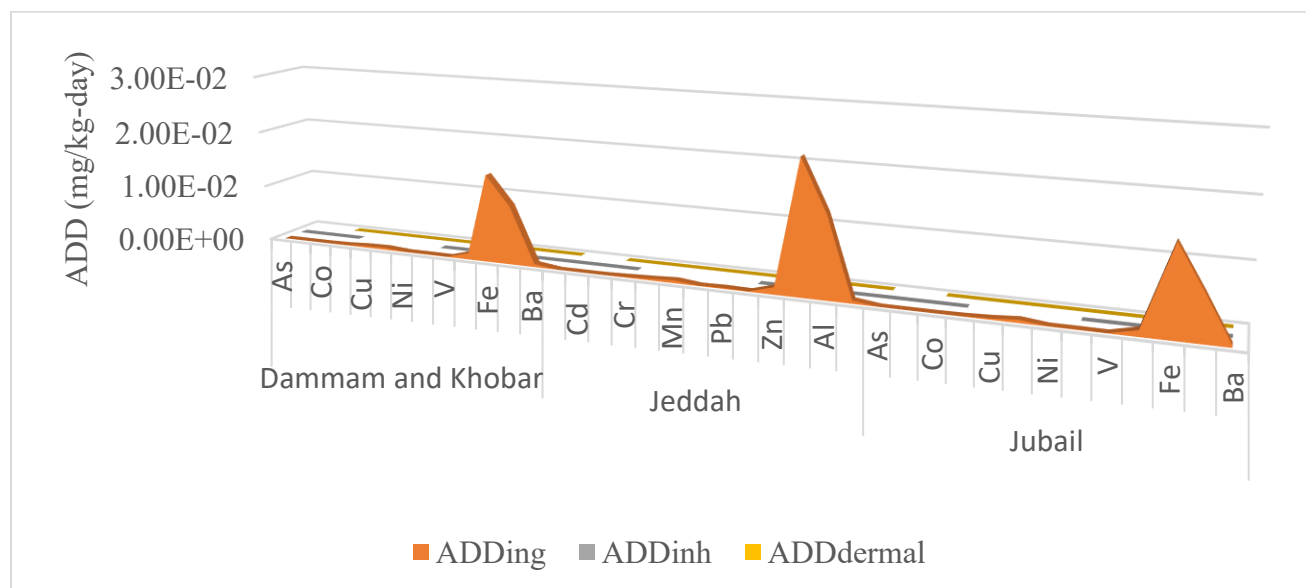


Figure 38 Average Daily Dose for Children

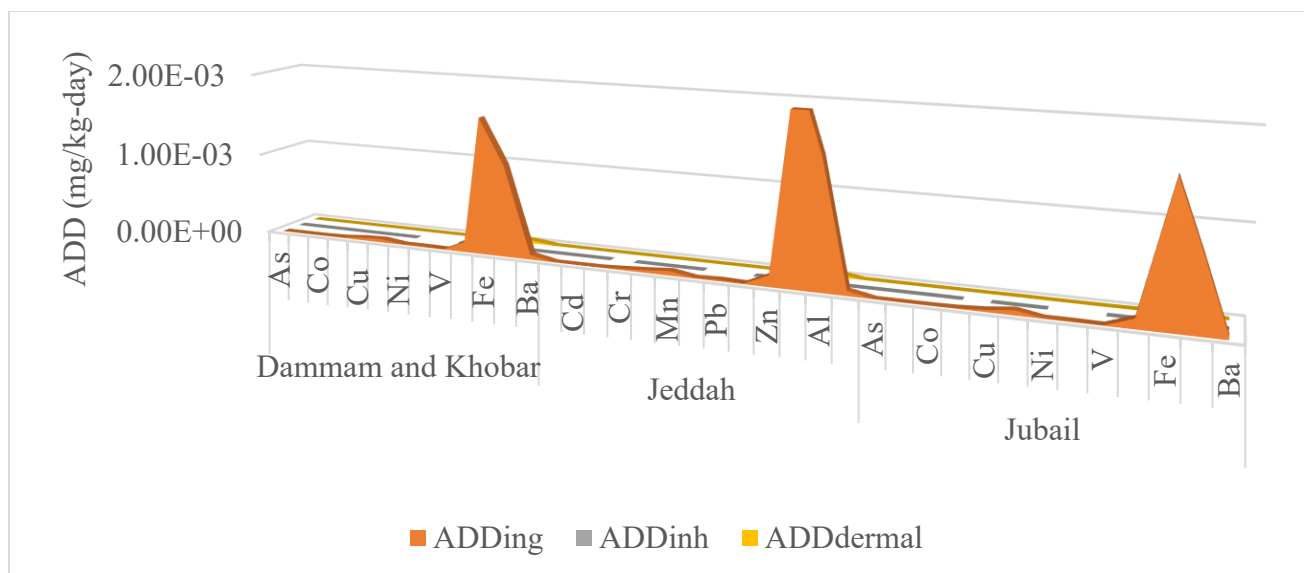


Figure 39 Average Daily Dose for Adult

4.6.2 Non-carcinogenic Risk

The term "non-carcinogenic risk" describes possible adverse health outcomes that are unrelated to the occurrence of cancer. It entails assessing the possibility and seriousness of health issues that might result from exposure to specific chemicals or environmental elements that are not proven to cause cancer. Non-carcinogenic risks are linked to other kinds of health problems, as opposed to carcinogens, which are compounds that have the potential to cause cancer. Using the ADD for HMs concentrations linked to the Ac filter of multiple Jubail, Dammam Khobar, and Jeddah in Tables 31 and 32 and the exposure factor values for children and adults (Table 8) as reference points, a computation of the HQ_{ing} , HQ_{inh} , HQ_{dermal} , aHI for both children and adults exposed to HMs was completed. The results of this computation are listed in Tables 30 and 31. In Figure 39, the values of HQ_{ing} , HQ_{inh} , and HI for children were found to be 9.09, 2.82, and 5.24 Jubail, 9.17, 2.78, and 5.32 Dammam and Khobar, and 9.33, 2.78, and 4.97 Jeddah times higher than adults in Jubail, Dammam, Khobar, and Jeddah respectively. In contrast, the HQ_{dermal} value was only 2.04 times higher than that of adults across all three populations. This increase in HM levels among

children compared to adults is likely due to their crawling habits and hand-to-mouth movements leading to greater ingestion of dust-containing HMs. This finding has been observed in prior studies (Alghamdi et al., 2019; Al-Harbi, Chemosphere, 2021).

Additionally, the HQ_{ing} value was higher than both HQ_{dermal} and HQ_{inh} , indicating a more non-cancer risk than inhalation and dermal exposure. Figure 45 shows the risk contributions of HQ_{inh} , HQ_{ing} , and HQ_{dermal} to the HI for children were calculated as 93.36%, 2.74%, and 3.90% Jubail, 93.78%, 4.50%, and 3.87% Dammam and Khobar, and 93.21%, 2.21%, and 4.58% Jeddah respectively. Similarly, the risk contributions of these elements to the HI for adults were found to be 52.79%, 5.20%, and 42.01% in Jubail, 52.49%, 4.50%, and 42.01% in Dammam and Khobar, 49.63%, 3.94 %, and 46.42 % in Jeddah. Ingestion was the primary route of exposure to HMs for adults and children, per the Ac filter of Jubail, Dammam, Khobar, and Jeddah. This is consistent with the results of past research studies on the topic (Alghamdi et al., 2019; Olujimi et al., 2015; Victor et al., 2018). According to USEPA (2011), if HQs are equal to or greater than 1, it suggests an unacceptable risk of harm to health. However, after assessing the HMs concentrations in Jubail, Dammam, Khobar, and Jeddah for both children and adults, the HQ_{ing} , HQ_{inh} , HQ_{dermal} , and HI values for individual HMs in Figures 40 and 41as well as $\sum HMs$ were found to be lower than 1, which indicates that there was no non-carcinogenic risk associated with any of these exposure routes. Regarding the contribution of HI to individual HM levels, Cr, As, and Pb were the most significant elements found in children. In all groups, Jubail, Dammam, Khobar, and Jeddah accounted for 18.32%, 17.45%, and 17.82%, respectively, of the value of $\sum HI$. When looking at each group separately, it was seen that Cr had the highest contribution with 25.20%, followed by Pb with 24.56%, while As contributed 9.06%. For both Jubail, Dammam, and Khobar, Cr had the

highest contribution at 18.75% and 16.86%, respectively, while Pb was marginally higher than As with 17.24% and 17 in Figures 39 and 40. For adults' in Figures 40 and 43, the concentration of Cr, As, and Pb were the most prominent elements in the indoor dust of Jubail, Dammam, Khobar, and Jeddah. Specifically, these three elements made up 10.46%, 9.87%, and 10.08% of Jubail, 10.80%, 9.62%, and 9.84% of Dammam and Khobar, and 13.55%, 4.82%, and 13.08% of Jeddah of the total potential hazard index (ΣHI). Thus, it is essential to be aware of possible non-carcinogenic risks associated with exposure to Cr, Pb, As, Mn, and V in these buildings due to their high concentrations in the dust. Regular monitoring and studies of potential hazards are needed to ensure the safety and health of people in buildings.

TABLE 31 Jubail Dammam and Khobar and Jeddah Hazard Quotient for Children

HM	Dammam and Khobar				Jubail				Jeddah			
	HQ _{ing}	HQ _{inh}	HQ _{derm}	HI	HQ _{ing}	HQ _{inh}	HQ _{derm}	HI	HQ _{ing}	HQ _{inh}	HQ _{derm}	HI
As	2.11E-02	5.89E-07	8.22E-05	2.11E-02	1.99E-02	5.56E-07	7.76E-05	2.00E-02	1.75E-02	4.89E-07	6.83E-05	1.76E-02
Cd	1.68E-03	4.72E-08	2.69E-04	1.95E-03	1.51E-03	4.24E-08	2.42E-04	1.75E-03	2.00E-03	5.61E-08	3.20E-04	2.32E-03
Co	4.57E-04	4.49E-05	9.14E-07	5.03E-04	3.19E-04	3.14E-05	6.39E-07	3.51E-04	7.79E-04	7.65E-05	1.56E-06	8.57E-04
Cr	2.34E-02	6.89E-05	2.25E-03	2.57E-02	2.09E-02	6.14E-05	2.00E-03	2.29E-02	4.86E-02	1.43E-04	4.67E-03	5.35E-02
Cu	7.24E-03	2.02E-07	3.86E-05	7.28E-03	5.59E-03	1.56E-07	2.98E-05	5.62E-03	7.53E-03	2.10E-07	4.02E-05	7.57E-03
Mn	8.02E-03	7.40E-04	3.28E-04	9.09E-03	1.14E-02	1.05E-03	4.66E-04	1.29E-02	1.08E-02	9.99E-04	4.43E-04	1.23E-02
Ni	3.34E-03	9.09E-08	1.98E-05	3.36E-03	3.03E-03	8.26E-08	1.80E-05	3.05E-03	3.77E-03	1.03E-07	2.24E-05	3.80E-03
Pb	2.15E-02	6.01E-07	2.30E-04	2.18E-02	2.03E-02	5.66E-07	2.17E-04	2.05E-02	4.74E-02	1.32E-06	5.06E-04	4.79E-02
V	6.48E-03	1.82E-07	1.04E-03	7.52E-03	5.66E-03	1.59E-07	9.05E-04	6.56E-03	1.26E-02	3.53E-07	2.01E-03	1.46E-02
Zn	3.85E-03	1.08E-07	3.08E-05	3.88E-03	3.54E-03	9.92E-08	2.83E-05	3.57E-03	4.25E-03	1.19E-07	3.40E-05	4.28E-03
Fe	1.84E-03	1.97E-03	3.54E-04	4.17E-03	1.79E-03	1.91E-03	3.43E-04	4.04E-03	2.74E-03	2.93E-03	5.26E-04	6.20E-03
Al	1.04E-02	5.80E-07	1.66E-05	1.04E-02	7.86E-03	4.40E-07	1.26E-05	7.88E-03	1.42E-02	7.95E-07	2.28E-05	1.42E-02
Ba	7.81E-03	1.07E-04	1.78E-04	8.09E-03	4.61E-03	6.33E-05	1.05E-04	4.78E-03	7.68E-03	1.06E-04	1.76E-04	7.96E-03

TABLE 32 Jubail Dammam and Khobar and Jeddah Hazard Quotient for Adults

HM	Dammam and Khobar				Jubail				Jeddah			
	HQ _{ing}	HQ _{inh}	HQ _{derm}	HI	HQ _{ing}	HQ _{inh}	HQ _{derm}	HI	HQ _{ing}	HQ _{inh}	HQ _{derm}	HI
As	2.26E-03	2.12E-07	1.68E-04	2.42E-03	2.13E-03	2.00E-07	1.58E-04	2.29E-03	1.87E-03	1.76E-07	1.39E-04	2.01E-03
Cd	1.80E-04	1.70E-08	5.49E-04	7.29E-04	1.62E-04	1.52E-08	4.93E-04	6.54E-04	2.14E-04	2.02E-08	6.53E-04	8.67E-04
Co	4.90E-05	1.61E-05	1.86E-06	6.70E-05	3.42E-05	1.13E-05	1.30E-06	4.68E-05	8.34E-05	2.75E-05	3.18E-06	1.14E-04
Cr	2.51E-03	2.48E-05	4.58E-03	7.12E-03	2.24E-03	2.21E-05	4.09E-03	6.35E-03	5.21E-03	5.15E-05	9.52E-03	1.48E-02
Cu	7.76E-04	7.27E-08	7.88E-05	8.55E-04	5.98E-04	5.60E-08	6.07E-05	6.59E-04	8.07E-04	7.56E-08	8.19E-05	8.89E-04
Mn	8.60E-04	2.66E-04	6.69E-04	1.79E-03	1.22E-03	3.78E-04	9.51E-04	2.55E-03	1.16E-03	3.59E-04	9.03E-04	2.42E-03
Ni	3.58E-04	3.27E-08	4.03E-05	3.98E-04	3.25E-04	2.97E-08	3.67E-05	3.62E-04	4.04E-04	3.70E-08	4.56E-05	4.50E-04
Pb	2.31E-03	2.16E-07	4.68E-04	2.78E-03	2.18E-03	2.04E-07	4.42E-04	2.62E-03	5.08E-03	4.75E-07	1.03E-03	6.11E-03
V	6.95E-04	6.54E-08	2.12E-03	2.81E-03	6.06E-04	5.71E-08	1.85E-03	2.45E-03	1.35E-03	1.27E-07	4.11E-03	5.45E-03
Zn	4.13E-04	3.89E-08	6.29E-05	4.76E-04	3.79E-04	3.57E-08	5.77E-05	4.37E-04	4.55E-04	4.29E-08	6.93E-05	5.25E-04
Fe	1.97E-04	7.09E-04	7.21E-04	1.63E-03	1.91E-04	6.87E-04	6.99E-04	1.58E-03	2.93E-04	1.05E-03	1.07E-03	2.42E-03
Al	1.11E-03	2.09E-07	3.38E-05	1.15E-03	8.43E-04	1.58E-07	2.57E-05	8.68E-04	1.52E-03	2.86E-07	4.64E-05	1.57E-03
Ba	8.36E-04	3.85E-05	3.64E-04	1.24E-03	4.94E-04	2.27E-05	2.15E-04	7.31E-04	8.23E-04	3.79E-05	3.58E-04	1.22E-03

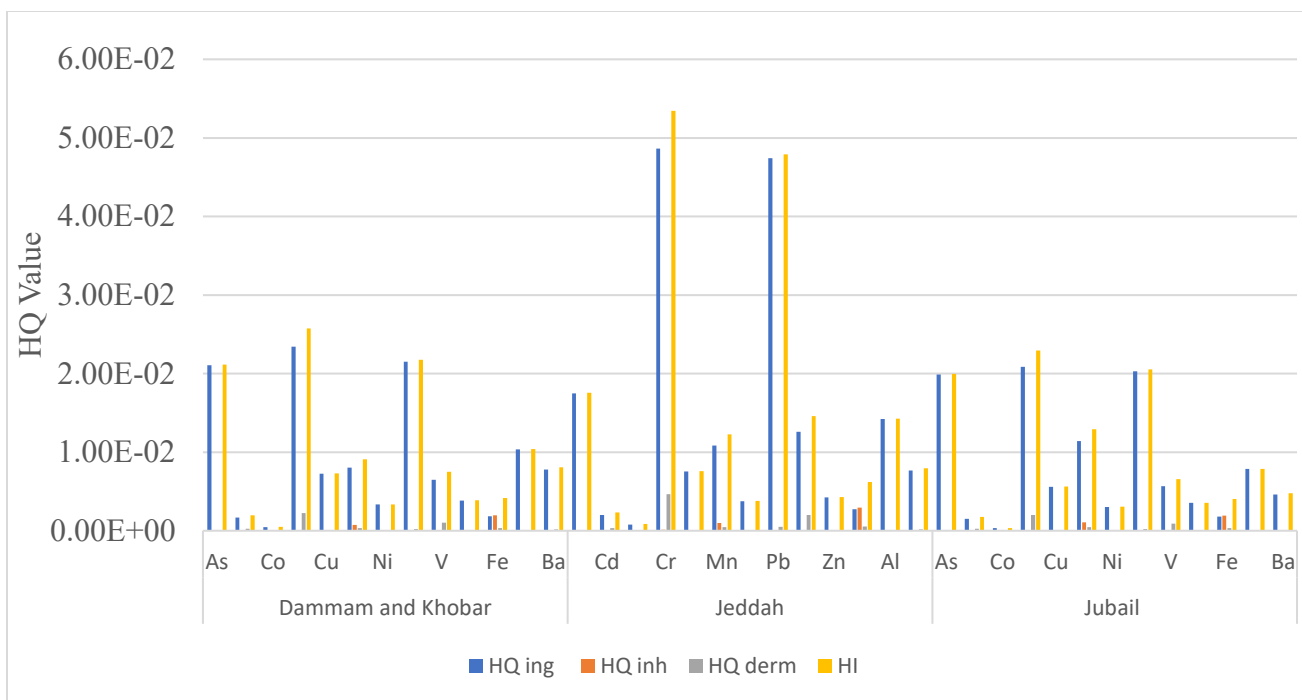


Figure 40 HI values for individual HMs for Children

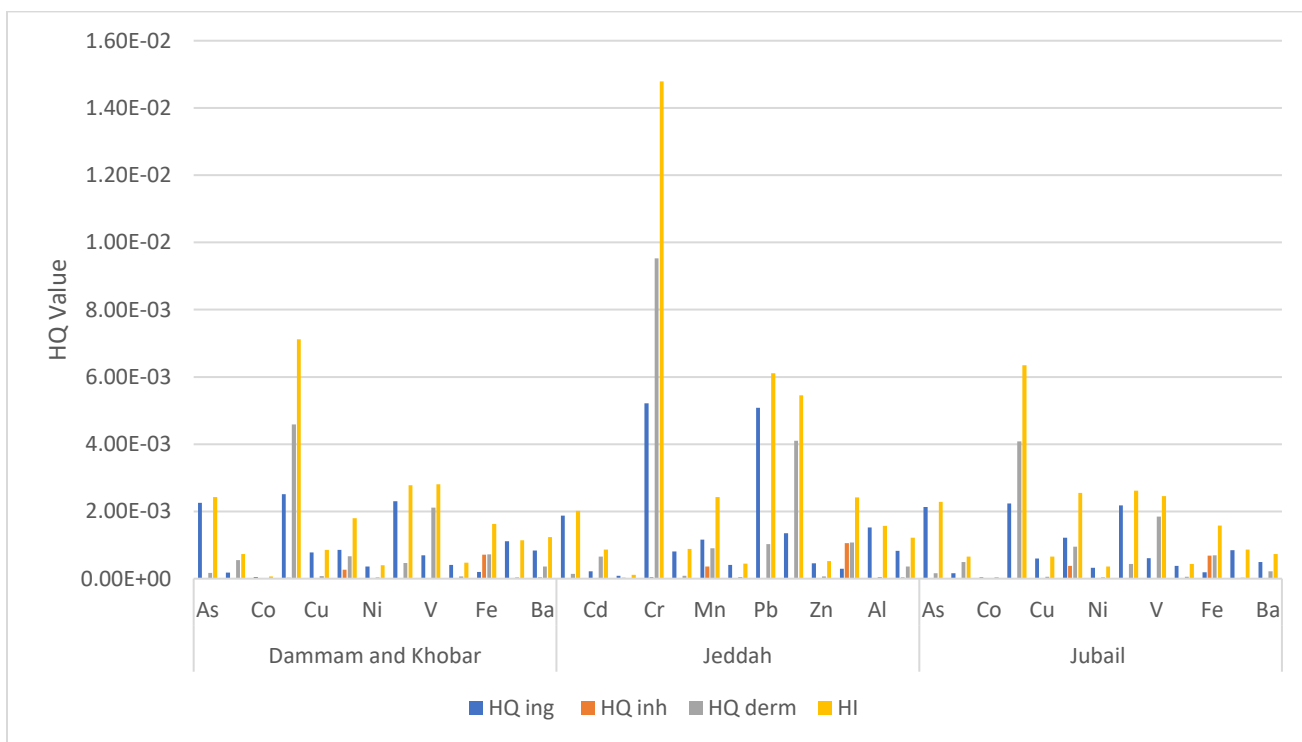


Figure 41 HI values for individual HMs for Adults

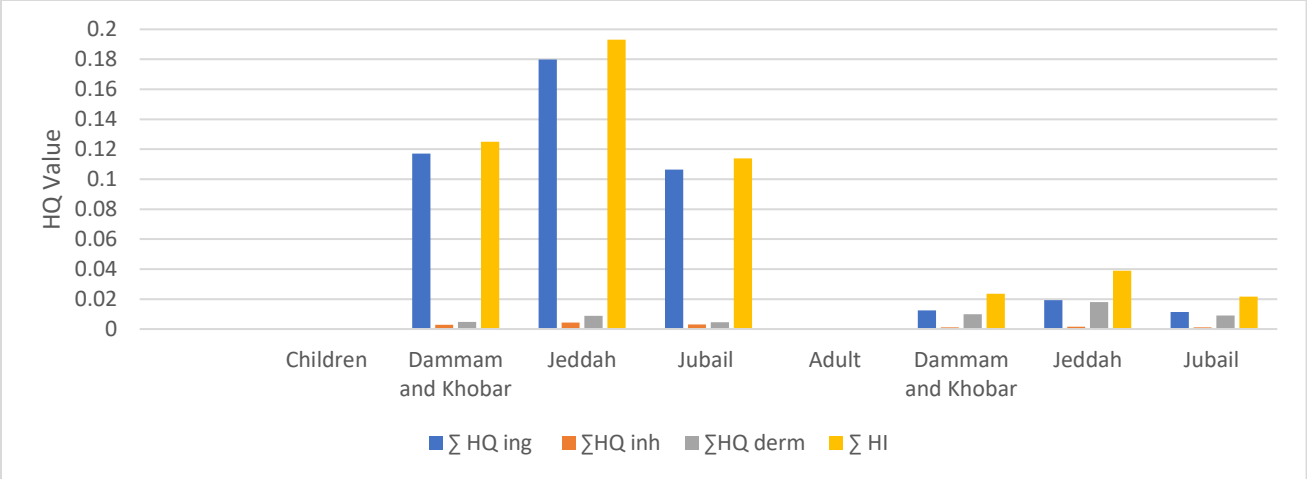


Figure 42 HQ and HI Total Values

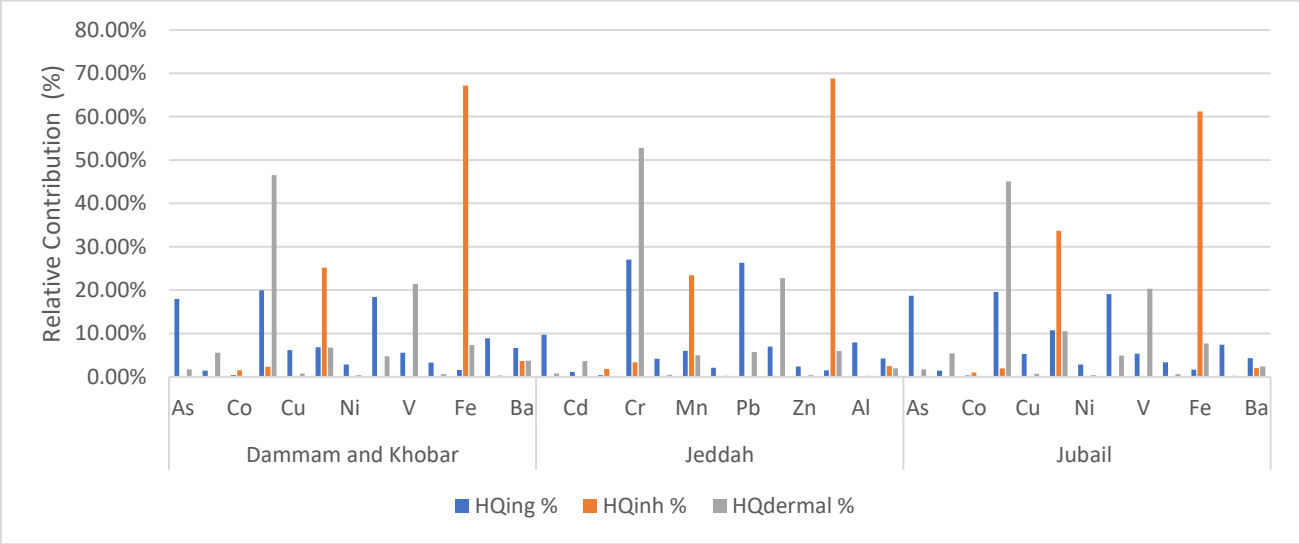


Figure 43 HQ Individual Relative Contribution for Children

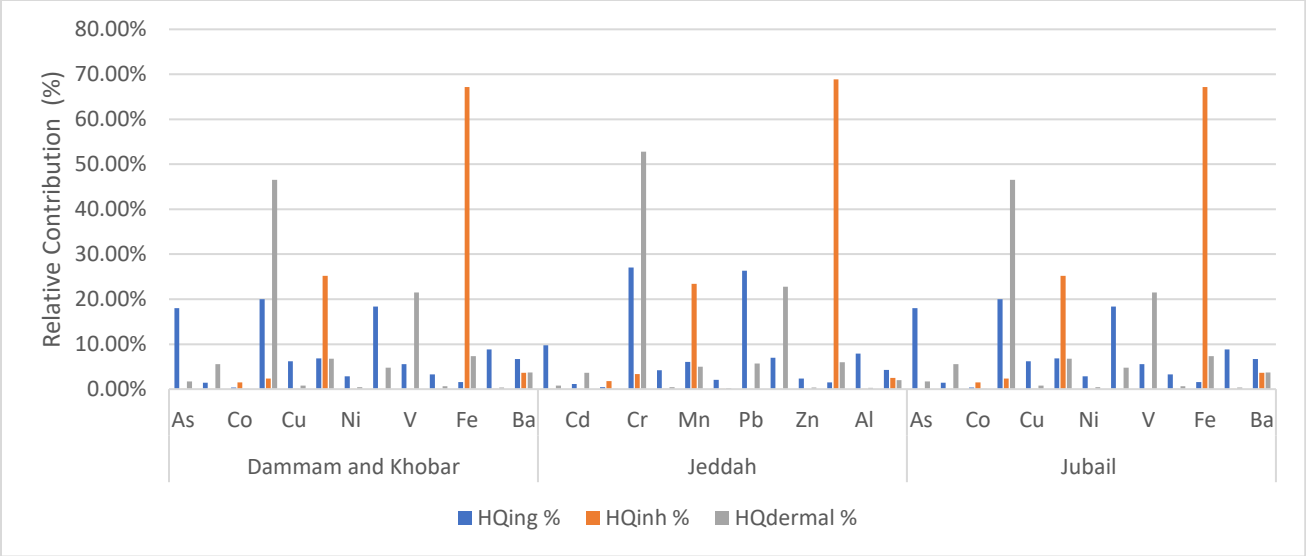


Figure 44 HQ Individual Relative Contribution for Adults

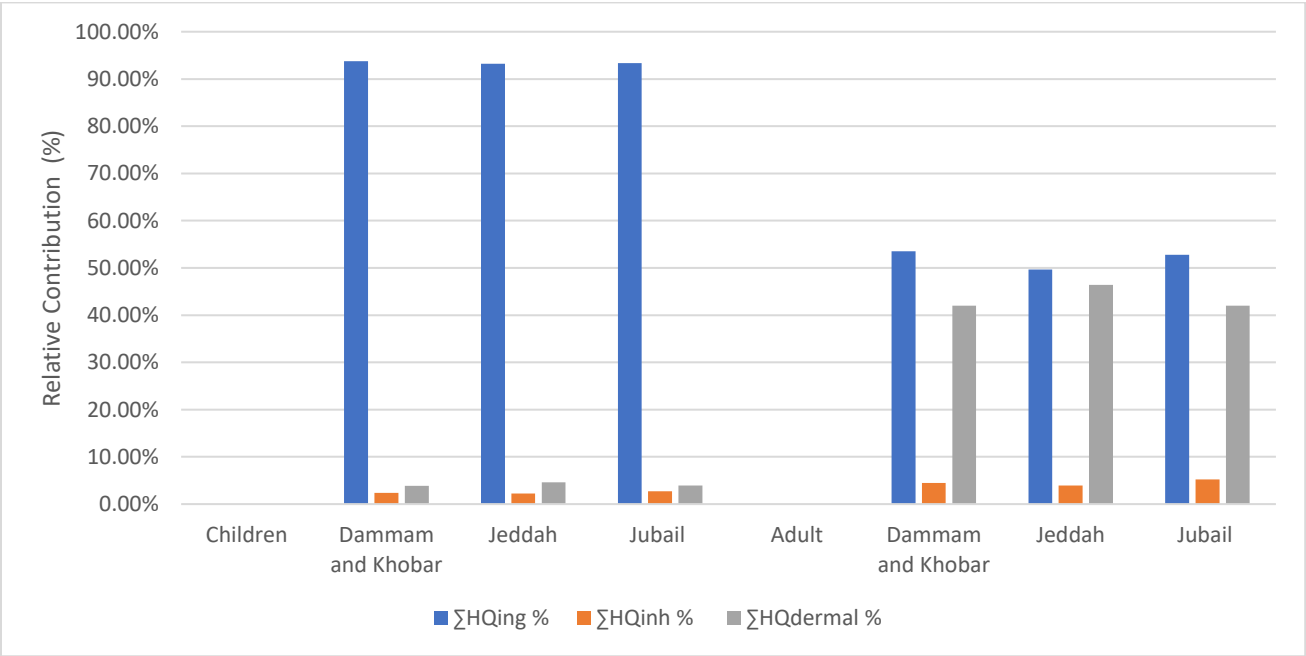


Figure 45 Relative Contribution for Total HQ

4.6.3 Carcinogenic Risk

The possibility that exposure to a chemical or environmental component might result in the development of cancer is known as the carcinogenic risk. An essential component of determining the possible health risks connected to certain chemicals, pollutants, or other agents is doing a risk assessment. The evaluation entails estimating the likelihood and severity of injury while accounting for variables including exposure quantity and duration, carcinogen potency, and individual vulnerability. To assess carcinogenic risk for both adults and children, thirteen HMs were measured, and then LCRs for six HMs, which included Pb, Ni, Cr, Co, Cd, and As in the AC filter of Jubail, Dammam, Khobar, and Jeddah, were considered [54]. Table 33 shows the calculated LCRs as well as the total cancer risk. The LCRs calculated include LCR_{ing} , LCR_{inh} , and LCR_{dermal} . $CR = (LRC_{ing} + LRC_{inh} + LCR_{dermal})$ gives the total cancer risk. LCR_{ing} , LCR_{inh} , and CR were higher in children than adults. The opposite was true for LCR_{dermal} in Jubail, Dammam, Khobar, and Jeddah. The LRC_{inh} and LCR_{ing} for children were 2.78 and 9.33 times more than that of adults. For adults, the LCR_{dermal} was 2.04 times more than that of children. Furthermore, for children, CR was 5.27 times higher compared to adults. This confirms that exposing children to indoor building dust causes more harm to them than to adults. The sequence of CR and LCRs for adults and children from this exposure to individuals and HMs in the AC filter of the distinct buildings was Jeddah>Dammam and Khobar>Jubail.

The cancer risk difference among these buildings in the selected three cities reveals the considerable consequences of HMs' source emissions on health risk. Based on the adults and children exposure pathways, the values of LCRs increased as follows: inhalation< dermal contact< ingestion in Jubail, Dammam, Khobar, and Jeddah, as shown in Figure 45. The risks contributed

by LCR_{ing} , LRC_{inh} , and LCR_{dermal} to cancer risk coming from the exposure of all the measured elements in the buildings were 95.83%, 0.05%, and 4.12% of Jubail, 95.81%, 0.05%, and 4.13% of Dammam and Khobar, and 95.46%, 0.08%, and 4.46% of Jeddah in children. For adults, this was 44.94% of Jubail, 54.86%, 0.10%, 45.04% of Dammam and Khobar, and 52.85%, 0.15%, and 47.00% for Jeddah in Figure 45. Ingestion in children and adults was revealed to be the primary exposure pathway for HMs, with AC filters of Jubail, Dammam, Khobar, and Jeddah. This was then followed by inhalation and dermal pathways. This corresponds to past studies, which revealed that ingesting and dermal pathways were the leading cause of most cancer risks (Shabbaj et al., 2018); Mansour et al., 2023).

Based on the cancer risk values for individual HMs, the concentration of Ni and Cr in the AC filter of the buildings revealed high carcinogenic levels when a comparison is made with the other elements in adults and children, as shown in Figures 45 and 46. When a comparison is made with individual CR to total CR 71.04, 70.91, and 60.21% in children and 69.00, 68.75, and 56.45% in adults of the cancer risk for HMs in Jubail, Dammam, Khobar, and Jeddah this is represented in Figure 47. In Jeddah, the indoor dust comprised higher levels of Ni to CR (Shabbaj et al., 2018). The values of CR, LCR_{ing} , LRC_{inh} , and LCR_{dermal} for individual HMs of Figure 42 and 43 in the buildings of the studied three cities were lower or within the acceptance level, which is 1×10^{-6} – 1×10^{-4} except LCR_{ing} of Ni which was 1.28×10^{-4} , 1.13×10^{-4} and 1.03×10^{-4} in Jeddah, Jubail, Dammam, and Khobar, which was one of the findings in a previous study (Alghamdi et al., 2019).

TABLE 33 All Cities Carcinogenic Risk for Children and Adults

City	HM	Children				Adults			
		LCR _{ing}	LCR _{inh}	LCR _{dermal}	ΣCR	LCR _{ing}	LCR _{inh}	LCR _{dermal}	ΣCR
Jubail	As	8.95E-06	2.51E-10	7.16E-08	9.02E-06	9.59E-07	9.02E-11	1.46E-07	1.10E-06
	Cd	5.74E-07	1.61E-11	1.47E-08	5.88E-07	6.15E-08	5.79E-12	3.00E-08	9.15E-08
	Co	-	1.76E-09	-	1.76E-09	-	6.31E-10	-	6.31E-10
	Cr	3.13E-05	7.38E-08	2.00E-06	3.34E-05	3.36E-06	2.65E-08	4.09E-06	7.47E-06
	Ni	1.03E-04	1.43E-09	4.13E-06	1.07E-04	1.10E-05	5.14E-10	8.41E-06	1.95E-05
	Pb	7.11E-07	7.98E-11	1.14E-09	7.12E-07	7.62E-08	2.87E-11	2.32E-09	7.85E-08
Dammam and Khobar	As	9.48E-06	2.66E-10	7.58E-08	9.55E-06	1.02E-06	9.56E-11	1.55E-07	1.17E-06
	Cd	6.39E-07	1.79E-11	1.64E-08	6.56E-07	6.85E-08	6.44E-12	3.35E-08	1.02E-07
	Co	-	2.51E-09	-	2.51E-09	-	9.03E-10	-	9.03E-10
	Cr	3.51E-05	8.28E-08	2.25E-06	3.75E-05	3.76E-06	2.98E-08	4.58E-06	8.38E-06
	Ni	1.13E-04	1.57E-09	4.54E-06	1.18E-04	1.22E-05	5.65E-10	9.26E-06	2.14E-05
	Pb	7.54E-07	8.46E-11	1.21E-09	7.55E-07	8.07E-08	3.04E-11	2.46E-09	8.32E-08
Jeddah	As	7.87E-06	2.21E-10	6.30E-08	7.93E-06	8.43E-07	7.94E-11	1.28E-07	9.72E-07
	Cd	7.60E-07	2.13E-11	1.95E-08	7.80E-07	8.15E-08	7.67E-12	3.98E-08	1.21E-07
	Co	-	4.28E-09	-	4.28E-09	-	1.54E-09	-	1.54E-09
	Cr	7.30E-05	1.72E-07	4.67E-06	7.78E-05	7.82E-06	6.18E-08	9.52E-06	1.74E-05
	Ni	1.28E-04	1.78E-09	5.13E-06	1.33E-04	1.38E-05	6.39E-10	1.05E-05	2.42E-05
	Pb	1.66E-06	1.86E-10	2.65E-09	1.66E-06	1.78E-07	6.69E-11	5.41E-09	1.83E-07

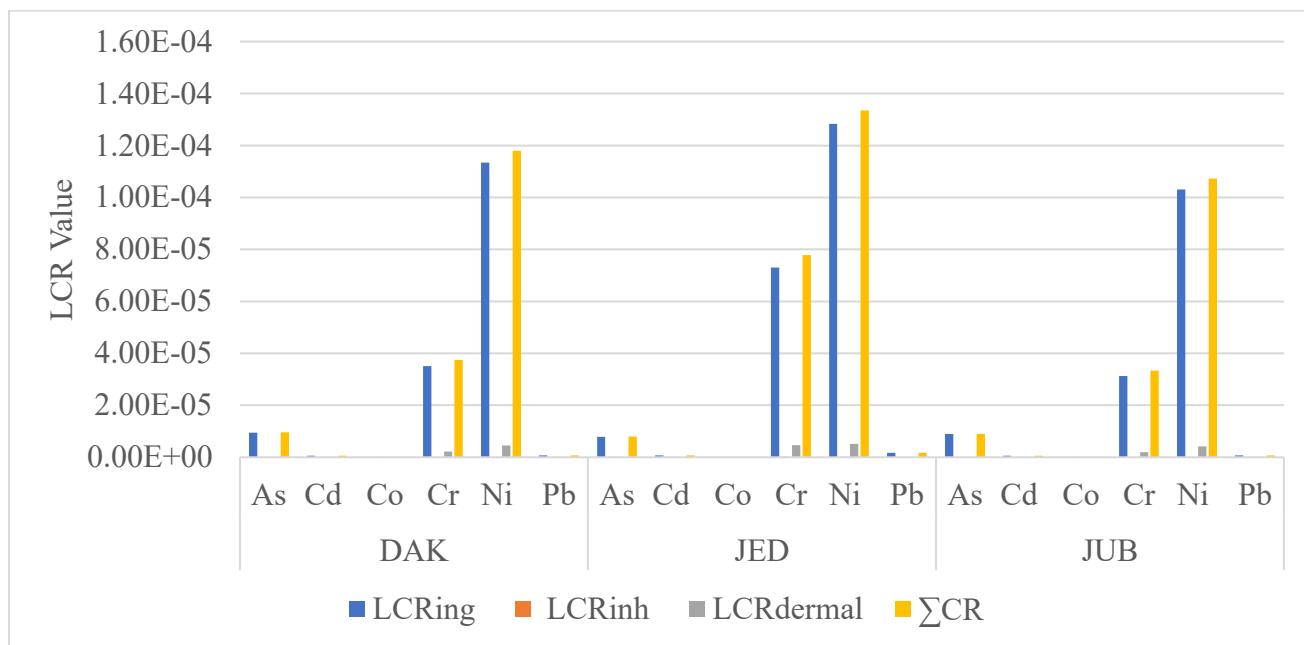


Figure 46 LCR values for individual HMs for Children

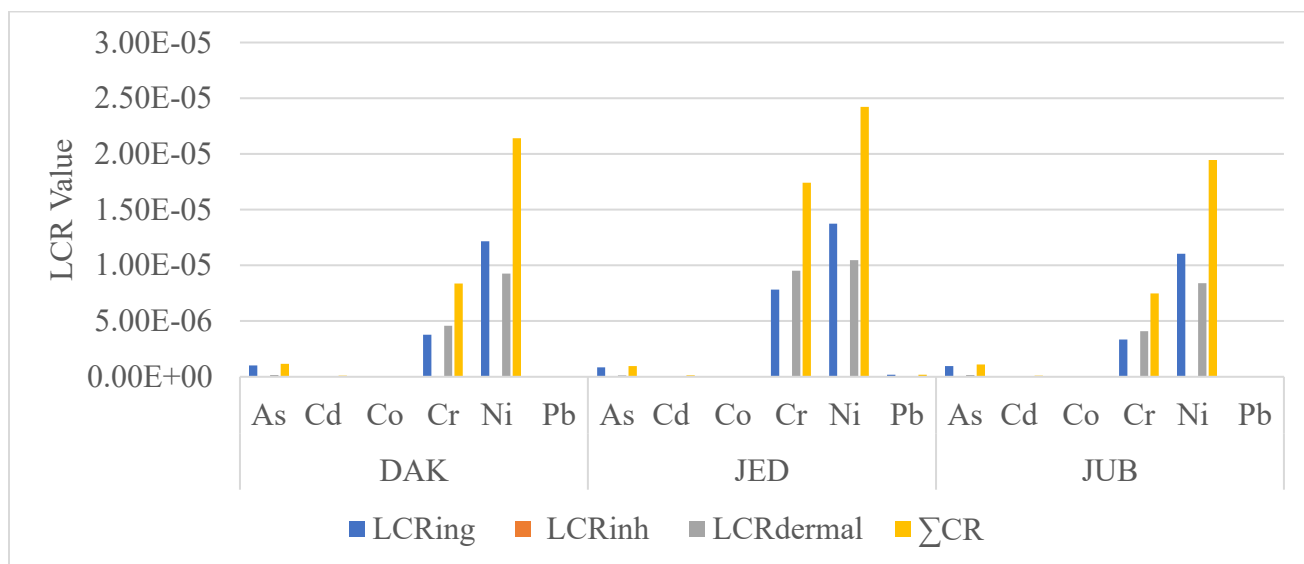


Figure 47 LCR values for individual HMs for Adults

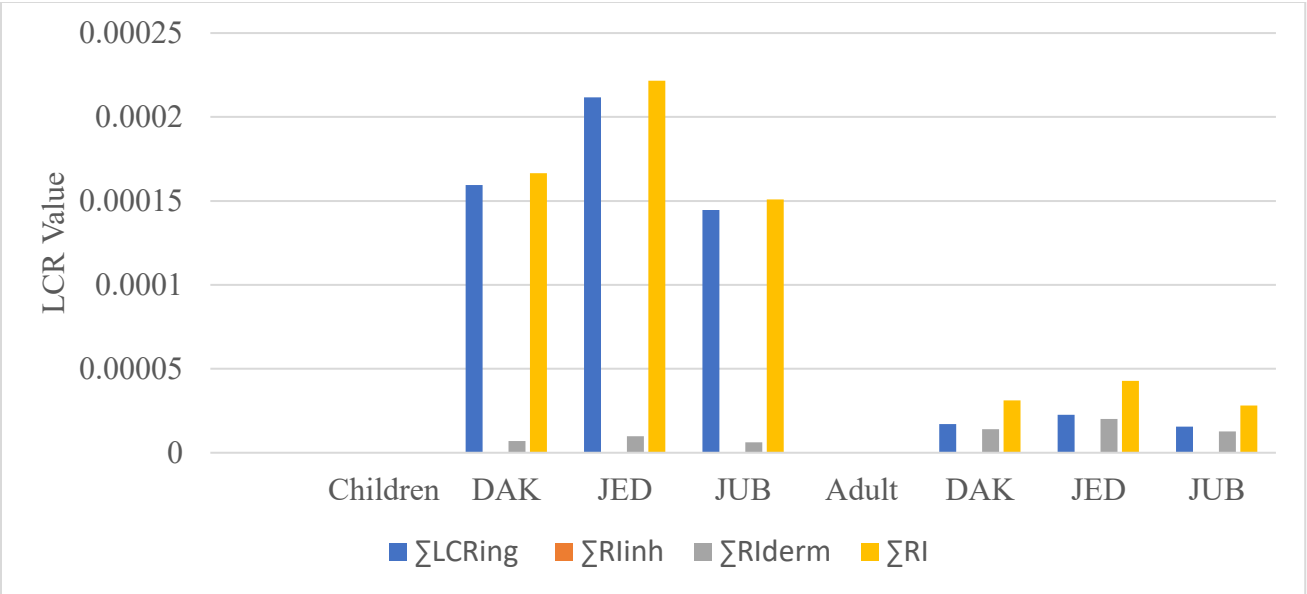


Figure 48 CR values for children and adults

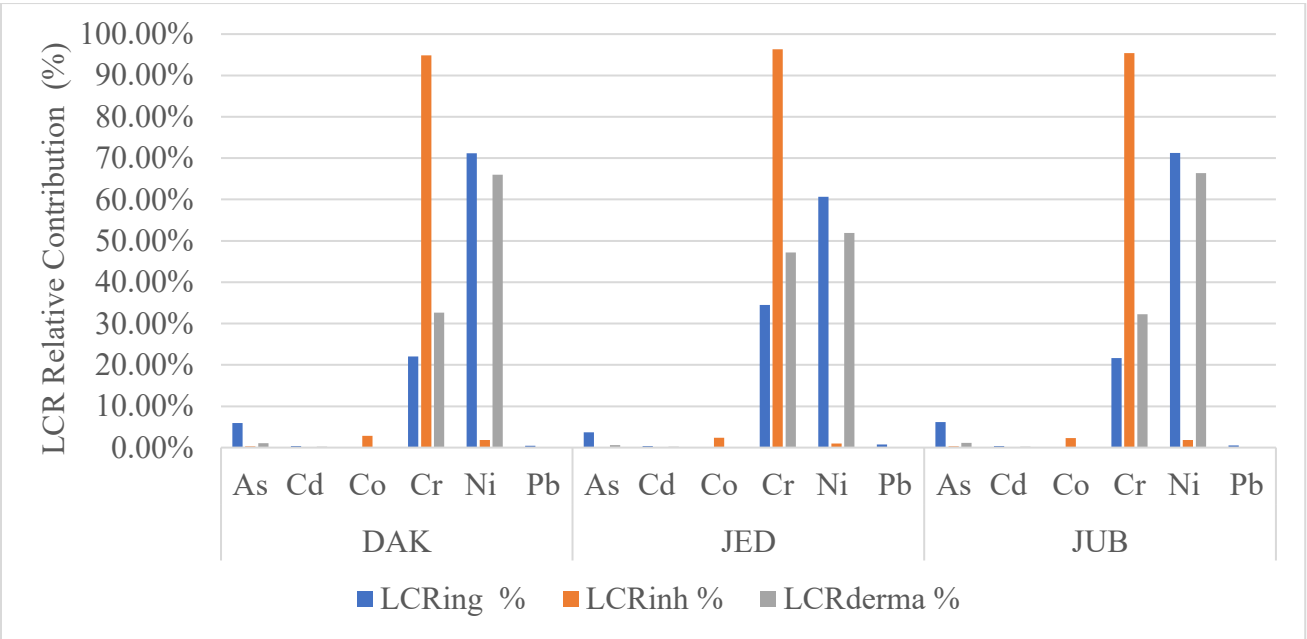


Figure 49 LCR Individual Relative Contribution for Children

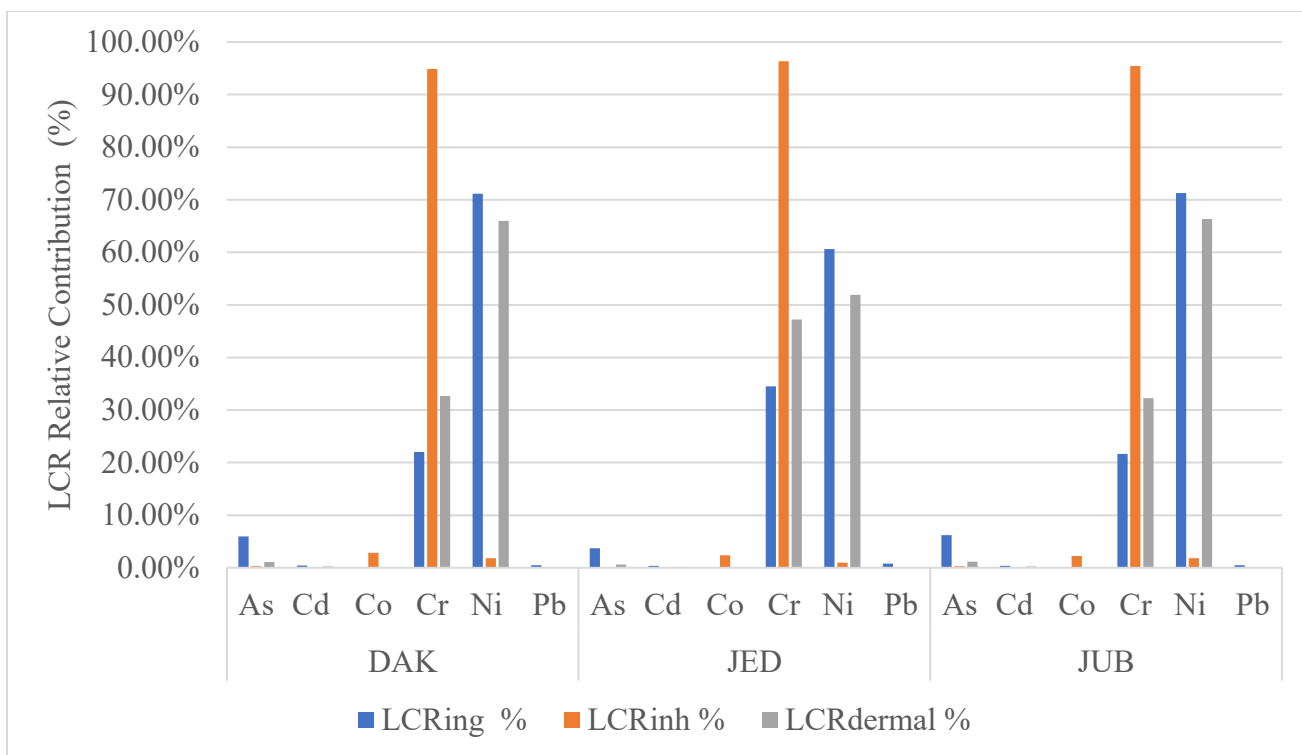


Figure 50 LCR individual relative contribution for adults

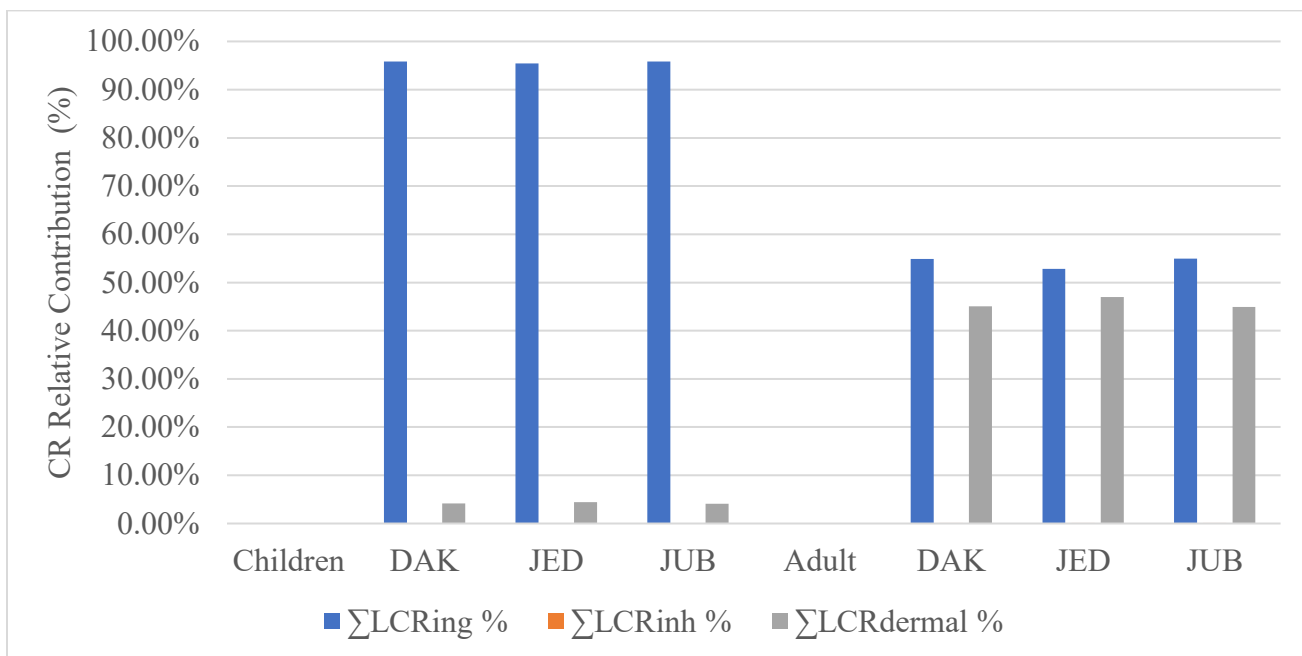


Figure 51 Relative Contribution for CR

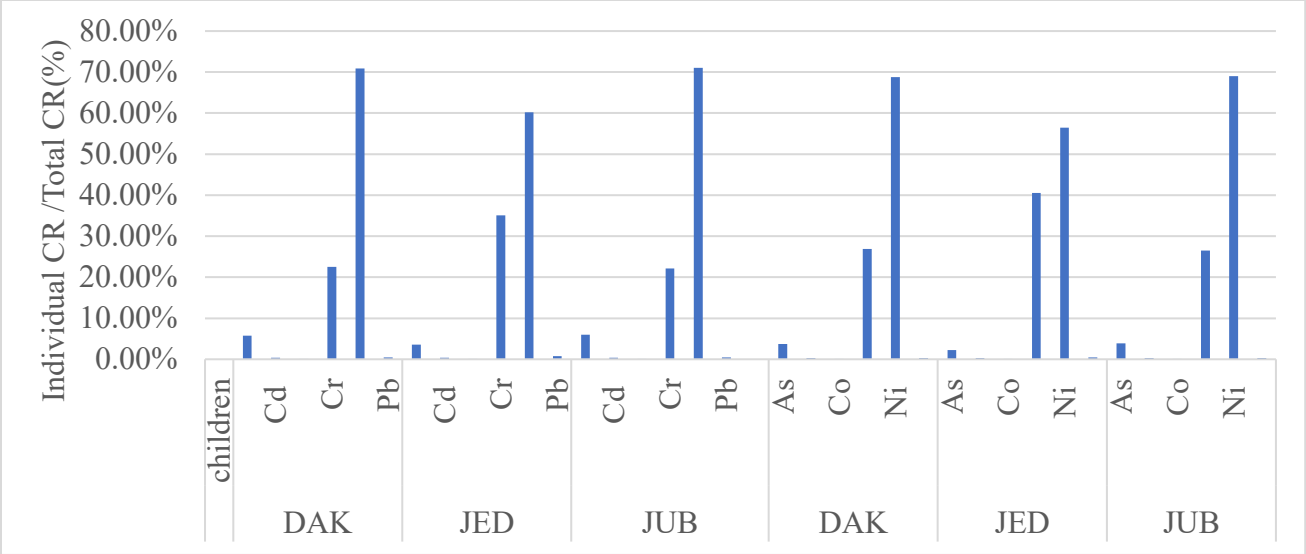


Figure 52 Individual CR /Total CR

4.7 PM Instantaneous Measuring

pDR-1500 was used to measure $PM_{2.5}$ and PM_{10} indoors and outdoors for three locations in each city: industrial, residential, and suburban areas, except Jeddah, which was only measured in the residential and suburban areas. With pDR-1500 data, the AQIs were calculated for each area and city. AQI of any area talks about air quality and its potential impacts on human health. The US EPA has provided guidelines that help to categorize AQI into different categories based on their potential health impacts. Reports showed that an AQI of 50 is healthy for human health, and 100 is a moderate level, while above this level, pollutants can cause significant destructive health impacts. Figures 52 and 53 show that AQI for most regions falls under moderate AQI. When interpreted with pDR-1500 for every area and especially for industrial areas in Dammam, it is found that outdoor AQI is categorized as unhealthy for everyone. In addition, it is polluted with fine-sized particulate matter ($PM_{2.5}$) regions; it causes health effects such as asthma, bronchitis, cardiovascular diseases, etc., from the outside atmosphere. Furthermore, only a few locations, such as industrial residential and suburban areas of Khobar, showed moderate air quality that is unhealthy for sensitive people if they are exposed for several hours; otherwise, it is moderate for everyone (i.e., those who have asthma, bronchitis, cardiovascular diseases, etc.).

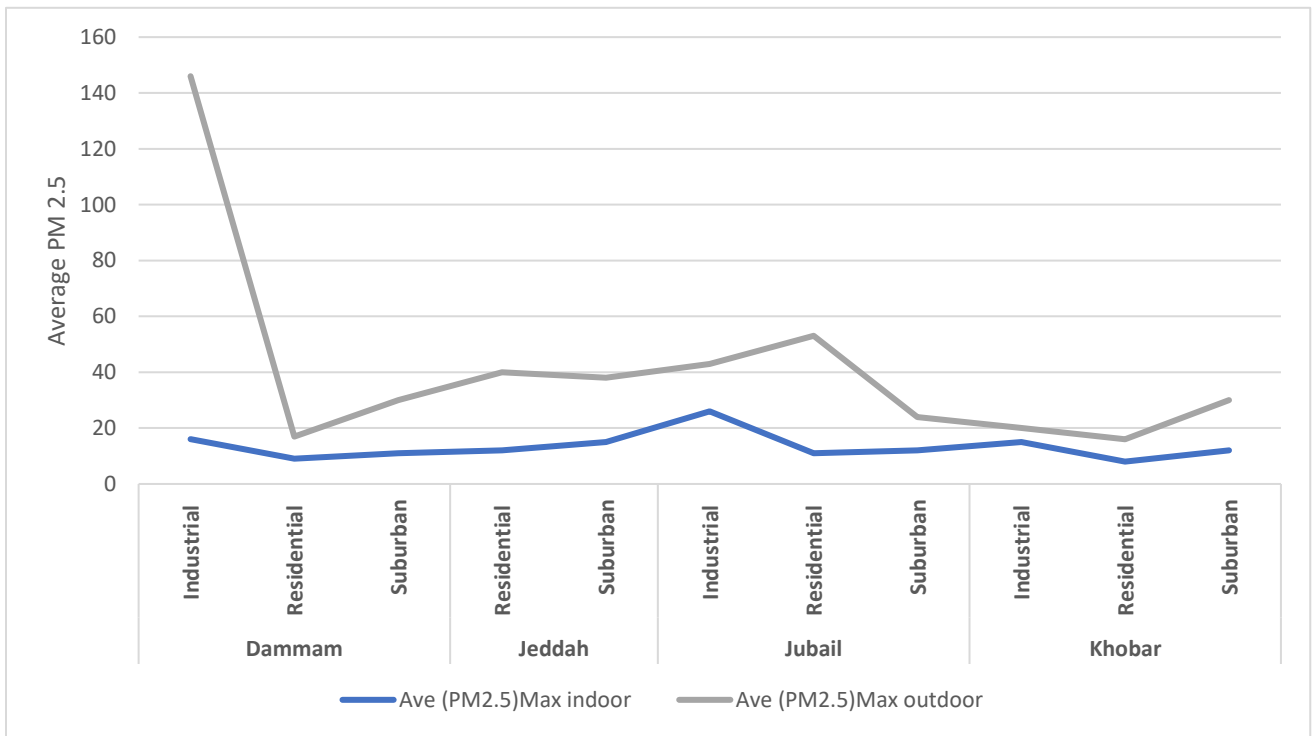


Figure 53 All Cities Average AQI for PM 2.5 Indoor and Outdoor

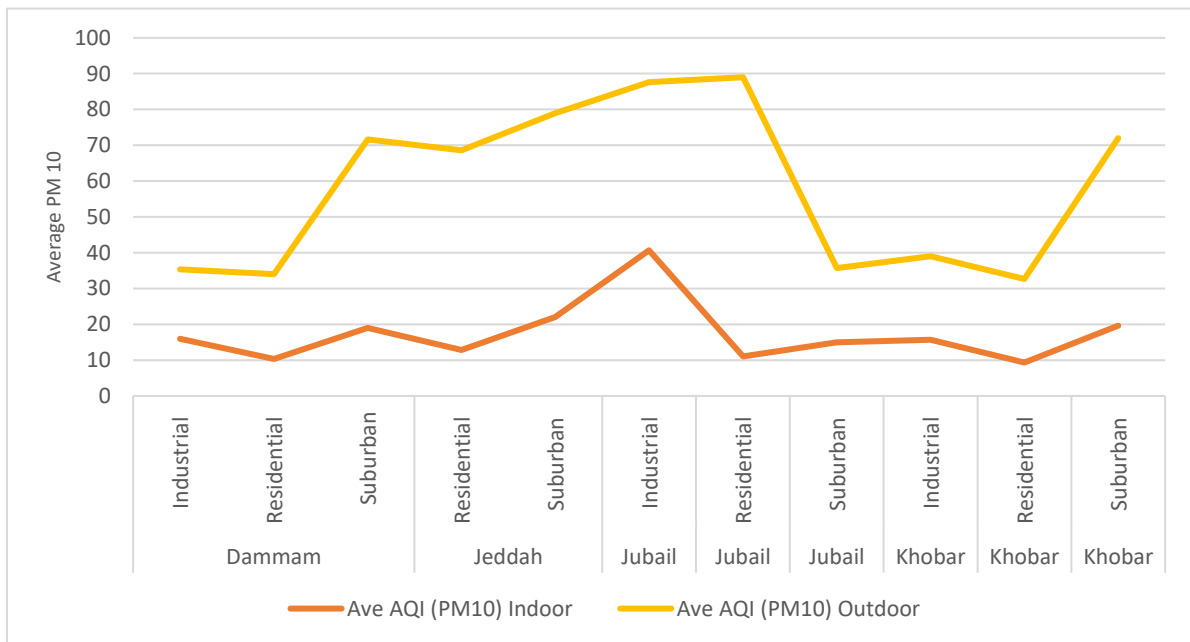


Figure 54 All Cities Average AQI for PM 10 Indoor and Outdoor

4.7.1 PMs Instantaneous Measuring and AQI for Jubail

Table 33 has the pDR-1500 data for the PM_{10} and $PM_{2.5}$ in Jubail. The data was gathered for different areas, such as industrial, residential, and suburban, for three different locations for each. However, the data was collected for maximum and fluctuated values to estimate the AQI of the area. After the analysis in Figure 54, Jubail is among the highly polluted cities with unhealthy outdoor $PM_{2.5}$ AQI for sensitive people. However, the outdoor air is badly affected by PM_{10} and $PM_{2.5}$. For PM_{10} , the bar chart reached up to 91, which is moderate, while for $PM_{2.5}$, it exceeds up to 150 AQI. The AQI average increased to 76, 119, and 119 for $PM_{2.5}$ and 36, 88, and 89 for PM_{10} in suburban, Industrial, and Residential areas, respectively.

Moreover, Figure 54 shows that indoor air has moderate AQI for $PM_{2.5}$ and is suitable for PM_{10} . For PM_{10} , the bar chart reached 41, which is good, while for $PM_{2.5}$, it reached up to 80 AQI. The AQI average rose 44, 50, and 79 for $PM_{2.5}$ and 11, 15, and 41 for PM_{10} in suburban, Industrial, and Residential areas, respectively. Figure 54 shows the same sequence of outdoor and indoor air quality areas.

TABLE 34 PMs Instantaneous Measuring and AQI for Jubail

AREA	Indoor								Outdoor							
	PM _{2.5} ug/m ³				PM ₁₀ ug/m ³				PM _{2.5} ug/m ³				PM _{2.5} ug/m ³			
	P M _{2.5}	Ave	AQI	P M _{2.5}	Ave	Ave	PM _{2.5}	Ave	P M _{2.5}	P M _{2.5}	Ave	Ave AQI	P M _{2.5}	Ave	AQI	PM _{2.5}
Industrial	26	26	80	79	45	44	41	41	43	43	120	119	130	130	88	88
	26		79		44		41		43		119		130		88	
	25		78		43		40		42		117		129		87	
Residential	10	11	40	44	13	13	11	11	52	53	142	144	131	132	88	89
	13		54		13		12		55		150		136		91	
	9		38		12		10		52		141		130		88	
Suburban	12	12	48	50	16	17	15	15	23	24	75	76	38	39	35	36
	12		51		17		15		24		76		39		36	
	12		51		17		15		24		76		39		36	

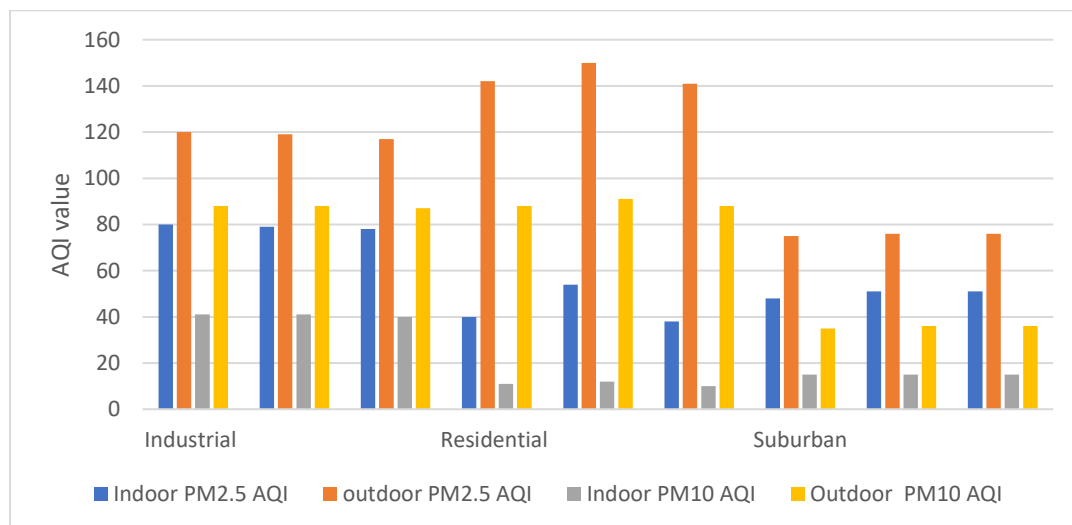


Figure 55 AQI of Jubail

4.7.2 PMs Instantaneous Measuring and AQI for Dammam

Table 34 has the pDR-1500 data for the PM_{10} and $PM_{2.5}$ in Dammam. The data was gathered for different areas, such as industrial, residential, and suburban, for three different locations for each. However, the data was collected for maximum and fluctuated values to estimate the area's AQI.

After the analysis in Figure 55, Dammam is the most polluted city with unhealthy outdoor $PM_{2.5}$ AQI. However, the outdoor air is badly affected by PM_{10} and $PM_{2.5}$. For PM_{10} , the bar chart reached up to 72, which is moderate, while for $PM_{2.5}$, it exceeds up to 198 AQI. The AQI average increased by 62, 88, and 197 for $PM_{2.5}$ in Residential, suburban, and industrial areas, respectively, and 34, 35, and 72 for PM_{10} in suburban, Industrial, and Residential areas, respectively.

Moreover, Figure 55 shows that indoor air has moderate to good AQI for $PM_{2.5}$ and is suitable for PM_{10} . For PM_{10} , the bar chart reached up to 19, which is good, while for $PM_{2.5}$, it reached up to 60 AQI. The AQI average rose 36, 47, and 59 for $PM_{2.5}$ in residential, suburban, and industrial areas, respectively, and 10, 16, and 19 for PM_{10} in residential, industrial, and suburban areas, respectively. Figure 55 shows the same sequence of areas in the outdoor and indoor air quality for $PM_{2.5}$.

TABLE 35 PMs Instantaneous Measuring and AQI for Dammam

AREA	Indoor								Outdoor							
	PM _{2.5} ug/m ³				PM ₁₀ ug/m ³				PM _{2.5} ug/m ³				PM ₁₀ ug/m ³			
	PM _{2.5}	Ave	AQ I	Ave AQ I	PM ₁₀	Ave	AQ I	Ave AQ I	PM _{2.5}	Ave	AQ I	Ave AQ I	PM ₁₀	Ave	AQ I	Ave AQ I
Industrial	16.4	16	60	59	18.3	18	17	16	146	146	198	197	39.4	39	36	35
	15.9		59		17.6		16		145.5		197		38.7		35	
	15.4		58		16.9		15		145		197		38		35	
Residential	8.1	9	34	36	11.1	12	10	10	16.7	17	61	62	36.6	37	33	34
	8.7		36		11.8		10		17.3		62		37.3		34	
	9.3		39		12.5		11		17.9		63		38		35	
Suburban	11.4	11	48	47	21.2	21	19	19	29.8	30	88	88	97	97	72	72
	11.1		46		20.7		19		29.5		88		96.5		71	
	11.5		48		21.7		19		29.9		88		97.5		72	

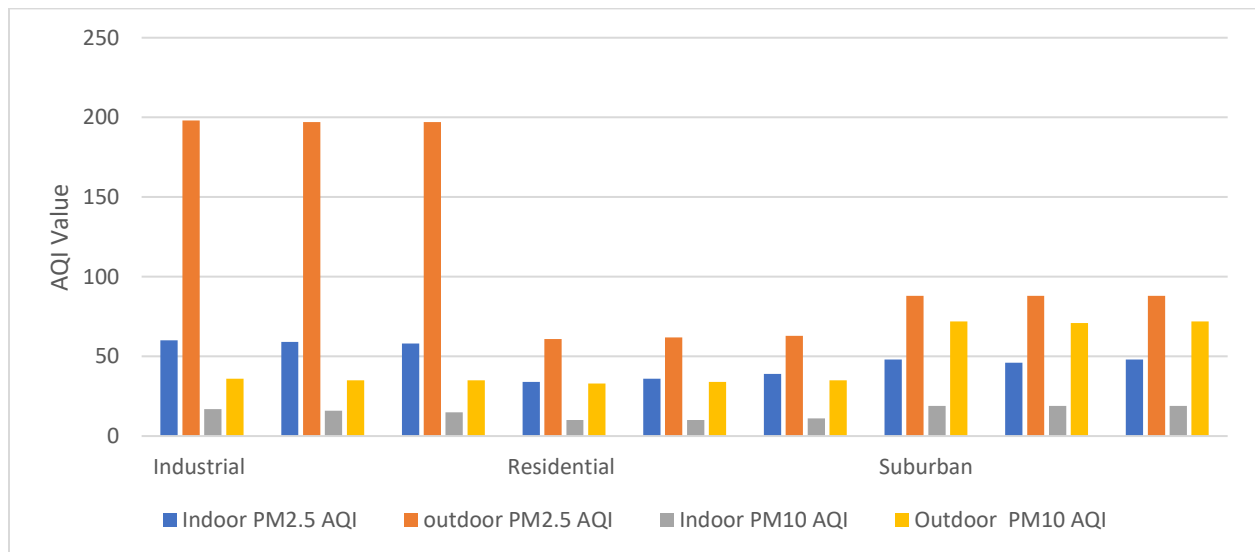


Figure 56 AQI of Dammam.

4.7.3 PMs Instantaneous Measuring and AQI for Khobar

Table 35 has the pDR-1500 data for PM_{10} and $PM_{2.5}$ in Khobar. The data was gathered for different areas, such as industrial, residential, and suburban, for three different locations for each. However, the data was collected for maximum and fluctuated values to estimate the area's AQI.

After the analysis in Figure 56, Khobar is a moderately polluted city with good outdoor $PM_{2.5}$ AQI. However, the outdoor air was moderately affected by PM_{10} and $PM_{2.5}$. For PM_{10} , the bar chart reached up to 72, which is moderate, while $PM_{2.5}$ exceeds up to 89 AQI. The AQI average increased to 60, 68, and 89 for $PM_{2.5}$ and 33, 39, and 72 for PM_{10} in residential, industrial, and suburban areas, respectively. Figure 56 shows the same sequence of areas in the outdoor air quality for $PM_{2.5}$ and PM_{10} .

Moreover, Figure 56 shows that indoor air has moderate to good AQI for $PM_{2.5}$ and is suitable for PM_{10} . For PM_{10} , the bar chart reached up to 20, which is good, while $PM_{2.5}$ reached up to 58 AQI. The AQI average was rising 32, 49, and 56 for $PM_{2.5}$ residential, suburban, and industrial areas, respectively, and 9, 16, and 20 for PM_{10} in residential, industrial, and suburban areas, respectively. Figure 56 shows the same sequence of areas in the indoor air quality for $PM_{2.5}$, PM_{10} , and PM_{10} outdoors.

TABLE 36 PMs Instantaneous Measuring and AQI for Khobar

AREA	Indoor								Outdoor							
	PM _{2.5} ug/m ³				PM ₁₀ ug/m ³				PM _{2.5} ug/m ³				PM _{2.5} ug/m ³			
	PM _{2.5}	Ave	AQI	PM _{2.5}	Ave	Ave	PM _{2.5}	Ave	PM _{2.5}	PM _{2.5}	Ave	Ave AQI	PM _{2.5}	Ave	AQI	PM _{2.5}
Industrial	14.1	5	55	56	16.4	17	15	16	19.8	20	67	68	41.7	42	38	39
	14.7		56		17.1		16		20.4		68		42.4		39	
	15.3		58		17.8		16		21		70		43.1		40	
Residential	7.5	8	31	32	10.4	11	9	9	16.1	16	59	60	35.9	36	32	33
	7.8		33		11.4		10		16.4		60		36.9		33	
	7.8		33		10.9		9		16.4		60		36.4		33	
Suburban	12	12	50	49	22.4	22	20	20	30.4	30	89	89	98.2	98	72	72
	11.6		48		21.4		19		30		89		97.2		72	
	12		50		22.4		20		30.4		89		98.2		72	

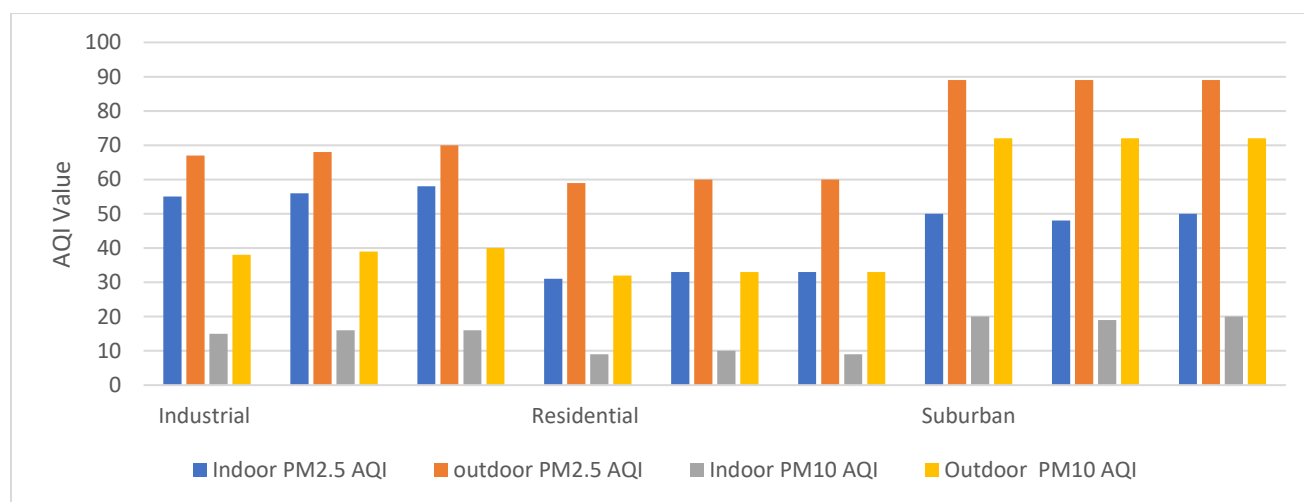


Figure 57 AQI of Khobar.

4.7.4 PMs Instantaneous Measuring and AQI for Jeddah

Table 36 has the pDR-1500 data for the PM_{10} and $PM_{2.5}$ in Jeddah. The data was gathered for three locations, including residential and suburban areas. However, the data was collected for maximum and fluctuated values to estimate the area's AQI.

After the analysis in Figure 57, Jeddah is among the highly polluted cities with unhealthy outdoor $PM_{2.5}$ AQI for sensitive people. However, the outdoor air is badly affected by PM_{10} and $PM_{2.5}$. For PM_{10} , the bar chart reached up to 91, which is moderate, while for $PM_{2.5}$, it exceeds up to 150 AQI. The AQI average was increased by 107 and 114 for $PM_{2.5}$ in suburban and residential areas, respectively, and 69 and 79 for PM_{10} in residential and suburban areas, respectively.

Moreover, Figure 57 shows that indoor air has moderate AQI for $PM_{2.5}$ and is suitable for PM_{10} . For PM_{10} , the bar chart reached 41, which is good, while for $PM_{2.5}$, it reached up to 80 AQI. The AQI average rose 48 and 56 for $PM_{2.5}$ and 13 and 22 for PM_{10} in residential and suburban areas, respectively. Figure 57 shows the same sequence of $PM_{2.5}$, PM_{10} indoor, and PM_{10} outdoor areas.

TABLE 37 PMs Instantaneous Measuring and AQI for Jeddah

AREA	Indoor								Outdoor							
	PM _{2.5} ug/m ³				PM ₁₀ ug/m ³				PM _{2.5} ug/m ³				PM _{2.5} ug/m ³			
	PM _{2.5}	Ave	AQI	PM _{2.5}	Ave	Ave	PM _{2.5}	Ave	PM _{2.5}	PM _{2.5}	Ave	Ave AQI	PM _{2.5}	Ave	AQI	PM _{2.5}
Residential	14.1	12	55	48	16.4	14	15	13	19.8	40	67	114	41.7	96	38	69
	11.6		48		16.2		15		19.8		67		41.7		38	
	13.4		54		13.2		12		55.4		150		136		91	
	9.8		41		12.7		11		52.3		142		131		88	
	9.6		40		12.6		11		52.1		142		131		88	
Suburban	11.5	15	48	56	21.7	25	19	22	29.9	38	88	107	97.5	112	72	79
	13.4		54		13.2		12		55.4		150		136		91	
	11.5		48		21.7		19		29.9		88		97.5		72	
	11.5		48		21.3		19		29.9		88		97.1		72	
	26.1		80		44.8		41		43.2		120		130		88	

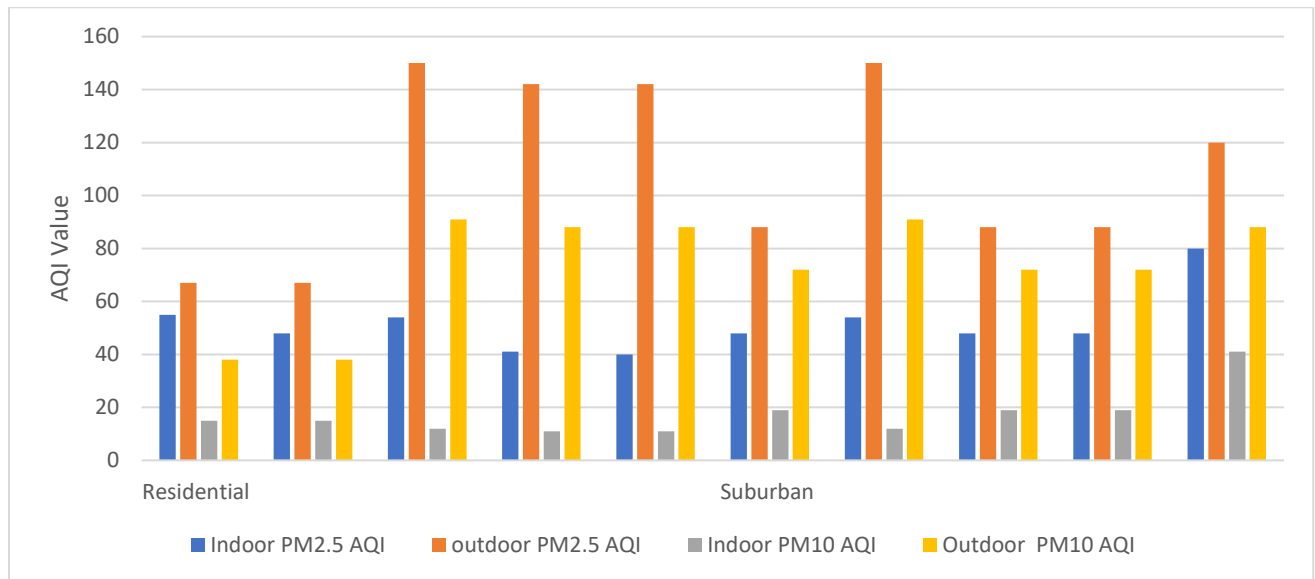


Figure 58 AQI of Jeddah.

CHAPTER 5

CONCLUSIONS AND RECOMMENDATION

5.1 Conclusion

In all cities, the concentration of the chosen MHs was distributed as follows: Cd, As, Co, V, Ni, Cr, Pb, Cu, Mn, Ba, Zn, and Fe. In comparison to the background concentration in the three cities, the MHs total concentration in the AC FILTER of buildings was greater and followed the order this study evaluated metal concentrations (MHs) in building AC FILTERs throughout four Saudi cities; it found that Dammam and Khobar had higher amounts than Jeddah and Jubail. Human activity affected air quality; permissible criteria for Zn, Cu, and Pb concentrations were exceeded. Extreme enrichment factors suggested severe levels of pollution, particularly in Jeddah. Zn, Pb, Cu, and Cd contamination was found using the Igeo index. According to the ecological risk assessment, Cd presented a significant risk, particularly in Jeddah. For both adults and children, the non-carcinogenic hazards of MH exposure by ingestion, inhalation, and skin contact were below acceptable bounds. Children have more significant cancer risks, highlighting their susceptibility. Finally, the study showed how outdoor PM_{2.5} affects interior air quality and poses health hazards, especially to people.

5.2 Recommendation

There are several proposed recommendations to deal with this issue. First, regular cleaning and maintenance should be done to avoid dust accumulation. Secondly, the door should remain shut to prevent dust from entering the buildings. Buildings should also enhance positive pressure to ensure that dust is forced out through open doors, windows, and cracks. An intermediary lobby should also separate the buildings and the main entrance. Carpet replacement with another type of material does not prevent dust accumulation and is cleaned quickly. Also, the public should be more aware of health risks existing in the environment. Researchers should be encouraged more, and results should be recorded in environmental databases to go deep into the harmful effects of HMs and then set specific permissible limits for each HM.

The AQI analysis based on PM_{2.5} and PM₁₀ showed that outdoor and indoor AQI in some significant areas showed hazardous levels, while maximum areas showed moderate to irritating AQI for sensitive people. To overcome the hazards of this situation, the following recommendations are being made:

1. An analysis must be conducted for indoor and outdoor conditions for ultrafine particulate matter (i.e., PM_{0.1}).
2. As the outdoor and indoor Air Quality of some areas is very hazardous, it is recommended that the residents and workers of the area wear PPE.
3. A detailed spatiotemporal analysis of the AQI of study areas based on PM and other pollutants must be conducted.
4. As a major anomaly has been detected in industrial areas, a continuous monitoring system and policy implementation are needed to lower PM-associated health hazards.

Reference

1. R. Derwent and A.-G. Hjelbrekke, *Air Pollution by Ozone Across Europe: Handbook of Environmental Chemistry*, no. 9. 2019.
2. P. J. Landrigan et al., “The Lancet Commission on pollution and health,” *Lancet*, vol. 391, no. 10119, pp. 462–512, 2018, doi: 10.1016/S0140-6736(17)32345-0.
3. A. J. Cohen et al., “Estimates and 25-year trends of the global burden of disease attributable to ambient air pollution: an analysis of data from the Global Burden of Diseases Study 2015,” *Lancet*, vol. 389, no. 10082, pp. 1907–1918, 2017, doi: 10.1016/S0140-6736(17)30505-6.
4. C. Men, R. Liu, F. Xu, Q. Wang, L. Guo, and Z. Shen, “Pollution characteristics, risk assessment, and source apportionment of HMs in road dust in Beijing, China,” *Sci. Total Environ.*, vol. 612, pp. 138–147, 2018, doi: 10.1016/j.scitotenv.2017.08.123.
5. S. Dytłow and B. Górka-Kostrubiec, “Concentration of HMs in street dust: an implication of using different geochemical background data in estimating the level of HMs pollution,” *Environ. Geochem. Health*, vol. 43, no. 1, pp. 521–535, 2021, doi: 10.1007/s10653-020-00726-9.
6. M. Y. Hanfi and I. V. Yarmoshenko, “Health risk assessment quantification from HMs contamination in the urban soil and urban surface deposited sediment,” *J. Taibah Univ. Sci.*, vol. 14, no. 1, pp. 285–293, 2020, doi: 10.1080/16583655.2020.1735735.
7. H. T. Moryani, S. Kong, J. Du, and J. Bao, “Health risk assessment of HMs accumulated on pm_{2.5} fractioned road dust from two cities of Pakistan,” *Int. J. Environ. res. Public Health*, vol. 17, no. 19, pp. 1–21, 2020, doi: 10.3390/ijerph17197124.
8. Y. Du, B. Gao, H. Zhou, X. Ju, H. Hao, and S. Yin, “Health Risk Assessment of HMs in Road Dusts in Urban Parks of Beijing, China,” *Procedia Environ. Sci.*, vol. 18, pp. 299–309, 2013, doi: 10.1016/j.proenv.2013.04.039.
9. C. Men, R. Liu, Q. Wang, L. Guo, Y. Miao, and Z. Shen, “Uncertainty analysis in source apportionment of HMs in road dust based on positive matrix factorization model and geographic information system,” *Sci. Total Environ.*, vol. 652, pp. 27–39, 2019, doi: 10.1016/j.scitotenv.2018.10.212.
10. Faheem, J. Bao, H. Zheng, H. Tufail, S. Irshad, and J. Du, “Adsorption-assisted decontamination of Hg(II) from aqueous solution by multi-functionalized corn-cob-derived biochar,” *RSC Adv.*, vol. 8, no. 67, pp. 38425–38435, 2018, doi: 10.1039/c8ra06622a.
11. B. Jancsek-Turóczi, A. Hoffer, I. Nyíró-Kósa, and A. Gelencsér, “Sampling and characterization of resuspended and respirable road dust,” *J. Aerosol Sci.*, vol. 65, no. September 2014, pp. 69–76, 2013, doi: 10.1016/j.jaerosci.2013.07.006.

12. B. H. Alharbi, A. Maghrabi, and N. Tapper, "The march 2009 dust event in Saudi Arabia: Precursor and supportive environment," *Bull. Am. Meteorol. Soc.*, vol. 94, no. 4, pp. 515–528, 2013, doi: 10.1175/BAMS-D-11-00118.1.
13. B. Alharbi, M. M. Shareef, and T. Husain, "Study of chemical characteristics of particulate matter concentrations in Riyadh, Saudi Arabia," *Atmos. Pollut. res.*, vol. 6, no. 1, pp. 88–98, 2015, doi: 10.5094/APR.2015.011.
14. M. A. Alghamdi, S. K. Hassan, N. A. Alzahrani, M. Y. Al Sharif, and M. I. Khoder, "Classroom dust-bound polycyclic aromatic hydrocarbons in Jeddah primary schools, Saudi Arabia: Level, characteristics and health risk assessment," *Int. J. Environ. res. Public Health*, vol. 17, no. 8, 2020, doi: 10.3390/ijerph17082779.
15. H. Ali, E. Khan, and I. Ilahi, "Environmental chemistry and ecotoxicology of hazardous HMs: Environmental persistence, toxicity, and bioaccumulation," *J. Chem.*, vol. 2019, no. Cd, 2019, doi: 10.1155/2019/6730305.
16. P. V. Suryawanshi, B. S. Rajaram, A. D. Bhanarkar, and C. V. Chalapati Rao, "Determining HMs contamination of road dust in Delhi, India," *Atmosfera*, vol. 29, no. 3, pp. 221–234, 2016, doi: 10.20937/ATM.2016.29.03.04.
17. Y. Jin, D. O'Connor, Y. S. Ok, D. C. W. Tsang, A. Liu, and D. Hou, "Assessment of sources of HMs in soil and dust at children's playgrounds in Beijing using GIS and multivariate statistical analysis," *Environ. Int.*, vol. 124, no. January, pp. 320–328, 2019, doi: 10.1016/j.envint.2019.01.024.
18. L. Jarup, "Hazards of HMs contamination," *Br. Med. Bull.*, vol. 68, pp. 167–182, 2003, doi: 10.1093/bmb/ldg032.
19. M. Jaishankar, B. B. Mathew, M. S. Shah, K. M. T.P., and S. G. K.R., "Biosorption of Few HMs Ions Using Agricultural Wastes," *J. Environ. Pollut. Hum. Heal.*, vol. 2, no. 1, pp. 1–6, 2014, doi: 10.12691/jephh-2-1-1.
20. D. O'Connor et al., "Lead-based paint remains a major public health concern: A critical review of global production, trade, use, exposure, health risk, and implications," *Environ. Int.*, vol. 121, no. August, pp. 85–101, 2018, doi: 10.1016/j.envint.2018.08.052.
21. Z. Shen et al., "Lead-based paint in children's toys sold on China's major online shopping platforms," *Environ. Pollut.*, vol. 241, no. 2018, pp. 311–318, 2018, doi: 10.1016/j.envpol.2018.05.078.
22. P. Zhang et al., "Green and Size-Specific Synthesis of Stable Fe-Cu Oxides as Earth-Abundant Adsorbents for Malachite Green Removal," *ACS Sustain. Chem. Eng.*, vol. 6, no. 7, pp. 9229–9236, 2018, doi: 10.1021/acssuschemeng.8b01547.
23. E. L. Z. and J. W. Ditri, HHS Public Access," *Physiol. Behav.*, vol. 176, no. 1, pp. 139–148, 2017, doi: 10.1016/j.atmosenv.2016.08.060.Characteristics.

24. Y. Tao, S. Mi, S. Zhou, S. Wang, and X. Xie, "Air pollution and hospital admissions for respiratory diseases in Lanzhou, China," *Environ. Pollut.*, vol. 185, pp. 196–201, 2014, doi: 10.1016/j.envpol.2013.10.035.
25. 2005 Tang et al., NIH Public Access," *Bone*, vol. 23, no. 1, pp. 1–7, 2008, doi: 10.1097/EDE.000000000000026.Ambient.
26. S. Y. Tan, S. M. Praveena, E. Z. Abidin, and M. S. Cheema, "A review of HMs in indoor dust and its human health-risk implications," *Rev. Environ. Health*, vol. 31, no. 4, pp. 447–456, 2016, doi: 10.1515/reveh-2016-0026.
27. "MEP and MLR announce the report on national general survey on soil contamination."
28. D. Hou and F. Li, "Complexities Surrounding China's Soil Action Plan," *L. Degrad. Dev.*, vol. 28, no. 7, pp. 2315–2320, 2017, doi: 10.1002/ldr.2741.
29. J. W. C. Wong and N. K. Mak, "HMs pollution in children playgrounds in hong kong and its health implications," *Environ. Technol. (United Kingdom)*, vol. 18, no. 1, pp. 109–115, 1997, doi: 10.1080/09593331808616518.
30. J. Yang, Y. Teng, L. Song, and R. Zuo, "Tracing sources and contamination assessments of HMs in road and foliar dusts in a typical mining city, China," *PLoS One*, vol. 11, no. 12, pp. 1–19, 2016, doi: 10.1371/journal.pone.0168528.
31. M. T. Latif et al., "Composition of HMs in indoor dust and their possible exposure: A case study of preschool children in Malaysia," *Air Qual. Atmos. Heal.*, vol. 7, no. 2, pp. 181–193, 2014, doi: 10.1007/s11869-013-0224-9.
32. W. Zgłobicki, M. Telecka, S. Skupiński, A. Pasierbińska, and M. Kozieł, "Assessment of HMs contamination levels of street dust in the city of Lublin , E Poland," *Environ. Earth Sci.*, vol. 77, no. 23, pp. 1–11, 2018, doi: 10.1007/s12665-018-7969-2.
33. M. S. El-Shobokshy, "A preliminary analysis of the inhalable particulate lead in the ambient atmosphere of the city of Riyadh, Saudi Arabia," *Atmos. Environ.*, vol. 18, no. 10, pp. 2125–2130, 1984, doi: 10.1016/0004-6981(84)90198-7.
34. I. A. Al-Saleh and A. Taylor, "Lead concentration in the atmosphere and soil of Riyadh, Saudi Arabia," *Sci. Total Environ.*, vol. 141, no. 1–3, pp. 261–267, 1994, doi: 10.1016/0048-9697(94)90032-9.
35. Mohammadi, A.; Hajizadeh, Y.; Taghipour, H.; Arani, A.M.; Mokhtari, M.; Fallahzadeh, H. Assessment of metals in agricultural soil of surrounding areas of Urmia Lake, northwest Iran: A preliminary ecological risk assessment and source identification. *Hum. Ecol. Risk Assess.* 2018, 24, 2070–2087.
36. M. A. Alghamdi, S. K. Hassan, N. A. Alzahrani, F. M. Almehmadi, and M. I. Khoder, "Risk assessment and implications of schoolchildren exposure to classroom HMs particles in Jeddah, Saudi Arabia," *Int. J. Environ. res. Public Health*, vol. 16, no. 24, pp. 1–24, 2019, doi: 10.3390/ijerph16245017.

37. I. I. Shabbaj, M. A. Alghamdi, M. Shamy, S. K. Hassan, M. M. Alsharif, and M. I. Khoder, "Risk assessment and implication of human exposure to road dust HMs in Jeddah, Saudi Arabia," *Int. J. Environ. res. Public Health*, vol. 15, no. 1, 2018, doi: 10.3390/ijerph15010036.
38. M. El-Sergany and M. El-Sharkawy, "HMs Contamination of Airborne Dust in the Environment of Two Main Cities in the Eastern Province of Saudi Arabia J. King Abdulaziz Univ. Environ. Arid L. Agric. Sci., vol. 22, no. 1, pp. 135–148, 2011, doi: 10.4197/met.22-1.10.
39. B. H. Alharbi, M. J. Pasha, M. D. Alotaibi, A. K. Alduwais, and M. A. S. Al-Shamsi, "Contamination and risk levels of metals associated with urban street dust in Riyadh, Saudi Arabia," *Environ. Sci. Pollut. res.*, vol. 27, no. 15, pp. 18475–18487, 2020, doi: 10.1007/s11356-020-08362-7.
40. A. Patrick, O. Hamid, S. B. Mahad, A. Al-Mamun " Indoor air pollution and exposure assessment of the gulf cooperation council countries: A critical review. 121, Part 1, 491-506, *Environment International* doi.org/10.1016/j.envint.2018.09.043.
41. Umme Aiman, Adeel Mahmood, Sidra Waheed, Riffat Naseem Malik, Enrichment, geo-accumulation and risk surveillance of toxic metals for different environmental compartments from Mehmood Booti dumping site, Lahore city, Pakistan,
42. Shen, Guohui & Ru, Xin & Gu, Yanting & Liu, Wei & Wang, Kunzhen & Li, Baiyi & Guo, Yanzhi & Han, Juan. (2023). Pollution Characteristics, Spatial Distribution, and Evaluation of HMs(loid)s in Farmland Soils in a Typical Mountainous Hilly Area in China. *Foods*. 12. 681. 10.3390/foods12030681.
43. Abdul Rehman, Guijian Liu, Balal Yousaf, Muhammad Zia-ur-Rehman, Muhammad Ubaid Ali, [45] Muhammad Saqib Rashid, Muhammad Raza Farooq, Zeeshan Javed, Characterizing pollution indices and children health risk assessment of potentially toxic metal(oid)s in school dust of Lahore, Pakistan, *Ecotoxicology and Environmental Safety*, Volume 190, 2020.
44. Aburas, Hani & Zytoon, Mohamed & Abdulsalam, Mohammed. (2011). Atmospheric Lead in PM2.5 after Leaded Gasoline Phase-out in Jeddah City, Saudi Arabia. *CLEAN – Soil, Air, Water*. 39. 711 - 719. 10.1002/clen.201000510.
45. Lim, Chris & Thurston, George & Shamy, Magdy & Alghamdi, Mansour & Khoder, Mamdouh & Mohorjy, Abdullah & Khalaf, Abbulrahman & Brocato, Jason & Chen, Lung & Costa, Max. (2017). Temporal variation of fine and coarse particulate matter sources in Jeddah, Saudi Arabia. *Journal of the Air & Waste Management Association*. 68. 10.1080/10962247.2017.1344158.
46. Wang, X.; Liu, E.; Lin, Q.; Liu, L.; Yuan, H.; Li, Z. Occurrence, Sources and Health Risks of Toxic Metal(Loid)s in Road Dust from a Mega City (Nanjing) in China. *Environ. Pollut.* 2020, 263, 114518.

47. Izhar, Saifi & Goel, Anubha & Chakraborty, Abhishek & Gupta, Tarun. (2016). Annual trends in occurrence of submicron particles in ambient air and health risk posed by particle bound metals. *Chemosphere*. 146. 582-590. 10.1016/j.chemosphere.2015.12.039.
48. Li, Na & Han, Weizheng & Tang, Jie & Bian, Jianmin & Sun, Siyue & Song, Tiehong. (2018). Pollution Characteristics and Human Health Risks of Elements in Road Dust in Changchun, China. *International Journal of Environmental research and Public Health*. 15. 1843. 10.3390/ijerph15091843.
49. Mansour A. Alghamdi, Salwa K. Hassan, Marwan Y. Al Sharif, Mamdouh I. Khoder, Roy M. Harrison, Pollution characteristics and human health risk of potentially toxic elements associated with deposited dust of sporting walkways during physical activity, *Atmospheric Pollution research*, Volume 14, Issue 1, 2023.
50. Lu, Xinwei & Zhang, Xiaolan & Li, Loretta & Chen, Hao. (2014). Assessment of metals pollution and health risk in dust from nursery schools in Xi'an, China. *Environmental research*. 128. 27–34. 10.1016/j.envres.2013.11.007.
51. Narsimha, Adimalla. (2020). HMs contamination in urban surface soils of Medak province, India, and its risk assessment and spatial distribution. *Environmental Geochemistry and Health*. 42. 10.1007/s10653-019-00270-1.
52. [55] Olujimi, O.; Steiner, O.; Goessler, W. Pollution Indexing and Health Risk Assessments of Trace Elements in Indoor Dusts from Classrooms, Living Rooms and Offices in Ogun State, Nigeria. *J. Afr. Earth Sci.* 2015, 101, 396–404.
53. Victor, O.; Kingsley Chukwuemeka, P.-I.; Eucharia Oluchi, N. HMs Contents, and Health Risk Assessment of Classroom Corner Dusts in Selected Public Primary Schools in Rivers State, Nigeria. *JEPHH* 2018, 6, 138–147.
54. Ali, M.U.; Liu, G.; Yousaf, B.; Abbas, Q.; Ullah, H.; Munir, M.A.M.; Fu, B. Pollution characteristics and human health risks of potentially (eco) toxic elements (PTEs) in road dust from metropolitan area of Hefei, China. *Chemosphere* 2017, 181, 111–121.
55. United States Environmental Protection, Agency (USEPA). Exposure Factors Handbook Edition; EPA/600/ R-09/052F; National Center for Environmental Assessment, Office of research and Development, U.S. Environmental Protection Agency: Washington, DC, USA, 2011.
56. United States Environmental Protection, Agency (USEPA). Reference Dose (RfD): Description and Use in Health Risk Assessments; Background Document 1 A; Integrated Risk Information System (IRIS): Washington, DC, USA, 1993.
57. Zhang, H.; Mao, Z.; Huang, K.; Wang, X.; Cheng, L.; Zeng, L.; Zeng, L.; Zhou, Y.; Jing, T. Multiple exposure pathways and health risk assessment of HMs(loid)s for children living in fourth- tier cities in Hubei Province. *Environ. Int.* 2019, 129, 517–524.
58. Wei, X.; Gao, B.; Wang, P.; Zhou, H.; Lu, J. Pollution characteristics and health risk assessment of HMs in street dust from different functional areas in Beijing, China. *Ecotoxicol. Environ. Saf.* 2015, 112, 186–192.

59. United States Environmental Protection, Agency (USEPA). Risk Assessment Guidance for Superfund: Human Health Evaluation Manual (Part A); EPA/540/1-89/002; Office of Emergency and Remedial response: Washington, DC, USA, 1989; Volume I.
60. Islam, A.R.M.T.; Islam, H.M.T.; Mia, M.U.; Khan, R.; Habib, M.A.; Bodrud-Doza, M.; Siddique, M.A.B.; Chu, R. Co-distribution, possible origins, status and potential health risk of trace elements in surface water sources from six major river basin, Bangladesh. *Chemosphere* 2020, 249, 126180.
61. Baptista, Lopes & De Miguel, Eduardo. (2005). Geochemistry and Risk Assessment of Street Dust in Luanda, Angola: A Tropical Urban Environment. *Atmospheric Environment*. 39. 4501-4512. 10.1016/j.atmosenv.2005.03.026.
62. Okedeyi, O.O.; Dube, S.; Awofolu, O.R.; Nindi, M.M. Assessing the enrichment of HMs in surface soil and plant (*Digitariaaeriantha*) around coal-fired power plants in South Africa. *Environ. Sci. Pollut. res.-Int.* 2014, 21, 4686–4696.
63. Li, H.H.; Chen, L.J.; Yu, L.; Guo, Z.B.; Shan, C.Q.; Lin, J.Q.; Gu, Y.G.; Yang, Z.B.; Yang, Y.X.; Shao, J.R. Pollution characteristics and risk assessment of human exposure to oral bioaccessibility of HMs via urban street dust from different functional areas in Chengdu, China. *Sci. Total Environ.* 2017, 586, 1076–1084.
64. Mediolla, L.; Domingues, M.; Sandoval, M.G. Environmental assessment of and active tailings pile in the State of Mexico (central Mexico). *res. J. Environ. Sci.* 2018, 2, 197–208.
65. Neto, J.A.B.; Gingele, F.X.; Leipe, T.; Brehme, I., Spatial distribution of HMs in surficial sediments from Guanabara Bay: Rio de Janeiro, Brazil. *Environ. Geol.* 2006, 49, 1051–1063.
66. Adimalla, N.; Qian, H.; Wang, H. Assessment of HMs (HM) contamination in agricultural soil lands in northern Telangana, India: An approach of spatial distribution and multivariate statistical analysis. *Environ. Monit. Assess.* 2019, 191, 246.
67. Jiang, H.-H.; Cai, L.-M.; Wen, H.-H.; Hu, G.-C.; Chen, L.-G.; Luo, J. An integrated approach to quantifying ecological and human health risks from different sources of soil HMs. *Sci. Total Environ.* 2020, 701, 134466.
68. Taylor, S.R. Abundance of chemical elements in the continental crust: A New Table. *Geochim. Cosmochim. Acta* 1964, 28, 1273–1285.
69. Taylor, S.R.; McLennan, S.M. *The Continental Crust: Its Composition and Evolution*; Blackwell Scientific Publications: Oxford, UK, 1985.
70. Guillén, M.T.; Delgado, J.; Albanese, S.; Nieto, J.M.; Lima, A.; De Vivo, B. Environmental geochemical mapping of Huelva municipality soils (SW Spain) as a tool to determine background and baseline values. *J. Geochem. Explore.* 2011, 109, 59–69.

71. Gope, M.; Masto, R.E.; George, J.; Balachandran, S. Tracing source, distribution, and health risk of potentially harmful elements (PHEs) in street dust of Durgapur, India. *Ecotoxicol. Environ. Saf.* 2018, 154, 280–293.
72. Wahab, M.I.A.; Razak, W.M.A.A.; Sahani, M.; Khan, M.F. Characteristics and health effect of HMs on non-exhaust road dust in Kuala Lumpur. *Sci. Total Environ.* 2020, 703, 135535.
73. Tomlinson, D.L.; Wilson, J.G.; Harris, C.R.; Jeffrey, D.W. Problems in the assessment of heavy-metal levels in estuaries and the formation of a pollution index. *Helgoländer Meeresunters.* 1980, 33, 566–575.
74. Wang, B.; Xia, D.; Yu, Y.; Jia, J.; Xu, S. Magnetic records of HMs pollution in urban topsoil in Lanzhou, China. *Chin. Sci. Bull.* 2012, 58, 384–395.
75. Hakanson, L. An ecological risk index for aquatic pollution control. A sedimentological approach. *Water res.* 1980, 14, 975–1001.
76. Odediran, E.T.; Adeniran, J.A.; Yusuf, R.O.; Abdulraheem, K.A.; Adesina, O.A.; Sonibare, J.A.; Du, M. Contamination levels, health risks and source apportionment of potentially toxic elements in road dust of a densely populated African City. *Environ. Nanotechnol. Monit. Manag.* 2021, 15, 100445.
77. Guo, W.; Liu, X.; Liu, Z.; Li, G. Pollution and potential ecological risk evaluation of HMs in the sediments around Dongjiang Harbor, Tianjin. *Procedia. Environ. Sci.* 2010, 2, 729–736.
78. Lu, X.; Li, L.Y.; Wang, L.; Lei, K.; Huang, J.; Zhai, Y. Contamination assessment of mercury and arsenic in roadway dust from Baoji, China. *Atmos. Environ.* 2009, 43, 2489–2496.
79. Xiao, H.; Shahab, A.; Xi, B.; Chang, Q.; You, S.; Li, J.; Sun, X.; Huang, H.; Li, X. HMs pollution, ecological risk, spatial distribution, and source identification in 551 sediments of the Lijiang River, China. *Environ. Pollut.* 2021, 269, 116189.
80. United States Environmental Protection, Agency (USEPA). Supplemental Guidance for Developing Soil Screening Levels for Superfund Sites; Office of Solid Waste and Emergency Response (OSWER): Washington, DC, USA, 2011.
81. United States Environmental Protection, Agency (USEPA). Child-Specific Exposure Factors Handbook; EPA-600-P-00e002B; National Center for Environmental Assessment: Washington, DC, USA, 2002.
82. United States Environmental Protection, Agency (USEPA). Risk Assessment Guidance for Superfund: Volume III—Part A, Process for Conducting Probabilistic Risk Assessment; EPA540-R-02-002; U.S. Environmental Protection Agency: Washington, DC, USA, 2001a.

83. United States Environmental Protection, Agency (USEPA). Child-Specific Exposure Factors Handbook; EPA-600-P-00-002B; National Center for Environmental Assessment: Washington, DC, USA, 2001b.
84. Khobar Climate, Weather by Month, Average Temperature (Saudi Arabia)—Weather Spark. Available online: <https://weatherspark.com/y/104952/Average-Weather-in-Khobar-Saudi-Arabia-Year-Round> (accessed on 2 December 2022).
85. Saudi Arabia Statistics (2023)—global media insight. Available online: <https://www.globalmediainsight.com/blog/saudi-arabia-population-statistics/> (accessed on 2 December 2022).
86. Azzam, A.; Ali, A.B. Urban sprawl in Wadi goes watershed (Jeddah city/Western Saudi Arabia) and its impact on vulnerability and flood hazards. Available online: <https://www.scirp.org/journal/paperinformation.aspx?paperid=93222> (accessed on 15 May 2019).
87. Alqurashi, A.; Kumar, L. An Assessment of the Impact of Urbanization and Land Use Changes in the Fast-Growing Cities of Saudi Arabia. *Geocarto Int.* 2019, 34, 78–97.
88. Saudi Arabia Population (2022)—Worldometer. Available online: <https://www.worldometers.info/world-population/saudi-arabia-population/> (accessed on 2 December 2022).
89. Al Jubayl Climate, Weather by Month, Average Temperature (Saudi Arabia)—Weather Spark. Available online: <https://weatherspark.com/y/104798/Average-Weather-in-Al-Jubayl-Saudi-Arabia-Year-Round> (accessed on 2 December 2022).
90. Ad-Dammam, Saudi Arabia Metro Area Population 1950–2022. Available online: <https://www.macrotrends.net/cities/22416/ad-dammam/population> (accessed on 2 December 2022).
91. Dammam Climate, Weather by Month, Average Temperature (Saudi Arabia)—Weather Spark. Available online: <https://weatherspark.com/y/104953/Average-Weather-in-Dammam-Saudi-Arabia-Year-Round> (accessed on 2 December 2022).
92. Ali, M.U.; Liu, G.; Yousaf, B.; Abbas, Q.; Ullah, H.; Munir, M.A.M.; Zhang, H. Compositional characteristics of black-carbon and nanoparticles in air-conditioner dust from an inhabitable industrial metropolis. *J. Clean. Prod.* 2018, 180, 34–42.
93. USEPA. Method 3050 B: Acid Digestion of Sediments, Sludges, and Soils; Revision 2; USEPA: Washington, DC, USA, 1996.
94. USEPA. Method 6010 C: Inductively Coupled Plasma—Atomic Emission Spectroscopy; Revision 3; USEPA: Washington, DC, USA, 2007.
95. Rastmanesh, F.; Safaie, S.; Zarasvandi, A.; Edraki, M. HMs enrichment and ecological risk assessment of surface sediments in Khorramabad River, West Iran. *Environ. Monit. Assess.* 2018, 190, 273.

96. Mmolawa, K.B.; Likuku, A.S.; Gaboutloeloe, G.K. Assessment of HMs pollution in soils along major roadside areas in Botswana. *Afr. J. Environ. Sci. Technol.* 2011, 5, 186–196.
97. Yaylalı-Abanuz, G. HMs contamination of surface soil around Gebze industrial area, Turkey. *Microchem. J.* 2011, 99, 82–92.
98. Tomlinson, D.L.; Wilson, J.G.; Harris, C.R.; Jeffrey, D.W. Problems in the assessment of heavy-metal levels in estuaries and the formation of a pollution index. *Helgoländer Meeresunters.* 1980, 33, 566–575.
99. Rinklebea, J.; Antoniadis, V.; Shaheena, S.M.; Roschef, O.; Altermann, M. Health risk assessment of potentially toxic elements in soils along the Central Elbe River, Germany. *Environ. Int.* 2019, 126, 76–88.
100. Yi, Y.; Yang, Z.; Zhang, S. Ecological risk assessment of HMs in sediment and human health risk assessment of HMs in fishes in the middle and lower reaches of the Yangtze River basin. *Environ Pollut.* 2011, 159, 2575–2585.
101. Mazurek, R.; Kowalska, J.; Gąsiorek, M.; Zadrożny, P.; J'ozefowska, A.; Zaleski, T.; Orłowska, K. Assessment of HMs contamination in surface layers of Roztocze National Park Forest soils (SE Poland) by indices of
102. Yuan, G.-L.; Sun, T.-H.; Han, P.; Li, J.; Lang, X.-X. Source identification and ecological risk assessment of HMs in topsoil using environmental geochemical mapping: Typical urban renewal area in Beijing, China. *J. Geochem. Explor.* 2014, 136, 40–47.
103. Phil-Eze, P.O. Variability of Soil Properties Related to Vegetation Cover in a Tropical Rainforest Variability of Soil Properties Related to Vegetation Cover in a Tropical Rainforest Landscape. *Afr. J. Geogr. Reg. Plan.* 2019, 6, 1–8.
104. Karim, Z.; Qureshi, B.A. Health Risk Assessment of HMs in Urban Soil of Karachi, Pakistan. *Hum. Ecol. Risk Assess. J.* 2014, 20, 658–667.
105. Yongming, H.; Peixuan, D.; Junji, C.; Posmentier, E.S. Multivariate analysis of HMs contamination in urban dust of Xi'an. *Cent. China* 2006, 355, 176–186.
106. Al-Awadhi, J.M.; Aldhafiri, B.T. HMs concentrations in roadside-deposited sediments in Kuwait City. *Arabian J. Geosci.* 2016, 9, 535.
107. Albar, H.M.S.A.; Ali, N.; Eqani, S.A.M.A.S.; Alhakamy, N.A.; Nazar, E.; Rashid, M.I.; Shahzad, K.; Ismail, I.M.I. Trace metals in different socioeconomic indoor settings, implications for human health via dust exposure. *Ecotoxicol. Environ. Saf.* 2020, 189, 109927.
108. Bradl, H. HMs in the Environment. Interface [HMs in the Environment. Interface]. *Sci. Technol.* 2005, 6, 269.

109. Al-Harbi, M.; Alhajri, I.; Whalen, J.K. Characteristics and health risk assessment of HMs contamination from dust collected on household HVAC air filters. *Chemosphere* 2021, 277, 130276.
110. Kabata-Pendias, A. *Trace Elements in Soils and Plants*; CRC Press: Boca Raton, FL, USA, 2010.
111. Bali, A.S.; Sidhu, G.P.S. *HMs Contamination Indices and Ecological Risk Assessment Index to Assess Metal Pollution Status in Different Soils, Hms in the Environment*; Elsevier: Amsterdam, The Netherlands, 2021; pp. 87–98.
112. Al Hejami, A.; Davis, M.; Prete, D.; Lu, J.; Wang, S. HMs in indoor settled dust in Toronto, Canada. *Sci. Total Environ.* 2020, 703, 134895.
113. Yangbing, L.; Fengman, F.; Yuesheng, L.; Yue, W.; Ying, K.; Minghong, W. HMs contamination and health risks of indoor dust around Xinqiao Mining Area, Tongling, China. *Hum. Ecol. Risk Assess.* 2020, 26, 46–56.
114. Rehman, A.; Liu, G.; Yousaf, B.; Zia-ur-Rehman, M.; Ali, M.U.; Rashid, M.S.; Farooq, M.R.; Javed, Z. Characterizing Pollution Indices and Children Health Risk Assessment of Potentially Toxic Metal(Oid)s in School Dust of Lahore, Pakistan. *Ecotoxicol. Environ. Saf.* 2020, 190, 110059.
115. Yadav, I.; Devi, N.; Singh, V.; Li, J.; Zhang, G. Spatial distribution, source analysis, and health risk assessment of HMs contamination in house dust and surface soil from four major cities of Nepal. *Chemosphere* 2019, 2018, 1100–1113.
116. Butte, W.; Heinzow, B. Pollutants in house dust as indicators of indoor contamination. *Rev. Environ. Contam. Toxicol.* 2002, 175, 1–46.
117. Trowbridge, P.R.; Burmaster, D.E. A parametric distribution for the fraction of outdoor soil in indoor dust. *Soil Sediment Contam.* 1997, 6, 161–168.
118. Sareban, V.H.; Saeb, S. HMs contamination in street precipitated dust in Tabriz City, Iran, and its ecological risk. *Biosci. Biotech. res. Comm.* 2018, 11, 291–299.
119. Moghtaderi, M.; Ashraf, M.; Moghtaderi, T.; Teshnizi, S.; Nabavizadeh, S. HMs concentration in classroom dust samples and its relationship with childhood asthma: A study from Shiraz, Islamic Republic of Iran. *East. Mediterr. Health J.* 2020, 26, 594–601.
120. Mahfouz, M.; Yigiterhan, O.; Elnaiem, A.; Hassan, H.; Alfoldy, B. Elemental compositions of particulate matter retained on air condition unit's filters at Greater Doha, Qatar. *Environ. Geochem. Health* 2019, 41, 2533–2548.
121. Iwegbue, C.; Obi, G.; Emoyan, O.; Odali, E.; Egobueze, F.; Tesi, G.; Nwajei, G.; Martincigh, B. Characterization of metals in indoor dust from electronic workshops, cybercafes and offices in southern Nigeria: Implications for on-site human exposure. *Ecotoxicol. Environ. Saf.* 2018, 159, 342–353.

122. Arar, S.; Al-Hunaiti, A.; Masad, M.; Maragkidou, A.; Wraith, D.; Hussein, T. Elemental contamination in indoor floor dust and its correlation with PAHs, fungi, and Gram⁺/bacteria. *Int. J. Environ. res. Public Health* 2019, 16, 1–15.
123. Plumejeaud, S.; Reis, A.; Tassistro, V.; Patinha, C.; Noack, Y.; Orsiere, T., Potentially harmful elements in house dust from Estarreja, Portugal: Characterization and genotoxicity of the bioaccessible fraction. *Environ. Geochem. Health* 2018, 40, 127–144.
124. Moghtaderi, T.; Aminiyan, M.; Alamdar, R.; Moghtaderi, M. Index-based evaluation of pollution characteristics and health risk of potentially toxic metals in schools dust of Shiraz megacity, SW Iran. *Hum. Ecol. Risk Assess.* 2019, 25, 410–437.
125. El-Mubarak, A.H.; Rushdi, A.I.; Al-Mutlaq, K.F.; Al Mdawi, F.Z.; Al-Hazmi, K.; Dumenden, R.S.; Pascu, R.A. Polycyclic aromatic hydrocarbons, and trace metals in mosque's carpet dust of Riyadh, Saudi Arabia, and their health risk implications. *Environ. Sci. Pollut. res.* 2016, 23, 21273–21287.
126. Gad, A.; Saleh, A.; Farhat, H.; Dawood, Y.H., Abd El Bakey, S.M. Spatial Distribution, Contamination Levels, and Health Risk Assessment of Potentially Toxic Elements in Household Dust in Cairo City, Egypt. *Toxics* 2022, 10, 466.
127. Rabe, J.M.; Agbaji, E.B.; Zakka, Y.; Muhammed, H.M.; Rabe, A.M. Assessment of Contaminated Soil with Some HMs in Selected Auto Repair Shops in Katsina North Western, Nigeria. *J. Waste Manag. Xenobiotics.* 2018, 1, 100–113.
128. Eluyera, I.M.; Tukura, B.W. Assessment of HMs in Soil of Automobile Workshops in Federal Capital Territory Abuja, Nigeria. *IOSR J. Environ. Sci. Toxicol. Food Technol.* 2020, 14, 4955.
129. Adelekan, A.B.; Abegunde, K.D. HMs contamination of soil and groundwater at automobile mechanic villages in Ibadan, Nigeria. *Int. J. Phys. Sci.* 2011, 6, 1045–1058.
130. Shaltout, A.A.; Hassan, S.K.; Karydas, A.G.; Harfouche, M.; Abd-Elkader, O.H.; Kregsamer, P.; Wobrauschek, P.; Streli, C. EDXRF analysis of suspended particulate matter (S P M) from residential and industrial areas in Cairo, Egypt. *X-ray Spectrom.* 2018, 47, 223–230.
131. Shi, G.; Chen, Z.; Xu, S.; Zhang, J.; Wang, L.; Bi, C.; Teng, J. Potentially toxic metal contamination of urban soils and roadside dust in Shanghai, China. *Environ. Pollut.* 2008, 156, 251–260.
132. Tahir, N.M.; Chee, P.S.; Jaafar, M. Determination of HMs content in soils and indoor dust from nurseries in Dungun, Terengganu Malaysian. *J. Anal. Sci.* 2007, 11, 280–286.
133. Doyi, I.N.Y.; Isley, C.F.; Soltani, N.S.; Taylor, M.P. Human Exposure and Risk Associated with Trace Element Concentrations in Indoor Dust from Australian Homes. *Environ. Int.* 2019, 133, 105125.

134. Al-Rajhi, M.A.; Seaward, M.R.D.; Al-Aamer, A.S. Metal Levels in Indoor and Outdoor Dust in Riyadh, Saudi Arabia. *Environ. Int.* 1996, 22, 315–324.
135. Chen, L.; Zeng, F.; Luo, D.; Cui, K. Study of the distribution characteristics of phthalate esters in road dust of the city. *Acta Sci. Circumstantial.* 2005, 25, 409–413.
136. Patel, D.K.; Jain, M.K. Contamination and Health Risk Assessment of Potentially Harmful Elements Associated with Roadside Dust in Dhanbad India. *Stoch. Environ. res. Risk Assess.* 2022, 36, 389–407.
137. Mondal, S.; Singh, G.; Jain, M.K. Spatio-Temporal Variation of Air Pollutants around the Coal Mining Areas of Jharia Coalfield, India. *Environ. Monit. Assess.* 2020, 192, 405.
138. Bourliva, A.; Kantiranis, N.; Papadopoulou, L.; Aidona, E.; Christophoridis, C.; Kollias, P.; Evgenakis, M.; Fytianos, K. Seasonal and Spatial Variations of Magnetic Susceptibility and Potentially Toxic Elements (PTEs) in Road Dusts of Thessaloniki City, Greece: A One-Year Monitoring Period. *Sci. Total Environ.* 2018, 639, 417–427.
139. Tan, S.Y.; Praveena, S.M.; Abidin, E.Z.; Cheema, M.S. A review of HMs in indoor dust and its human health-risk implications. *Rev. Environ. Health* 2016, 31, 447–456.
140. Al-Rajhi, M.A.; Seaward, M.R.D.; Al-Aamer, A.S. Metal Levels in Indoor and Outdoor Dust in Riyadh, Saudi Arabia. *Environ. Int.* 1996, 22, 315–324.
141. Chen, L.; Zeng, F.; Luo, D.; Cui, K. Study of the distribution characteristics of phthalate esters in road dust of the city. *Acta Sci. Circumstantiae.* 2005, 25, 409–413.
142. Aiman, U.; Mahmood, A.; Waheed, S.; Malik, R.N. Enrichment, Geo-Accumulation and Risk Surveillance of Toxic Metals for Different Environmental Compartments from Mehmood Booti Dumping Site, Lahore City, Pakistan. *Chemosphere* 2016, 144, 2229–2237.
143. Zhao, G.; Zhang, R.; Han, Y.; Meng, J.; Qiao, Q.; Li, H. Pollution Characteristics, Spatial Distribution, and Source Identification of HMs in Road Dust in a Central Eastern City in China: A Comprehensive Survey. *Environ. Monit. Assess.* 2021, 193, 796.
144. Khodeir, M.; Shamy, M.; Alghamdi, M.; Zhong, M.; Sun, H.; Costa, M.; Chen, L.-C.; Maciejczyk, P. Source apportionment and elemental composition of PM_{2.5} and PM₁₀ in Jeddah City, Saudi Arabia. *Atmos. Pollut. res.* 2012, 3, 331–340.
145. Lim, C.C.; Thurston, G.D.; Shamy, M.; Alghamdi, M.; Khoder, M.; Mohorjy, A.M.; Al Khalaf, A.K.; Brocato, J.; Chen, L.C.; Costa, M. Temporal variation of fine and coarse particulate matter sources in Jeddah, Saudi Arabia. *J. Air Waste Manag. Assoc.* 2018, 68, 123–138.
146. Nematollahi, M.J.; Dehdaran, S.; Moore, F.; Keshavarzi, B. Potentially Toxic Elements and Polycyclic Aromatic Hydrocarbons in Street Dust of Yazd, a Central Capital City in

- Iran: Contamination Level, Source Identification, and Ecological–Health Risk Assessment. *Environ. Geochem. Health* 2021, 43, 485–519.
147. Wang, X.; Liu, E.; Lin, Q.; Liu, L.; Yuan, H.; Li, Z. Occurrence, Sources and Health Risks of Toxic Metal(Loid)s in Road Dust from a Mega City (Nanjing) in China. *Environ. Pollut.* 2020, 263, 114518.
 148. Habil, M.; Massey, D.D.; Taneja, A. Exposure of Children Studying in Schools of India to PM Levels and Metal Contamination: Sources and Their Identification. *Air. Qual. Atmos. Health* 2013, 6, 575–587.
 149. Khoder, M.I.; Alghamdi, M.A.; Shiboob, M.H. HMs distribution in street dust of urban and industrial areas in Jeddah, Saudi Arabia. *J. King Abdelaziz Univ. Meteorol. Environ. Arid. Land Agric. Sci.* 2012, 23, 55–75.
 150. He, K.; Wang, S.; Zhang, J. Blood lead levels of children and its trend in China. *Sci. Total Environ.* 2009, 407, 3986–3993.
 151. Cheng, H.; Hu, Y. Lead (Pb) Isotopic Fingerprinting and Its Applications in Lead Pollution Studies in China: A Review. *Environ. Pollut.* 2010, 158, 1134–1146.
 152. Banerjee, A.D.K. HMs Levels and Solid Phase Speciation in Street Dusts of Delhi, India. *Environ. Pollut.* 2003, 123, 95–105.
 153. Aelion, C.M.; Davis, H.T.; McDermott, S.; Lawson, A.B. Metal Concentrations in Rural Topsoil in South Carolina: Potential for Human Health Impact. *Sci. Total Environ.* 2008, 402, 149–156.
 154. Hunt, A.; Johnson, D.; Griffith, D. Mass transfer of soil indoors by track-in on footwear. *Sci. Total Environ.* 2006, 370, 360–371.
 155. Gope, M., Masto, R.E., George, J., Hoque, R.R., Balachandran, S., 2017. Bioavailability and health risk of some potentially toxic elements (Cd, Cu, Pb, and Zn) in street dust of Asansol, India. *Ecotoxicology and Environmental Safety*, 138, 231–241.
 156. Peng, C.; Chen, W.; Liao, X.; Wang, M.; Ouyang, Z.; Jiao, W.; Bai, Y. Polycyclic aromatic hydrocarbons in urban soils of Beijing: Status, sources, distribution, and potential risk. *Environ. Pollut.* 2011, 159, 802–808.
 157. Zheng, N.; Liu, J.; Wang, Q.; Liang, Z. Health risk assessment of HMs exposure to street dust in the zinc smelting district, Northeast of China. *Sci. Total Environ.* 2010, 408, 726–733.
 158. ESAG. Environmental Site Assessment Guideline; DB11/T656–2009; Adelaide Airport: Adelaide, Australia, 2009. (In Chinese).
 159. United States Environmental Protection, Agency (USEPA). Risk Assessment Guidance for Superfund: Volume III—Part A, Process for Conducting Probabilistic Risk

Assessment; EPA540-R-02-002; U.S. Environmental Protection Agency: Washington, DC, USA, 2001a.

160. United States Environmental Protection, Agency (USEPA). Child-Specific Exposure Factors Handbook; EPA-600-P-00-002B; National Center for Environmental Assessment: Washington, DC, USA, 2001.
161. Hu, X.; Zhang, Y.; Luo, J.; Wang, T.J.; Lian, H.Z.; Ding, Z.H. Bioaccessibility and health risk of arsenic, mercury, and other metals in urban street dust from a mega-city, Nanjing, China. *Environ. Pollut.* 2011, 159, 1215–1221.
162. Lu, X.; Wang, L.; Li, L.Y.; Lei, K.; Huang, L.; Kang, D. Multivariate statistical analysis of HMs in street dust of Baoji NW China. *J. Hazard. Mater.* 2010, 173, 744–749.
163. United States Environmental Protection, Agency (USEPA). Risk Assessment Guidance for Superfund, Vol. I: Human Health Evaluation Manual (Part A); EPA/540/1-89/002; Office of Emergency and Remedial Response: Washington, DC, USA, 1989.
164. USEPA. Risk Assessment Guidance for Superfund. Volume I: Human Health Evaluation Manual (Part E, Supplemental Guidance for Dermal Risk Assessment); EPA/540/R/99; USEPA: Washington, DC, USA, 2004.
165. Li, R.Z.; Zhou, A.J.; Tong, F.; Wu, Y.D.; Zhang, P.; Yu, J. Distribution of metals in urban dust of Hefei and health risk assessment. *Chin. J. Environ. Sci.* 2011, 32, 2661–2668.
166. Wei, X.; Gao, B.; Wang, P.; Zhou, H.; Lu, J. Pollution characteristics and health risk assessment of HMs in street dusts from different functional areas in Beijing, China. *Ecotoxicol. Environ. Saf.* 2015, 112, 186–192.
167. Shabbaj, I.I.; Alghamdi, M.A.; Shamy, M.; Hassan, S.K.; Alsharif, M.M.; Khoder, M.I. Risk Assessment and Implication of Human Exposure to Road Dust HMs in Jeddah, Saudi Arabia. *Int. J. Environ. res. Public Health* 2018, 15, 36.
168. Li, H.-H.; Chen, L.-J.; Yu, L.; Guo, Z.-B.; Shan, C.-Q.; Lin, J.-Q.; Gu, Y.-G.; Yang, Z.-B.; Yang, Y.-X.; Shao, J.-R.; Zhu, X.-M.; Cheng, Z. Pollution characteristics and risk assessment of human exposure to oral bioaccessibility of HMs via urban street dust from different functional areas in Chengdu, China. *Sci. Total Environ.* 2017, 586, 1076–1084.
169. Patel, D.K.; Jain, M.K. Contamination and health risk assessment of potentially harmful elements associated with roadside dust in Dhanbad India. *Stoch. Environ. res. Risk Assess.* 2022, 36, 389–407.
170. Zheng, X.; Zhao, W.; Yan, X.; Shu, T.; Xiong, Q.; Chen, F. Pollution characteristics and health risk assessment of airborne HMs collected from Beijing Bus Stations. *Int. J. Environ. res. Public Health* 2015, 12, 9658–9671.

171. Kamunda, C.; Mathuthu, M.; Madhuku, M. Health risk assessment of HMs in soils from Witwatersrand Gold Mining Basin, South Africa. *Int. J. Environ. res. Public Health* 2016, 13, 663.
172. Liu, Y.; Lei, S.; Chen, X. Assessment of HMs pollution and human health risk in urban soils of a coal mining city in East China. *Hum. Ecol. Risk Assess. Int. J.* 2016, 22, 1359–1374.
173. Lu, X.; Zhang, X.; Li, L.Y.; Chen, H. Assessment of metals pollution and health risk in dust from nursery schools in Xi'an, China. *Environ. res.* 2014, 128, 27–34.
174. Pavilonis, B.; Grassman, J.; Johnson, G.; Diaz, Y.; Caravanos, J. Characterization and risk of exposure to elements from artisanal gold mining operations in the Bolivian Andes. *Environ. res.* 2017, 154, 1–9.
175. Bello, S.; Muhammad, B.G.; Bature, B. Total excess lifetime cancer risk estimation from enhanced HMs concentrations resulting from tailings in Katsina Steel Rolling Mill, Nigeria. *J. Mater. Sci. Eng.* 2017, 6, 338.
176. Johnbull, O.; Abbassi, B.; Zytner, R.G. Risk assessment of HMs in soil based on the geographic information system-Kriging technique in Anka, Nigeria. *Environ. Eng. res.* 2019, 24, 150–158.
177. Zhang, J.; Hua, P.; Krebs, P. Influences of land use and antecedent dry-weather period on pollution level and ecological risk of HMs in road-deposited sediment. *Environ. Pollut.* 2017, 228, 158–168.
178. Liu, E.; Wang, X.; Liu, H.; Liang, M.; Zhu, Y.; Li, Z. Chemical speciation, pollution and ecological risk of toxic metals in readily washed off road dust in a megacity (Nanjing), China. *Ecotoxicol. Environ. Saf.* 2019, 173, 381–392.
179. Zhao, K.; Fu, W.; Qiu, Q.; Ye, Z.; Li, Y.; Tunney, H.; Qian, X. Spatial patterns of potentially hazardous metals in paddy soils in a typical electrical waste dismantling area and their pollution characteristics. *Geoderma* 2019, 337, 453–462.
180. W. Wu, Y. Jin, and C. Carlsten, “Inflammatory health effects of indoor and outdoor particulate matter,” *Journal of Allergy and Clinical Immunology*, vol. 141, no. 3, pp. 833–844, Mar. 2018, doi: 10.1016/J.JACI.2017.12.981.
181. US EPA, “Particle Pollution Exposure,” 2023. <https://www.epa.gov/pmcourse/particle-pollution-exposure> (accessed Jun. 22, 2023).
182. Francisco Sánchez Soberón, “ASSESSMENT OF THE HUMAN HEALTH RISKS AND TOXICITY ASSOCIATED TO PARTICLES (PM10, PM2.5 AND PM1), ORGANIC POLLUTANTS AND METALS AROUND CEMENT PLANTS,” Doctoral, The University of Rovira I Virgili, Spain, 2017.

183. P. Kalia and M. A. Ansari, "IOT-based air quality and particulate matter concentration monitoring system," *Mater Today Proc*, vol. 32, pp. 468–475, 2020, doi: 10.1016/J.MATPR.2020.02.179.
184. LAW A, "Factsheet: Why is air quality important?," Land, Air, Water Aotearoa (LAW A), 2021.
185. S. Algarni, R. A. Khan, N. A. Khan, and N. M. Mubarak, "Particulate matter concentration and health risk assessment for a residential building during COVID-19 pandemic in Abha, Saudi Arabia," *Environmental Science and Pollution Research*, vol. 28, no. 46, pp. 65822–65831, Dec. 2021, doi 10.1007/S11356-021-15534-6/FIGURES/6.
186. R. Akhbarizadeh, S. Dobaradaran, M. Amouei Torkmahalleh, R. Saeedi, R. Aibaghi, and F. Faraji Ghasemi, "Suspended fine particulate matter (PM_{2.5}), microplastics (MPs), and polycyclic aromatic hydrocarbons (PAHs) in the air: Their possible relationships and health implications," *Environ Res*, vol. 192, p. 110339, Jan. 2021, doi: 10.1016/J.ENVRES.2020.110339.
187. J. Chen and G. Hoek, "Long-term exposure to PM and all-cause and cause-specific mortality: A systematic review and meta-analysis," *Environ Int*, vol. 143, p. 105974, Oct. 2020, doi: 10.1016/J.ENVINT.2020.105974.
188. L. G. Costa, T. B. Cole, K. Dao, Y. C. Chang, J. Coburn, and J. M. Garrick, "Effects of air pollution on the nervous system and its possible role in neurodevelopmental and neurodegenerative disorders," *Pharmacol Ther*, vol. 210, Jun. 2020, doi: 10.1016/J.PHARMTHERA.2020.107523.
189. AirNow, "The AQI Equation - Air Quality and AQI Info," AirNow - US EPA, 2016.dustdustdustResponseWadidustdustdust dust, dust Response dustdust.

Vitae

Personal Information:

Name : Mubarak Mufarreh Alenazi

Nationality: Saudi

Date of Birth: 6/29/1985

Email: Mubarak.m.m@hotmail.com

Address: Jubail industrial city , Alfarooq district, street number 20 house number 112.

Academic Background:

- Master's Degree: Environmental Science, King Fahad University of Petroleum and Minerals, KSA
- Bachelor's Degree: Chemical Engineering GPA 2.67/4 Jubail Industrial college KSA.

Publication a paper:

Potentially Harmful Elements Associated with Dust of Mosques: Pollution Status, Sources, and Human Health Risks

Work Experience:

Currently (at SADARA):

Company: SADARA chemical Co.

Location: Industrial Jubail.

Position: Operation manager.

Date: Present.

Previous employment (at SADARA):

Company: SADARA chemical Co.

Location: Industrial Jubail.

Position: Safety and Environment Engineer

Date: from 2012 to 2014

Previous employment (at SABIC):

Company: Saudi Kayan petrochemicals, SABIC affiliate

Location: Industrial Jubail.

Position: lead operator

Date: from 2012 to 2014.

Previous employment (at NAMA):

Company: Jubail Chemical Industries (JANA) , NAMA affiliate

Location: HSSAD Petrochemical Project. Industrial Jubail.

Position: shift supervisor.

Date: from 2005 to 2012.

Courses and Trainings:

- Participate Armco 85th Downstream Frontline Leadership Safety Workshop in 2022.
- process safety at JIC October 2017.
- Three days leadership Effectiveness training.
- One day management skills training.
- Lot of in-house trainings on management, technical matters, safety, and environment.
- Root cause analysis RCA by ARMS Reliability 24 Aug 2017.
- LIFE CRITICAL STANDARD at SADARA 2015
- Three weeks Site introduction training at FSA 2014.
- o A training in Epichlorohydrin & Chlor alkali Plants between 5th June till 31st August 2006, Tamilnado Petroproducts Limits., CHENNAI - INDIA.
- Course on Basic Operation Program from period 06/08/2005 to 06/02/2006 with total (720 hours), MEIRC SAUDI ARABIA, TRAINING CENTER, Jubail.