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REVIEW

A Critical Review of Urban Geochemical Pollution and Health Risks from Harmful Elements Using Geochemical Indices

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ABSTRACT

Urban geochemical alteration and transformation are complex processes that affect air, water, and soil, potentially posing serious health risks to the residents. Our health is determined by where we live now, and where we have previously lived and how long we have been there. This review explores patterns of urban environmental pollution and public health risks associated with potentially harmful elements. Academic databases including Scopus, Web of Science, and Google Scholar were used to find pertinent peer-reviewed papers, reports, and case studies. It discusses urban environmental and medical geochemistry, focusing on toxic heavy metals of public health concern and their urban sources. Case studies on geochemical anomalies in street dust, atmospheric, lithochemical, and hydrochemical contexts are critically examined. The review evaluates the effectiveness of geochemical indices in assessing pollution and health risk patterns in road dust, soil, air, and water, emphasizing the importance of geochemical background in urban geochemistry and medical geology. Strategies to reduce toxic heavy metal pollution in urban areas are also reviewed to protect public health. Finally, it offers conclusions and recommendations for future research. It is obvious that the environmental geochemistry of soil, street dust, water, and air contain a wealth of information about the state of urban environments. The outcomes of this study will help to raise public awareness of urban pollution and associated health risks, promoting environmental preservation and health protection in urban settings.

Keywords: Urban Geochemistry; Medical Geology; Geochemical Indices; Health Risk Assessment; Heavy Metals; Urbanisation

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1. Introduction

Urban environments are complex systems that exist at the intersection of the natural, built, and social worlds [1]. The percentage of the global population living in cities has increased dramatically over the last century [2]. In 2018, 4.2 billion people lived in cities, with an extra 2.5 billion expected by 2050 [3], putting significant strain on various environmental compartments such as soil, air, and water [4]. High population densities in cities, which lead to increased consumption and waste, dominate geochemical cycles in relatively small areas [3]. The composition of elements in environmental compartments in an urban area changes due to human activities during landscape formation [5]. Urban geochemical alteration and transformation is a complex process that affects air, water, and soil. Pollution of these environmental compartments by point and nonpoint sources caused by natural and anthropogenic impacts is one of the primary driving forces of urban geochemical alteration [6].

Large volumes of elements are released into the environment by natural events like weathering, gas and fluid escape along significant crustal fissures, and volcanic activity [7]. In addition to natural causes, a lot of elements have been discharged into the urban environment as a result of intensive human activities like construction, fast development, heavy traffic, road weathering, vehicle wear and tear, combustion, power plants, inadequate waste management, wastewater effluents, agriculture, and corrosion of paints and building materials [1,8–10]. As a result of these activities, various toxic elements (**Table 1**) may be released into various urban environmental settings, such as street dust, water, air, and soil. Among them, N, P, K, Ca, S, and Mg are macronutrients, Fe, Zn, Cu, B, Mn, Mo, and Cl^- are micro-nutrients elements while As, Cd, Cr, Pb and Hg are regarded as toxic elements of public health concern [10,11].

Heavy metal pollution is a problem in many urban and industrialised areas around the world [3]. As a result, environmental chemical pollution is a serious concern [12], because metals and metalloids are not decomposable and thus remain in the environment i.e., soil, street dust, air, and water for long periods of time [13,14]. Exposure to highly contaminated soil, water, air, and street dust, whether through inhalation, ingestion, or dermal contact absorption, can have serious health consequences for city residents [15,16]. These include cancer, miscarriages, hearing and visual impairment, asthma, renal failure, high blood pressure, headaches and dizziness, reproductive system problems, cardiovascular disorders, writhing, ataxia, skin and eye irritation, and lung granulomas [10,17,18]. It can also inhibit enzymes and cause damage to the nervous, skeletal, circulatory, endocrine, and immune systems [19–21]. Thus, understanding urban geochemical characteristics is critical because it can aid scientists to comprehend better the links between the urban setting and human health [22].

Table 1. Potential toxic heavy metals in urban environment [10,11].

Potential Toxic Heavy Metals	Chemical Symbol
Arsenic	As
Barium	Ba
Cadmium	Cd
Calcium	Ca
Cobalt	Co
Chromium	Cr
Copper	Cu
Iron	Fe
Lead	Pb
Magnesium	Mg
Manganese	Mn
Mercury	Hg
Molybdenum	Mo
Nickel	Ni
Niobium	Nb
Nitrogen	N
Phosphorus	P
Potasium	K
Rubidium	Rb
Scandium	Sc
Sulphur	S
Strontium	Sr
Thorium	Th
Vanadium	V
Yttrium	Y
Zinc	Zn
Zirconium	Zr

An elected important field, medical geology (in this study, urban environmental and medical geochemistry) aims to comprehend the risks of the geo-environment on human health and the ecosystem as a whole [11,23,24]. It discusses the intricate relationships and interactions between chemical elements and their compounds in urban settings, the impact of industrial and human activities on the environment both now and in the past, and the effects of urban geochemical parameters on living things [25,26]. According to Guagliardi [27], urban environmental and medical geochemistry is crucial in establishing geochemical anomalies, identifying potential sources of pollution, evaluating the risks, and mitigating future effects of potentially harmful elements using various pollution and risk indices. Pollution (i.e., geo-accumulation, enrichment factor, contamination factor, pollution index, pollution load index, degree of contamination, etc.) and risk (i.e., ecological risks and human health risks) indices are tools that have been consolidated to assess environmental contamination by chemical elements [28]. These indices offer a methodical approach to comprehending the kind and degree of pollution, identifying possible health risks hazards, and directing management and remediation plans [27]. Cities' past, present, and future are inextricably linked, as evidenced by the long-term effects of their geochemical legacies [1]. Because of the intense anthropogenic activities associated with cities, they are geographic hotspots for heavy metal emissions [29]. Cities, as a unique population centre as well as a source of employment and industry, have a long history of polluting practices and at times with negative effects for inhabitants' health [1]. According to recent estimates, environmental pollution killed approximately 9 million people in 2019 [3]. These situations or developments around the world have resulted in cities playing an increasingly vital role in protecting and improving the health of their residents. Health is a valuable asset and the foundation of long-term urban development. As a result, continuous high-quality and accurate urban environmental investigations and analyses are critical to any contamination assessment and subsequent decision-making process. This critical knowledge is required to comprehend the roots of various endemic diseases and thus add to improving the nutritional status of the population living in contaminated urban areas [30].

Therefore, for a complete geospatial data on site pollution, a detailed and comprehensive area assessment is necessary. This information is a requirement for effective site description and reclamation [31]. To date, no comprehensive review has been conducted that critically synthesizes available data on urban geochemical anomalies across multiple environmental compartments, including street dust, atmospheric deposits, lithochemical matrices, and hydrochemical systems. Existing reviews on urban geochemical anomalies predominantly address individual environmental media in isolation, often neglecting the interconnected nature of atmospheric, lithochemical, hydrochemical, and street dust compartments. This study addresses this gap by providing a comprehensive synthesis of global data on urban environmental geochemistry across air, water, soil, and road dust. Furthermore, it evaluates the applicability and potential effectiveness of various geochemical indices for monitoring urban geochemical pollution and supporting risk assessment frameworks. To achieve this, the study will delve into (i) the concept of urban environmental and medical geochemistry (ii) summarises the heavy metals of public health concern, their associated risks and sources (iii) review worldwide case studies on geochemical composition of urban environment i.e. air, soil, road sediments and water, (iv) efficacy of pollution and risk assessment indices (v) relevance of geochemical background in urban environmental and medical geochemistry research and (vi) mitigation of environmental quality and public health in urban settings. The information gathered in this study will raise public awareness on urban pollution and health risk patterns.

Research Method

In order to investigate urban geochemical pollution and related health hazards, this critical review uses a methodical literature search. Using terms like "urban pollution," "geochemical indices," "heavy metals," and "health risks," academic databases including Scopus, Web of Science, and Google Scholar were searched to find pertinent peer-reviewed papers, reports, and case studies. In order to reflect recent developments, studies released from 1985 to 2025 were cited in this study. Based on their emphasis on geochemical evaluations of potentially hazardous elements in urban settings and their connection to public health consequences, a selection of papers was vetted for relevance. The types of geochemical indices employed, the contaminants examined, the temporal and regional trends, and the purported health effects were the main topics of data extraction. The advantages and disadvantages of various indices in various urban contexts were determined by comparative study. This approach guarantees a thorough and critical assessment of existing approaches, knowledge gaps, and suggestions for further study in the fields of medical geology and urban environmental health.

2. Urban Environmental and Medical Geochemistry: A Medical Geology Perspective

Urban settings are the epicentre of human-environment interactions because of their dense populations, high levels of both stationary and mobile sources of emissions that are formed or enhanced by humans, heavy traffic, and the repeated incident of industrial activities situated close to residential areas [1]. As a results of these factors, chemical emissions are concentrated in urban areas. Human activity's massive release of chemicals into the environment has resulted in the enrichment of numerous metals in the atmosphere, surface waters, road dust, and soils of many urban spaces [32], which has a significant effect on the standard of living those urban dwellers experience [21]. According to Boulos and Le Blond [33], our health is also influenced by where we currently reside, where we have previously resided, and how long we have lived there. Studying these anomalies in urban environments has become an essential part of urban environmental and medical geochemistry research (medical geology in this study) [34]. A subfield of geo-medicine known as "medical geology" is dedicated to the association between the urban environment and human health [23,35–37] and the basic understanding that disease is a consequence of exposure to the environment [33]. It is the branch of science that examines how the geo-environment affects human health and the ecosystem as a whole, whether in a positive or negative way. It is based on multi-, cross- and inter-disciplinary approaches bringing together experts from various fields of science including epidemiology, toxicology, geoscience, the environmental disciplines and public health [11,38,39]. Thornton et al. [36] define medical geology as the study of the complex connections and interrelationships between chemical elements and their compounds in the urban environment, as well as the impact of past and present human and industrial activities on these, and the risks of geochemical parameters in urban areas on plant, animal, and human health. As a result, urban environmental and medical geochemistry is a critical field of research that can improve the well-being of urban communities [11,25,39,40]. This field of study is critical because it helps to understand the geological history and urban geochemical background, which contributes to a better and deeper understanding of the range of natural hazards that can affect ecosystems and human health [24,41]. This understanding (i.e., the amounts, behaviours, sources, forms, dispersion, uptake, and health impacts of chemical substances) may lead to the reduction or prevention of impacts, as well as the prevention of some of the most widespread and serious health risks, potentially saving lives [42].

3. Heavy Metals of Public Health Concern and their Associated Risks

Heavy metal contamination is a major environmental concern caused by the discharge of metallic elements into the urban environment, such as water, street dust, soil, and air, which pose significant risks to ecosystems and human well-being in the long run. The term "heavy metal" refers to metallic elements and metalloids with a density over 5000 kg/m^3 and an atomic mass greater than 20. Heavy metals are persistent and do not degrade; however, they can be leaked, dissolved, and/or converted, often into more toxic forms, and accumulate in the environment and living beings [43]. Some of the elements that may be released into various urban environmental settings i.e., street dust, water, air and soil as results of various anthropogenic activities are Al, Bi, Br, Cd, Au, K, Ca, N, Mo, As, Fe, Mg, Mn, B, Ba, Co, Cr, Cu, Ni, Pb, Zn, Li, P, Hg, Ag, I, F, Zr, Nb, Rb, Sc, Sr, Th, V, S, Y and etc. According to whether or not biological processes maintain these elements at the appropriate level in our bodies, they are divided into two categories [44]. Based on their biological effects, diseases brought on by deficiencies, and toxicity from overdose, they are categorised as either essential (Fe, Zn, Cu, Co, Cr, F, I, Mn, Mo, and Se) or non-essential (Al, As, Ba, Bi, Br, Cd, Au, Pb, Li, Hg, Rb, Ag, Sr, Ti, and Zr) [17,45,46]. Moreover, elements As, Cd, Cr, Pb and Hg are considered toxic elements of public health concern [10,11] as they may pose negative health effects on organisms regardless of their concentration [17,47,48].

Due to their long biological half-lives for elimination and non-biodegradability, heavy metals have a long-term negative effect on human health [49,50]. City dwellers may eventually suffer major health consequences if they are exposed to highly contaminated soil, water, air, and street dust through ingestion, inhalation, or absorption through the skin [15,16]. At low concentrations, arsenic is thought to cause cancer in humans. Long-term exposure to an As-contaminated medium, such as water, air, soil, or street dust, can have negative health effects, including blood, lung, and skin cancer. Additionally, it may cause cardiovascular and neurological effects [51,52]. Lung conditions, bronchitis, emphysema, kidney damage, osteoporosis, osteomalacia, renal dysfunction, and anaemia can all result from exposure to high levels of cadmium in urban environments [17]. Excessive levels of mercury in the air, water, soil, and street dust can cause tremors, sleeplessness, memory loss, neuromuscular effects, headaches, genetic changes, and cognitive and motor dysfunction [10,53,54]. There are two forms of chromium: hexavalent Cr (VI) and trivalent Cr (III). While hexavalent chromium is extremely toxic, trivalent chromium is thought to be a necessary nutrient for humans. Asthma, chronic bronchitis, irritation, pharyngitis, rhinitis, renal failure, lung, nasal, and sinus cancers are among the health consequences that urban dwellers may encounter as a result of exposure to elevated levels of Cr [55,56]. Lead is thought to be carcinogenic to humans and toxic at low concentrations. Persistent exposure to high levels of lead in the air, water, soil, and street dust can cause miscarriages, hormonal changes, decreased potency in humans, irregular menstruation, girls' puberty interruptions, memory loss, mood swings, muscle disorders, and cardiovascular, skeletal, and kidney issues [17].

4. Sources of Toxic Heavy Metals in Urban Environmental Settings

Universally, urbanisation has drastically altered the environment's composition and quality, including the air, soil, water, and street dust. Rapid population growth, significant infrastructure development, and intensive land use are its defining characteristics. Heavy metal contamination is one of the many environmental challenges brought on by urbanisation [57]. Large volumes of heavy metals may be released into the environment due to natural events like weathering, gas and fluid escape along significant crustal fissures, and volcanic activity [7]. Besides natural factors, numerous elements of public health concern, such as Pb, Cd, As, Cr, and Hg, have been released into the urban environment as a result of intensive anthropogenic activities (**Figure 1**), including construction, rapid development, high road traffic, road weathering and maintenance, vehicle wear and tear, combustion, poor waste management, burning of waste, wastewater effluents, agriculture, and corrosion of building materials and paints [1,8–10]. The dispersion of anthropogenic trace metals can occasionally also be significantly influenced by other metal-emitting facilities, such as coal power plants and mining and smelting operations, if they are situated in or close to urban areas [58,59]. In any case, atmospheric emissions are the main way that trace metals from these "urban" sources are released. They have a tendency to stick to particulate matter when they are released, forming dust and fine particles [60,61].

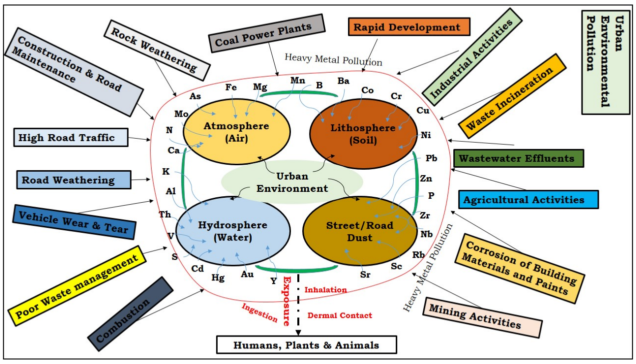

Figure 1. Sources of Toxic Heavy Metals in Urban Settings.

Numerous studies have verified that anthropogenic activities and natural events are the sources of heavy metals in urban environments. For instance, a study conducted in Dhanbad, India by Jena and Singh [62] on airborne trace elements found that the main sources of metals in PM_{10} were mine fire, coal combustion, road dust resuspension, and vehicle emissions. In Dhanbad, India, vehicle traffic was the primary source of metals in particulate matter and road dust, according to a different study by Kumari et al. [32]. The high levels of heavy metals in the soil of Serbia's industrialised cities were linked to heavy traffic, industrial processes, and the soil's geological foundation [21]. Human activity, industrial operations, and natural sources like wind-blown soil mineral dust have all been connected to toxic elements in urban soil in the Chennai, India [63]. In a different study, Heidari et al. [64] determined that the primary sources of heavy metals in road dust from Bandar Abbas, Iran, were lithogenic, traffic emissions, and industrial and construction activities.

5. Urban Environmental Geochemistry: Case Studies

One of the characteristics of the modern era is rapid urbanisation, which propels social development, economic expansion, and technological advancement [65]. But because of the dense and unequally distributed population in urban areas, a lot of natural resources are consumed, and a lot of pollutants are released into the environment, including heavy metals like Pb, Hg, Cd and As [10]. By contaminating the air, water, soil, and food, these pollutants pose major effects to human health and the ecosystem through ingestion, inhalation, and skin contact [66]. Thus, this subsection provides a real glimpse of global urban atmochemical, lithochemical, street dust and hydrochemical anomalies.

5.1. Urban Atmochemical Anomalies

Changes in the chemical makeup of atmospheric aerosols are referred to as urban atmochemical anomalies in this study. Various studies have reported the presence of toxic heavy metals in urban atmosphere. For example, in Dhanbad city, India, Kumari et al. [32] examined particulate matter for heavy metals like Fe, Pb, Cd, Ni, Cu, Cr, and Zn. According to the study, the average mass concentrations of $PM_{2.5}$ and PM_{10} were 129.73 μg/m^3 and 229.54 μg/m^3, respectively. It was discovered that $PM_{2.5}$ had a higher average concentration of heavy metals than PM_{10}. The presence of trace element concentrations in PM_{10} was documented by another study conducted in Dhanbad city, India. The study's findings showed that the average annual concentration of PM_{10} was a comparatively high (216 mg/m^3), exceeding both the WHO and NAAQS air quality guidelines [62]. The average atmochemical anomalies of trace metals in La Plata City, Argentina, were also reported to be Cd (0.41), Pb (64), Mg (1472), Cu (30), Ca (5343), Ni (3.2), Fe (1183), Zn (273), Cr (4.3), and Mn (26) ng/m^3. According to the study, these metals' values were below the overall trend for urban particulates and comparable to those reported for cities that were not extremely polluted [40].

5.2. Urban Lithochemical Anomalies

Unusual alterations in the chemical makeup of soils are referred to as urban lithochemical anomalies. U (1.42), Th (27.90), K (13940.06), Fe (52035.91), Cr (131.65), Cu (89.43), Ni (54.80), Pb (90.70), Zn (256.41), As (5.22), and Ti (5405.22) ppm were the selected potentially hazardous elements in urban soil near Chennai, India. All measured elements, with the exception of U and K, were above the permitted limits determined by the values of the continental crust composition [63]. Pavlovic, et al [21], analysed occurrence of selected heavy metals namely Co, Cr, Cu, Fe, Mn, Ni, Pb, Sr, and Zn in several industrialised cities in Serbia. In Pancevo, their mean concentrations were as 8.76; 40.97; 31.12; 32,843.09; 570.46; 61.35; 46.56; 42,46; and 45.56 mg kg^{-1}. The average values of Ni, Pb and Cu were above the upper continental crust. In Smederevo, their respective mean concentrations were as 9.46; 77.85; 48.54; 29,435.41; 508.51; 104.05; 99.11; 70.06; and 114.82 mg kg^{-1}. Compared to upper continental crust, Zn, Ni, Cu and Pb were slightly higher. In Obrenovac, the study revealed the mean concentration of these metals as 11.75; 45.73; 33.54; 34,641.16; 640.29; 75.69; 53.26; 84.58; and 48.30 mg kg^{-1} respectively. Only Cu, Ni and Pb were above upper continental crust. Moreover, their mean concentrations in Belgrade were as 8.34; 27.48; 49.84; 27,668.93; 452.01; 44.60; 327.03; 122.24 and 135.33 mg kg^{-1} respectively. In this City, only Cu, Pb and Zn were above their geochemical background. In Shanghai, China, the mean concentration of Cr, Co, Ni, Cu, Cd, Sb, Pb, Hg, Mn, and Zn were as 68.63; 11.52; 34.89; 46.03; 0.46; 4.01; 57.07; 0.13; 529.38; and 255.26 mg/kg in Hutai roadside soil and 66.89; 11.52; 34.49; 38.41; 0.25; 1.02; 34.77; 0.12; 499.89; and 288.47 mg/kg in Wunign-Caoan roadside soil respectively. When matched to the local background values, majority of these metals were higher [67].

5.3. Urban Street Dust Anomalies

In this study, urban street dust anomalies refer to changes in chemical composition of dust building-up on the surface of roads and streets particularly in urban areas. A number of contaminants, together with heavy metals, accumulating in street dust can trigger health effects on city dwellers [68]. Rana et al. [69] monitored the level of hazardous heavy metals in urban street dust from industrial areas and city of Bangladesh. The average concentrations of identified metals Cr, Mn, Co, Ni, Cu, Zn, Cd, and Pb in particle size of ≤ 20 μm from these areas were 238.31 and 45.21; 444.35 and 236.72; 10.93 and 9.81; 45.66 and 43.27; 54.22 and 55.76; 299.25 and 205.19; 2.73 and 3.14 as well as 52.78 and 27.42 mg/kg respectively. Heidari et al. [64], monitored the level of heavy metal pollution of road dust in Bandar Abbas city, Iran. The study reported the average concentration of heavy metals As, Cd, Co, Cr, Cu, Mn, Ni, Pb and Zn in road dust collected from the city and surrounding suburban as 8.28 and 26.88; 0.42 and 3.12; 9.90 and 15.83; 73.51 and 55.17; 149.75 and 1173.25; 458.75 and 555.58; 65.97 and 68.83; 59.85 and 620.83 as well as 292.92 and 1139.58 μg/g respectively. In comparison to the local background values As, Cd, Cr, Cu, Pb, and Zn in road dust from the city centre were high while in surrounding suburban As, Cd, Co, Cu, Mn, Pb and Zn were above. Zgłobicki and Telecka[68], reported occurrence of heavy metals in urban street dust from Lublin, Poland. The average concentration of Cd, Cr, Cu, Ni, Pb, and Zn in two different years (2013 and 2018) were 6.3 and 5.5; 108.5 and 112; 114.9 and 120.6; 21.4 and 17.1; 62.0 and 46.6 as well as 364.4 and 296.2 $mg \cdot kg^{-1}$ correspondingly. In comparison to the geochemical background, all the analysed elements were significantly higher. Moryani, et al.[70] monitored heavy metals accumulated in road dust from Karachi and Shikarpur of Pakistan. The average concentrations of Cu, Pb, Zn, Cd, Ni, Sb, and Cr in road dust from these two cities were as 332.9 and 245.8; 426.6 and 538.4; 4254.4 and 8351.0; 62.3 and 57.6; 389.7 and 131.7; 70.4 and 314.5 as well as 148.1 and 346.6 mg/kg respectively.

5.4. Urban Hydrochemical Anomalies

Hoque, et al.[71] in Chattogram, Bangladesh monitored contamination of groundwater with heavy metals. The average concentrations of toxic metals in shallow, intermediate and deep wells were as Fe (2.68; 1.14; 0.98), Mn (0.49; 0.17; 0.13), As (0.003; 0.003; 0.001), Cr (0.028; 0.02; 0.02), Cu (0.08; 0.03; 0.028), Zn (0.20; 0.20; 0.20), Cd (0.01; 0.01; 0.01) and Pb (BDL) mg/L respectively. Only the value of Mn, Cu and Cd were above the Bureau of Indian Standards. Another study in Sichuan Basin, China appraised trace elements accumulation in urban groundwater. The mean concentrations of trace elements in this study were as Cu (2.12), Fe (70.09), Pb (0.24), As (1.51), Mn (109.46), and Zn (12.83) μg/L respectively. Only Mn and Fe exceeded the Chinese drinking water guidelines[72]. In Xiamen City, China, Li, et al.[73] monitored the hydrochemical characteristics of the groundwater. The study reported the median concentrations of Al^{3+}, Fe, Pb, Cu, Zn, As and Cr^{6+} as ND, 0.03, 0.001, ND, 0.01, ND and ND mg/L respectively. Among detected metals, Fe had the highest median value.

The geochemistry of soil, street dust, water, and air offer valuable evidence about the urban environment status-quo. The majority of the metals found in urban environments were above the average shale values, upper continental crust values, or local soil background values. Depending on a number of variables, including industrial layout, local geology, land use, natural disasters, and population distribution, these chemical anomalies differ from city to city. These metals can cause bioaccumulation and biomagnification when they build up in soil, water, air, and street dust, which can be extremely dangerous for both people and wildlife. Furthermore, through contaminated water and food sources, this pollution affects biodiversity and poses a threat to public health and food security. Therefore, to safeguard the environment and humanity, this calls for more urban environmental and medical geochemistry studies that can continuously monitor the level, distribution, sources, morphology and risks of chemicals. Assessing the level and spatial distribution of harmful metals can help determine the health risks associated with them and support appropriate urban environmental management. These results give policymakers important new information to better understand the current state of affairs and implement quick fixes, such as appropriate zoning, to limit exposure to heavy metals and lower related effects.

6. Urban Geochemical Pollution and Risk Assessment Indices

Heavy metal contamination can be evaluated using a number of different approaches and criteria. The enrichment factor (EF), contamination factor (CF), geo-accumulation index (Igeo), pollution load index (PLI), pollution index (PI), degree of contamination (Cdeg), modified degree of contamination (mCd), ecological risk (ER), potential ecological risk index (PERI), risk assessment code (RAC) and human health risk assessment (HHRA) are some of the geochemical indices used to understand the impact of urbanisation on the environment and human health[74]. In this subsection, the theory around these indices and their applications in studies linking urban environmental geochemistry to public health are reviewed. Where possible, case studies on their application in pollution and risk assessment of heavy metals in urban settings i.e. road dust, soil, atmosphere and water sources are also provided. The application of these indices in other settings were not reviewed.

6.1. Urban Geochemical Pollution Indices

6.1.1. Geo-Accumulation Index

Müller[75] proposed the Geo-accumulation index (Igeo) to measure the pollution levels in bottom sediments. However, it is now also applied to assess contamination level in other environmental medium using Equation (1):

$$Igeo = Log_2\left(\frac{C_{sample}}{1.5\ x\ B_n}\right) \quad (1)$$

C_{sample}: concentration of selected element in a sample, B_n: geochemical background content in average shale value, upper continental crust or local sample. The 1.5 is the factor compensating the background content due to lithogenic effects. Based on Igeo index, pollution level rating ranges from practically uncontaminated to extremely contaminated [75,76].

Efficacy of Igeo Index

Urban road dust: Heavy metal pollution (Cr, Mn, Ni, Zn, Fe, Cu, and Cd) in street dust from Wuhan City, China was assessed by Igeo index. The Igeo values of Cd, Zn, and Cu were classified as moderately contaminated while for Cr, Mn, Fe, and Ni were classified as practically uncontaminated [77]. Pollution of urban road dust by selected metals Cd, Cr, Cu, Ni, Pb, Zn, Fe, Se, Sr, Ba, Ti, and Pd in Katowice, Poland was assessed using Igeo index. In this study, contamination level of finest fractions of road dust was classified as extremely contaminated (Ti), strongly contaminated (Cr, Ni, and Cu), moderately contaminated (Zn), and uncontaminated to moderately contaminated (Fe, Pb, Ba) [78].

Urban soil: The soil of Chennai's megacity, India were analysed to understand the pollution level of K, Fe, Cu, Zn, Ti, Th, As, Pb, U, Cr, and Ni using Igeo index. Their Igeo values ranged from 0.11–1.20 with an average value of 0.65. The Igeo index classified the study areas as either uncontaminated or moderately contaminated [63]. In the city of Xiangyang, China, the pollution level of Pb, Ni, Cr, As, Zn, Cd and Cu in soil were also assessed using Igeo index. The mean Igeo of Cr was an indicative of extremely polluted conditions, whereas Cd showed strongly to extremely polluted conditions. Meanwhile, the mean Igeo values for Cu, As, and Pb were indicative of unpolluted to moderately polluted conditions, while Zn and Ni showed that the urban soils were practically unpolluted in terms of these two metals [79].

Urban atmosphere: Kumari et al. [32] used Igeo index to assess level of heavy metals pollution in particulate matter in Dhanbad City, India. The Igeo values of heavy metals in PM_{10} were classified as moderately contaminated for Ni, Pb, Zn, and Cu as well as uncontaminated to moderately contaminated for Cr, and Cd. In $PM_{2.5}$, the pollution level was classified as moderately contaminated for Ni, Zn, and Pb as well as uncontaminated to moderately contaminated for Cd, Cr, and Cu.

Urban water sources: Nduka et al. [80] study in Enugu city, Nigeria reported the occurrence of selected heavy metals namely: Cu, Ni, Fe, Pb, Mn, Hg and Cr in water sources. Using the Igeo index to understand the level of pollution, they reported that the water sources in the city were uncontaminated with Cr, Ni, Cu, Pb, Fe, and Mn, uncontaminated to moderately contaminated with As and moderately to strongly contaminated with Hg.

6.1.2. Enrichment Factor

One of the instruments that enables the assessment of the impact of human activities on the environment is the enrichment factor (EF) [81]. This index establishes the normalisation of an element's concentration when its contamination is assessed in relation to the concentration of a reference metal that occurs in the earth's crust with little variation e.g., Mn, Al and Fe [82]. EF is computed using Equation (2):

$$EF = \frac{\left(\frac{C_n}{C_m}\right) sample}{\left(\frac{C_n}{C_m}\right) background} \quad (2)$$

The (C_n/C_m) sample: ratio between the concentration of element *n* (C_n) and the concentration of the reference metal (C_m) in the collected sample. The (C_n/C_m) background: ratio between the background concentrations of the element *n* and the reference metal. Based on EF, pollution level classification ranges from minimal enrichment to extremely high enrichment as shown in the following table [10].

Efficacy of EF Index

Urban road dust: In Bandar Abbas, Iran, EF index was adopted to better describe the level of heavy metal pollution i.e., Zn, As, Cr, Cu, Co, Pb, Ni, Cd and Mn in road dust. Except for Cr and Ni, the majority of toxic elements had EF values greater than two. The highest being Cu with significant enrichment [64]. Road dust in urban informal settlement around Ekurhuleni Metropolitan Municipality, South Africa were accumulated with heavy metals such as U, Pb, Cr, Ni, Ba, Nb, Rb, Zn, Sr, Cu, Zr, Co, V, Y, Th, As, and Sc. Based on EF values, Cr had significant degree of enrichment, Zn was classified as minimally enriched, whereas all other trace elements were of natural origin [10].

Urban soil: The level of pollution for Zn, Pb, Co, Mn, Cr, Fe, Sr, Cu, and Ni in soil around Pancevo, Smederevo, Obrenovac, and Belgrade cities of Serbia were examined using EF. The study reported no enrichment with the examined toxic metals in the soils except for Pb, which had moderate enrichment in Pancevo and significant enrichment in Belgrade [21]. In Shanghai, China, assessment of soil heavy metal pollution using EF revealed moderate enrichment (Sb, Cd, Pb and Zn), minimal (Cu, Cr, Co, Ni, Hg and Mn) and significant pollution (Zn) [67]. Gopal, et al. [63] assessed pollution level of K, Cr, Ti, Cu, U, Pb, Fe, Zn, As, Ni and Th in Chennai, India using EF. The EF values ranged from 1.14 to 3.32, indicating notable metal enrichment in a small number of locations and high levels of enrichment in the northern study area. The average EF values of these metals showed minimal mineral enrichment deficiency.

Urban atmosphere: Kumari et al. [32], analysed the level of trace elements in particulate matter around Dhanbad city, India, using EF index. For PM_{10}, the EF values were showed moderately contaminated for Ni, Pb, Zn, and Cu as well as uncontaminated to moderately contaminated for Cr, and Cd. For $PM_{2.5}$, the EF value showed moderately contaminated for Ni, Zn, and Pb while Cd, Cr, and Cu were classified as uncontaminated to moderately contaminated. Jena and Singh [62] analysed airborne trace elements such as As, Cu, Fe, Co, Cd, Zn, Ni, Mn, Cr, and Pb in Dhanbad, India. The assessment of pollution level using EFs were observed in three distinct groups such as, highly enriched (Zn and Cd), moderately enriched (Pb, Cu and As) and slightly enriched (Ni, Co, Cr and Mn). Airborne trace metals Cd, Cr, Mn, Pb, Ca, Cu, Mg, Zn, Ni, and Fe were measured in La Plata city area, Argentina by Bilos et al. [40]. The EF values were highest for Pb, Zn, Cd and Cu, indicating that anthropic inputs prevail over normal crustal weathering processes. EFs values for Mn, Cr, Ni, Ca and Mg were lower indicating that their main source in airborne particles are soil-derived dusts.

Urban water sources: To access the contribution of anthropogenic and natural sources of heavy metals Cr, Fe, Cu, Mn, Ni, Hg and Pb in water sources around Enugu city, Nigeria, EF index was adopted. The EF values of studied heavy metals in all the sampling locations were poorly enriched with the exception of Hg in Enugu/PH and Agbani roads and As in Ogui showed moderate pollution [80].

6.1.3. Contamination Factor

The contamination factor (CF) is defined as the ratio between the concentration of a heavy metal whose pollution is being measured and its preindustrial concentration in the region under study [28]. The pollution level is determined using Equation (3):

$$CF = \frac{C_{sample}}{C_{pi}} \tag{3}$$

The C_{sample} is the concentration of the element in the collected samples, C_{pi} is the preindustrial concentration of the element studied. Preferably, the C_{pi} sample should be an average value of at least five sampling sites. Based on CF, pollution level classification ranges from low contamination to very high contamination as shown in the following table [10,83].

Efficacy of CF Index

Urban road dust: The pollution level of As, Cd, Ni, Pb, Hg, and Cr in road dust from the city of Urumqi, China, were determined using CF index. The average CF values of these heavy metals in the urban surface dust were ranked as Pb > Hg > Cr > Ni > As > Cd. In this study there was a moderate contamination for As, Pb, Hg, Cr, and Ni as well as low contamination for Cd [84]. Mugudamani et al. [10], reported that CF values for heavy metals in road dust from urban informal settlement in Ekurhuleni Metropolitan Municipality, South Africa exhibited road dust to be very highly contaminated by Cr, moderately contaminated by Ba, Cu, Zr, Zn, and Pb and lowly contaminated by Th, Sr, Co, Ni, Sc, U, Y, Nb, Rb, As and V.

Urban soil: Pavlovic et al. [21] used CF to assess pollution level of selected heavy metals in soil around Pancevo, Smederevo, Obrenovac, and Belgrade city in Serbia. The average CF values for Co, Cu, Cr, Mn, Ni, Sr, and Zn were classified as low contamination in all sites. However, in Smederevo (Cu, Fe), Belgrade (Fe, Mn and Sr), Pancevo (Ni) and Obrenocav (Sr) were classified as moderate contamination. Most notable in this study was extremely high CF values for Pb in Belgrade. Gopal, et al. [63] assessed the level of pollution for K, Zn, Ni, U, As, Fe, Cr, Th, Cu, Pb, and Ti in urban soil of Chennai, India using CF. The CF values ranged from moderate contamination to considerable contamination. The study also revealed that the average CFs of these toxic elements were classified as considerable contamination.

Urban atmosphere: According to Kumari et al. [32], the CF values Cu, Zn, Cd, Pb, Cr, and Ni in PM_{10} and $PM_{2.5}$ around Dhanbad city, India showed variation across study locations. Generally, the contamination levels were classified as low contamination, moderate contamination; considerable contamination, and very high contamination.

Urban water sources: In Khyber Pakhtunkhwa, Pakistan, CF was adopted to assess the level of groundwater pollution by selected heavy metals Fe, Cr, Cd, Pb, Zn, Mg, and Ni. In this study, Fe had the high level of contamination, Mg as classified as moderate contamination while other elements were classified as low contamination [85]. In selected urban centres of Onitsha, Nigeria, contamination of groundwater sources by Cr, Cu, Pb, Mn, Cd, Ni, and Fe was reported. The heavy metal contamination factor index, revealed 70.83% of the total samples are unsuitable for drinking [86].

6.1.4. Degree of Contamination

The degree of contamination (Cdeg) index is used mostly for assessment of pollution level in environmental compartments [28]. It is assessed based on Equation (4):

$$C_{\text{deg}} = \sum_{i=1}^{n} CF \quad (4)$$

Based on Cdeg, the level of pollution classification ranges from low degree of contamination to very high degree of contamination as presented in the following table [21].

Efficacy of Cdeg Index

Urban soil: In Pancevo, Smederevo, Obrenovac, and Belgrade cities, Serbia, Pavlovic et al. [21] assessed the pollution level of Zn, Cu, Ni, Co, Pb, Sr, Fe, Cr, and Mn in soil using Cdeg. The average Cdeg values obtained at all the sampling sites were classified as a low level of contamination except in Belgrade were the Cdeg values of toxic elements were classified as a moderate degree of contamination. In urban soil of Chennai, India, the pollution level of U, Th, K, Pb, Ni, Cr, Zn, As, Ti, Fe, Cu was also assessed using Cdeg. The study area Cdeg mean values for identified metals were classified as very high contamination [63].

Urban atmosphere: In the city of Sarnia, Canada, the level of contamination of PM by Ni, Zn, Cr (VI), Cd, As, Mn, Cu, Pb, and Fe was assessed using degree of contamination. According to the study, when Zn and Fe are excluded, the Cdeg values indicated moderate degree of contamination [87].

6.1.5. Modified Contamination Factor

A multi-element index called the modified contamination factor (mCdeg) is used to understand the degree of environmental pollution [88]. Equation (5) is used to determine the level of pollution in a given medium [28].

$$mC_{\text{deg}} = \frac{1}{n}\sum_{i=1}^{n} CF_i \quad (5)$$

The *n* is the number of toxic metals targeted and *CF* is the contamination factor for identified toxic metals [89]. Pollution classification ranges from very low contamination to ultra-high contamination as presented in the following table [28].

Efficacy of mCdeg Index

Urban atmosphere: In Dhanbad City, India, the pollution level for Cr, Cu, Ni, Cd, Zn and Pb in PM_{10} and $PM_{2.5}$ based on mCd ranged from moderate degree of contamination to high degree of contamination [32].

6.1.6. Pollution Index

The pollution index (PI) estimates the chemical pollution level in the environment [90] using Equation (6).

$$PI = \frac{C_{sample}}{C_{background}} \quad (6)$$

The C_{sample} is the element concentration in a given sample while $C_{\text{background}}$ is the element's background in the region studied. Pollution level is classified as either unpolluted: PI < 1, moderately polluted: $1 \leq \text{PI} \leq 3$ or strongly polluted: PI ≥ 3 [90,91].

Efficacy of PI

Urban road dust: The study conducted in Anshan city, China used PI to assess pollution level of Ni, Sn, Cd, Pb, Cr, Fe, Mn, Sb, Cu and Zn in road dust. The study revealed that Cd, Fe, Sb and Zn in road dusts presented high level of pollution while Pb, Cu, Cr, Mn, Sn and Ni pertained to moderate level of pollution [91].

Urban soil: Wu et al. [92] also used PI to assess the pollution level of Ni, Pb, Cr, Cd, As, Cu and Zn in soil around the city of Xiangyang, China. The PI results indicated that the soils were heavily contaminated with Cr and Cd. The PI values for the other metals showed low level of pollution.

Urban water sources: In selected urban centres of Onitsha, Nigeria, contamination of groundwater sources by Fe, Cr, Cu, Pb, Ni, Mn, and Cd was reported. The PI value revealed that that 45.83% of the total samples are unsuitable for drinking [86].

6.1.7. Pollution Load Index

The pollution load index (PLI) is also utilised for the overall evaluation of the level of environmental contamination. This index offers a simple means of demonstrating how the build-up of heavy metals has caused the environmental conditions to deteriorate. It is computed as a geometric average of PI based on Equation (7).

$$PLI = (CF_1 \times CF_2 \times .... \times CF_n)\frac{1}{n} \quad (7)$$

The CF's are the contamination factors of the analysed elements in a particular sample. Pollution classification ranges from not polluted to polluted as presented in the following table[84].

Efficacy of PLI index

Urban road dust: The PLI was used to assess the pollution level of As, Cd, Ni, Pb, Hg, and Cr in urban road dust from the city of Urumqi, China. The overall results of the study revealed that Hg contributed the most to the PLI of these metals in surface dust, accounting for 68.25% of the PLI of the selected heavy metals[84]. Mugudamani et al.[10] reported that as per PLI value, the urban informal settlement road dust in Ekurhuleni Metropolitan Municipality, South Africa was very highly polluted by U, Pb, Cr, Ni, Ba, Nb, Rb, Zn, Sr, Cu, Zr, Co, V, Y, Th, As, and Sc.

Urban soil: Gopal, et al.[63] study in Chennai, India used PLI to assess pollution level for Ni, U, K, Ti, Cu, Cr, As, Pb, Fe, Th, Zn, and Ni in soil. The study reported polluted soil based on PLI values. In Xiangyang, China, the PLI values for Ni, Pb, Cr, Cd, Zn, As and Cu revealed slight pollution[92].

Urban atmosphere: In the city of Sarnia, Canada, the level of contamination of PM by Ni, Zn, Cr (VI), Cd, As, Cu, Fe, Pb, and Mn was assessed using the PLI. Based on PLI values, the study confirmed the existence of pollution in the area[87].

Urban water sources: Ishtiaq et al.[85] used PLI to understand the whole pollution level of toxic metals Mg, Fe, Cd, Pb, Cr, Zn and Ni in urban groundwater sources around the semi-arid multi-industrial metropolitan areas of Khyber Pakhtunkhwa, Pakistan. The PLI mean values of targeted elements in groundwater were classified as low pollution and high pollution in some area.

Table 2 summarizes the classification of urban geochemical pollution indices.

6.2. Relevance of Geochemical Background Concentrations in Urban Environmental and Medical Geochemistry Studies

Numerous elements in soil, water sources, atmosphere, and street sediments have been enriched as a result of human activity's massive chemical introduction into the environment, especially in urban areas. Understanding these urban geochemical anomalies has become an essential part of medical geology research. The concept of geochemical background in geochemistry was first applied in mineral prospecting to offer information on the dispersion of geochemical anomalies, which was vital when searching for new mineral deposits[34]. Nowadays, geochemical background is relevant in urban environmental and medical geochemistry studies because urban environmental compartments are a complex mix of natural and man-made elements[93]. Pollution indices can serve as a tool and source of guidance for all-inclusive geochemical assessment of the urban environment, including soil, air, water, and street dust. However, for their efficiency, it is essential to first assess the geochemical background. It is important to note that, most geochemical background studies are centres around trace elements as contaminants[94]. A relative metric to differentiate between the concentrations of natural elements or compounds and those induced by humans in a particular environmental sample is called the geochemical background[95]. Swain et al.[74] argue that the ability to assess urban environmental risk and deterioration demonstrates the comprehensive nature of measuring environmental quality using geochemical indices. In medical geology, the findings of chemical analyses are applied in detection and assessment of the level of anthropogenic contamination. In most geochemical indices applied to assess urban geochemical background, anthropogenic anomalies are defined as enrichment of environmental samples in a given substance, while the absence of such anomalies is regarded as geochemical background[34]. When attempting to estimate the level of contamination in urban environment, majority of studies choose to compare the sample chemical composition relative to local background values[68,78,96,97], upper continental crust[21,63] or the average shale[10,98].

Table 2. Classification of urban pollution based on geochemical indices.

Geochemical Indices	Interpretation	References
	Geo-accumulation Index	
Igeo Index	Extremely contaminated: 5 < Igeo Heavily to extremely contaminated: 4 ≤ Igeo ≤ 5 Heavily contaminated: 3 ≤ Igeo ≤ 4 Moderately to heavily contaminated: 2 ≤ Igeo ≤ 3 Moderately contaminated: 1 ≤ Igeo ≤ 2 Uncontaminated to moderately contaminated: 0 ≤ Igeo ≤ 1 Practically uncontaminated: Igeo ≤ 0	Muller; Santos et al.[75,76]
	Enrichment Factor	
EF	Extremely high enrichment: EF > 40 Very high enrichment: 20 < EF ≤ 40 Significant enrichment: 5 < EF ≤ 20 Moderate enrichment: 2 < EF ≤ 5 Minimal mineral enrichment deficiency: EF ≤ 2	Mugudamani et al.[10]
	Contamination Factor	
CF	Very high contamination: CF ≥ 6 Considerable contamination: 3 ≤ CF ≤ 6 Moderate contamination: 1 ≤ CF ≤ 3 low contamination: CF < 1	Mugudamani et al.; Kowalska et al.[10,83]
	Degree of Contamination	
Cdeg	Very high degree of contamination: 32 ≤ Cdeg Considerable degree of contamination: 16 ≤ Cdeg ≤ 32 Moderate degree of contamination: 8 ≤ Cdeg ≤ 16 Low degree of contamination: Cdeg < 8	Pavlović et al.[21]
	Modified Contamination Factor	
mCdeg	Ultra-high contamination: 32 ≤ mCdeg Extremely high contamination: 16 ≤ mCdeg ≤ 32 Very high contamination: 8 ≤ mCdeg ≤ 16 High contamination: 4 ≤ mCdeg ≤ 8 Moderate contamination: 2 ≤ mCdeg ≤ 4 Low contamination: 1.5 ≤ mCdeg ≤ 2 Very low contamination: mCdeg ≤ 1.5	Ferreira et al.[28]
	Pollution Load Index	
PLI	Polluted: PLI > 1 Baseline levels of pollution: PLI = 1 Not polluted: PLI < 1	Kavsar et al.[84]

6.3. Urban Geochemical Risk Assessment Indices

6.3.1. Ecological Risk Factor

Hakanson[99] proposed the ecological risk factor (ER) index. It characterises the ecological risk of a chemical element in a medium under study using Equation (8)[99]:

$$ER = T_r^i CF \tag{9}$$

Tr: the toxic-response factor of a heavy metal while CF: is the contamination factor of a selected metals element. The classification risks normally range from low ecological risk to serious ecological risk as presented in the following table[28,81,83].

Efficacy of ER Index

Urban road dust: Heidari et al.[64] used ER index to assess the risks of heavy metals in road dust around Bandar Abbas City, Iran. The study categorised heavy metal in road dust as low risk class. In street dust from Wuhan City, China, ER values showed slight ecological risks (Zn, Cu, Ni, Cr and Mn), and strong ecological risk for Cd[77]. In Zhengzhou City, China, the ecological risk assessment outcomes indicated that the most abundant contaminant was Hg, followed by Cu and Cd, while other heavy metals (Cr, Ni, Zn, As, and

Pb) fell into the no pollution or low pollution category [100].

Urban soil: The ER of Pb, Zn, Co, Sr, Cu, Ni, Cr, Mn and Fe in soil around Pancevo, Smederevo, Obrenovac, and Belgrade cities in Serbia revealed that only Pb was at the level of 'medium risk' at Belgrade. The study also emphasised that the overall ER of identified toxic elements was at a low level in all sampling sites [21].

Urban water sources: In Lengshuijiang city, China, Xie and Ren [101] evaluated the potential ecological risk posed by Cd, Sb, Hg, Pb, As, Zn and Mn in the surface water sources. 17.14% of the samples had a low ecological risk, 11.43–65.71% of the samples had a moderate to high risk, and more than 50% had a very high risk. Toxic elements Sb and As were reported as the main pollutants. In selected urban centres of Onitsha, Nigeria, contamination of groundwater sources by Cr, Pb, Fe, Ni, Mn, Cd and Cu was reported. In this study, 58.33% of the samples pose a very high ecological risk [86].

6.3.2. Potential Ecological Risk Index

The potential ecological risk index (PERI) evaluates the ecological risk associated with targeted toxic metals in the area in question and it is calculated by adding the individual ecological risks of these elements, as shown in Equation (10) [102].

$$PERI = \sum ER \tag{10}$$

Risk classifications based on PERI normally range from low ecological risk to significantly high ecological risk [28,89].

Efficacy of PERI Index

Urban road dust: Chen et al. [77] used PERI index to assess the risks of Cu, Cd, Cr, Fe, Zn, Mn and Ni in street dust of Wuhan city, China. In their study, the risk of these elements was ranging as Cd > Mn > Cu > Zn > Ni > Cr. Among them, The PERI value for Cr indicated minor ecological risk, Ni and Zn showed medium ecological risk while Mn, Cu and Cd showed strong ecological risks.

Urban soil: PERI index was used to assess the ecological risk related to the presence of As, Ti, Cr, Ni, Zn, Pb and Cu in soil of Chennai, India. The PERI values ranged from 55.48 to 231.02 which showed low ecological risk to moderate ecological risk. However, based on their average PERI value of 115.84 the study was classified as low ecological risk. The order of targeted toxic elements was as Z > Cu > Ti > Cr > As > Ni, Pb [63]. To reflect the sensitivity of various biological communities to toxic substances and represent the potential ecological risks posed by these hazardous elements, the PERI index was applied in in the city of Xiangyang, China. The outcomes of the study revealed the risks of metals decreasing as Cd > Cr > As > Pb > Cu > Ni > Zn with Cd posing a high risk. The study also reported that the overall PERI values for all sampling sites indicated a potential very high risks [92].

6.3.3. Risk Assessment Code

Perin et al. [103] introduced the risk assessment code (RAC). It defines the risk level based on the percentage share of individual metals in the most mobile speciation fractions, and it is computed based on Equation (11) [81,104].

$$RAC = F1\,(\%) \tag{11}$$

F1 is the percentage level of selected metal in the fraction F1. The risk classifications range from no risks to very high risk as presented in the following table [81,103].

Efficacy of RAC Index

Urban road dust: Zhu et al. [105] assessed the risk of Cu, Zn, Cd and Pb in street sediments of Xiawan Port in Zhuzhou city using RAC. The comparative quantities of easily dissolved phase of heavy metals in the dust were in the order of Cd > Zn > Cu > Pb. According to RAC, the risks of Cd and Zn were very high.

Urban Soil: In Shenzhen, China, the RAC index was used to assess risks posed by the non-stable forms of the metals in soil. The average RAC values of each metal were 2.31% for As, 2.57% for Cr, 6.60% for Cu, 2.78% for Pb, and 0.12% for V. They were ranging as Cu > Pb > Cr > As > V. Except for V which presented no risk, other trace metals presented low risk in urban soils [106].

6.3.4. Human Health Risk Assessment Index

Assessing the possible health risks of both carcinogenic and non-carcinogenic substances is essential to preserving the general welfare. One popular technique for assessing people's exposure levels to specific heavy metals found in urban environments, such as soil, road sediments, air, and water sources, is the health risk assessment (HHRA) index. It does this by calculating the possible negative effects of these substances and comparing them to predetermined safety standards. As a result, this subsection offers an overview of the HHRA index backed by pertinent case studies to demonstrate its effectiveness in evaluating associated risks [107].

According to exposure assessment, ingestion, inhalation, and skin contact are the primary ways that city dwellers can be exposed to heavy metals in different environmental compartments. Equations (12) through (15) are utilised to evaluate the average daily dose (ADD) of city dwellers through each exposure pathway [81].

$$ADD_{ing} = \frac{C \times IR_{ing} \times EF \times ED}{BW \times AT} \times CF \quad (12)$$

$$ADD_{inh} = \frac{C \times IR_{inh} \times EF \times ED}{PEF \times BW \times AT} \quad (13)$$

$$ADD_{derm} = \frac{C \times SA \times AF \times ABS \times EF \times ED}{BW \times AT} \times CF \quad (14)$$

$$ADD = ADD_{ing} + ADD_{inh} + ADD_{derm} \quad (15)$$

where ADD_{ing}, AD_{inh}, and ADD_{dermal} are the average daily dose (mg/kg/day) for ingestion, inhalation, and dermal contact, respectively. ADD is the average daily total exposure dose (mg/kg/ day) [81].

The hazards of the contaminants can be categorised as either carcinogenic or non-carcinogenic. Equations (16) and (17) are used to estimate the hazard quotient (HQ) and hazard index (HI), which are used to evaluate the overall non-carcinogenic effects of the toxic metals under analysis as well as the non-carcinogenic risk posed by each exposure pathway [10].

$$HQ_{(ing,\ inh,\ derm)} = \frac{ADD}{RfD} \quad (16)$$

$$HI = \sum HQ \quad (17)$$

RfD: reference dose of individual metal (mg/kg/day), HI: hazard index while HQ is the hazard quotient. The risk is interpreted as ether HQ/HI > 1: possible non-carcinogenic effects, or HQ/HI < 1: no likelihood of health risks [21,108].

Equations (18) and (19) are used to evaluate the potential for toxic heavy metals to cause carcinogenic risk (CR) and total carcinogenic risk (TCR) in urban residents.

$$CR\,(inh,\ ing,\ derm) = ADD \times SF \quad (18)$$

$$TCR = \sum CR \quad (19)$$

SF: cancer slope factor (mg/kg/day) through exposure pathways of each element. The risk classifications range from no carcinogenic-to-carcinogenic risks [108,109].

Efficacy of HHRA Index

Urban Road dust: In urban informal settlement form Ekurhuleni Metropolitan Municipality, South Africa, heavy metals in road dust showed no possibility of health risks except Cr that presented the possibility of both non-carcinogenic and carcinogenic risks. Ingestion and dermal pathways were the main drivers for risks [10]. Human health risks assessment of Cd, Zn, Cu, Cr and Ni in street dust from the city of Wuhan, China revealed that the HQ and HI values presented no non-carcinogenic risks to the city dwellers. It was also revealed that Cr, Ni, and Cd did not pose a carcinogenic risk [77].

Urban Soil: Chakraborty, et al. [109] assessed the human health risk of As, Cd, Pb, Cr, Ni, and Cu in urban soil around Bangladesh. The overall non-cancer risk was below the acceptable limit, while the cancer risks for As exceeded the acceptable limit. Ingestion was reported as the main driver for risks in the entire population. Chonokhuu, et al. [96] assessed health risk of Zn, As, Cr, Ni and Pb in the soil of major cities namely: Ulaanbaatar, Erdenet, and Darkhan cities in Mongolia. The overall non-cancer and cancer risks showed no possibility of risks.

Urban atmosphere: Kumari et al. [32] assessed health risks of Cr, Zn, Cu, Fe, Ni, Cd and Pb in PM_{10} and $PM_{2.5}$ in the city of Dhanbad, India. The overall health risks showed no possibility of non-carcinogenic and carcinogenic risks for the entire population. A study on human health risk assessment of airborne trace elements in Dhanbad, India reported occurrence of Cd, Co, Zn, As, Fe, Cr, Cu, Ni, Mn and Pb. The HI values of these elements showed some possible risks on children group while the carcinogenic risk assessment illustrated very high probability of CR to the inhabitants in the area [62].

Urban water sources: In urban areas of Nnewi and Awka, Nigeria, the HI values of heavy metals in urban groundwater exceeded permissible levels in all samples while the CR revealed that approximately 40% of Nnewi samples and 80% of Awka samples exceeded the permitted limit [110]. Alidadi, et al. [111] assessed the health risks of Pb, Ni, Cr, and Hg through ingestion and dermal contact with treated drinking water in Mashhad Metropolitan city, Iran. The overall non-carcinogenic risks showed no risks in adults and possibilities of non-carcinogenic risks in children. The carcinogenic risks for both children and adults suggested the probability of risk. In Gold Coast, Australia, HI value of toxic heavy metals in relation to fine solids in storm water posed no risk to human health. In terms of toxic heavy metals associated with total solids, the HI index suggested risk to local residents. The risks of selected heavy metals were in the order of Cr > Mn > Pb > Al > Fe > Cd > Zn > Cu > Ni [112].

Table 3 summarizes the classification of urban geochemical risk assessment indices.

Table 3. Urban geochemical risk assessment indices.

Risk Assessment Indices	Interpretation	References
	Ecological Risk Factor	
ER	Serious ecological risk: Eir ≥ 320 High ecological risk: 160 ≤ Eir < 320 Considerable ecological risk: 80 ≤ Eir < 160 Moderate ecological risk: 40 ≤ Eir < 80 Low ecological risk: Eir < 40	Ferreira et al.; Tytła et al.; Kowalska et al. [28,81,83]
	Potential Ecological Risk Index	
PERI	Significantly high ecological risk: PERI ≥ 600 High potential ecological risk: 300 < PERI < 600 Moderate ecological risk: 150 < PERI < 300 low ecological risk: PERI < 150	Ferreira et al.; Klik et al. [28,89]
	Risk Assessment Code	
RAC	RAC > 50%: very high risk 30% < RAC ≤ 50%: high risk 10% < RAC ≤ 30%: medium risk 1% < RAC ≤ 10% low risk or RAC ≤ 1%: no risk	Tytła et al. Perin et al. [81,103]
	Human Health Risk Assessment Index	
HHRA	Carcinogenic risk: CR > 0.0001 Acceptable carcinogenic risks: 0.000001–0.0001 No carcinogenic risk: < 0.000001	Chakraborty et al. [109]

Although there are various toxic heavy metals, the case studies above have revealed metals such as Pb, Zn, Cu, Cr, Ni, with Cd, As, and Hg as the most detected and most often risk-driving elements in may urban areas. Analysis from these case studies also revealed that Asian countries have the highest levels of urban contamination by these toxic metals. Most of these toxic heavy metals exceeded background values and they also showed potential ecological and human health risks. These outcomes are primarily due various factors such as rapid urbanization, illegal dumping, legacy mining impacts, sewage overflow, intensive industrial activities, coal combustion, high traffic emissions, and smelting operations. In contrast, Africa has significant pollution hotspots, particularly in places affected by e-waste processing and metallurgical smelters, however more studies are needed. Europe and North America have lower contemporary risk levels. In addition, the prevalent of these toxic heavy metals in many cities is a public health concern as most of them are carcinogenic. Some of the health effects associated with exposure to these metals are presented in **Table 4**.

Moreover, it is clear that geochemical indices are efficient tools in exploring urban environmental pollution and health risks pattern of potentially harmful element in urban environments. They help quantify the level of pollution, identify sources, and inform remediation efforts. They can play a significant role in assessing environmental quality and predicting future ecosystem sustainability, particularly in urban areas. Moreover, ecological and human health risk assessments are vital for understanding and managing environmental stressors that can impact ecosystems and human health. They help determine the potential harm from substances, activities, or events, informing decisions about remediation, permitting, and protection efforts. By promoting environmentally sound practices, they contribute to long-term human health and well-being, as well as the health of the urban settings. They are useful instruments for environmental monitoring since their standardized formulas make comparisons between various research and geographical areas easier.

Table 4. Public health risks associated with most detected toxic metals in urban cities [19–22].

Toxic Elements	Public Health Risks
Lead (Pb)	It can cause cognitive impairment, behavioral problems, and developmental delays. Chronic exposure is associated with hypertension, renal impairment, and reproductive damage.
Zinc (Zn)	Overexposure can cause immune system malfunction, gastrointestinal distress, disruption of copper metabolism, and, in severe situations, neurological problems.
Copper (Cu)	High levels of copper exposure can irritate the gastrointestinal tract, harm the liver and kidneys, and in extreme situations, result in hemolysis and neurological impairment.
Chromium (Cr)	While Cr (III) is an important vitamin that might cause irritation at high amounts, Cr (VI) is a proven carcinogen that causes lung cancer, skin ulcers, and respiratory issues.
Nickel (Ni)	Long-term exposure can raise the risk of lung and nose malignancies, induce respiratory tract irritation, and cause allergic dermatitis.
Cadmium (Cd)	Long-term exposure is categorized as a human carcinogen that affects the prostate and lungs and can cause bone demineralization, as well as renal impairment.
Arsenic (As)	It is associated with malignancies of the skin, bladder, lungs, and liver. Neurotoxicity, cardiovascular illness, and skin lesions are the results of prolonged exposure.
Mercury (Hg)	It may influence the central nervous system, causing tremors, cognitive problems, and developmental delays in children; as well as harming the kidneys and gastrointestinal tract.

These indices, however, do have some significant drawbacks. Inconsistent results may arise from variations in background reference values, particularly in urban soils that are heterogeneous and contain a combination of natural and industrial inputs. Furthermore, a lot of indices fail to take into consideration the chemical speciation and bioavailability of pollutants, which are two important aspects of determining true health hazards. Since most indicators are based on single-point observations, seasonal and temporal variations can make interpretation even more difficult. Furthermore, knowledge of the practical effects of pollution may be limited if geochemical indicators are the only ones used. Therefore, in order to adequately capture the environmental and health effects, geochemical indices should be used in conjunction with comprehensive multidisciplinary techniques, even though they are essential for initial screening and spatial assessment of urban pollution.

7. Minimisation of Toxic Heavy Metal Pollution in Urban Settings

Although they make up only about 5% of the world's land area, cities have a significant impact on the environment as a whole. Among the many problems that cities face, heavy metal pollution of the environment is becoming a bigger issue and is a major concern because of the negative effects that it is having globally [113]. Due to a variety of human activities and occasionally natural processes, these inorganic pollutants are being dumped into our soils, streets, and waters [114]. In order to support people, environmental protection has become a major global norm. Multifaceted strategies are needed to minimise toxic heavy metal pollution in urban areas (**Figure 2**), which includes reducing sources, providing more trash cans, cleaning up contaminated areas, avoiding waste burning, providing community services, using renewable energy sources, lowering heavy metal levels in fuel, and encouraging sustainable practices [66,113–118].

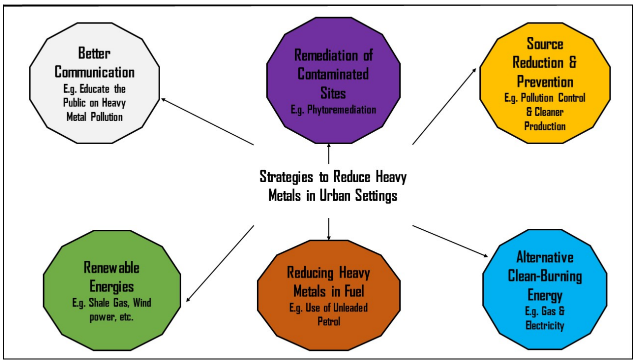

Figure 2. Strategies to reduce heavy metals in urban areas.

7.1. Communication and Education

Reduced urban heavy metal pollution may be largely dependent on better community communication regarding the value of the environment, waste management, and health.

Promoting sustainable practices and educating the public about the dangers heavy metal pollution poses to human health are vital. Furthermore, it is important to inform and persuade city dwellers to abide by the rules governing waste management [116].

7.2. Renewable Energies

Heavy metal pollution may be reduced by developing renewable energy sources to reduce the amount of coal used in energy consumption. This can be accomplished by enacting laws that encourage the production and commercialisation of renewable energy; lowering the cost of renewable energy by giving power producers access to new technologies; and creating financial support structures to boost the use of clean and renewable energy sources, particularly shale gas, wind, and solar power [117].

7.3. Source Reduction and Prevention

These include moving industrial land uses, implementing green infrastructure, and utilising technology. Urban heavy metal levels can be decreased by implementing technologies like pollution control and cleaner production techniques that reduce heavy metal emissions from industrial processes. Heavy metal particles can be captured before they are released into the atmosphere by utilising technologies such as electrostatic precipitators, bag houses, and sophisticated filtration systems. Furthermore, heavy metal inputs can be greatly decreased by implementing procedures that minimise waste and emissions, such as utilising fewer hazardous materials and making the best use of available resources. Incorporating green areas, like urban forests and green roofs, can lessen the impact of heavy metals by absorbing and filtering them from the air and water. Furthermore, by reducing industrial emissions and runoff into urban environments, relocating industrial activities away from urban areas is a good way to reduce heavy metal contamination [66,118].

7.4. Alternative Clean-Burning Energy Sources

In most urban areas, informal settlements are the predominant feature, with most informal settlers cooking primarily with wood and charcoal. Clean-burning energy sources should be used in place of the wood or charcoal that the informal settlers currently use. Gas and electricity are potential alternatives. Heavy metal emissions may also be decreased by improved wood-burning technology [116].

7.5. Remediation of Contaminated Sites

Cleaning up polluted areas to safeguard the environment and public health is known as remediation of contaminated sites. Usually, this procedure entails evaluating the location, clearing or treating pollutants, and preparing the land for future use. Typical remediation methods consist of:

Phytoremediation, a technique used to clean contaminated soil and water, is the process by which plants take up heavy metals from the soil and store them in their tissues. During this process, deep-rooted plants can absorb heavy metals from the soil through their roots. Following absorption, the metals are moved to the plant's stems, leaves, or roots, among other areas. The heavy metals can then be extracted from the contaminated environment by harvesting and removing the plant biomass. In certain situations, plants can also aid in the detoxification or transformation of heavy metals, reducing their toxic effects. The main method for doing this is a process known as phytovolatilization, in which plants take up heavy metals from the soil and change them into less harmful, volatile forms that are subsequently released into the atmosphere [113,114].

Another remediation method for lowering the concentrations of heavy metals in contaminated soil is soil washing, which includes chemical leaching or physical separation. Physical separation, which effectively concentrates the contaminants into a smaller volume of soil, is frequently accomplished by employing a water-based process to separate fine particles (like clay and silt) from coarser particles (like sand and gravel). Adding chemical reagents, like acids, surfactants, or chelating agents, to the water used for washing is known as chemical extraction. By mobilising and solubilising the metals, these reagents facilitate their separation [66].

7.6. Reducing Heavy Metals in Fuel

Heavy metals are released into the atmosphere when automobile fuel is burned. Since lead also harms the catalytic converter, which regulates other pollutants from vehicle exhaust, new cars should be required to use petrol with less lead [117].

8. Conclusion

The study summarised and synthesised existing urban environmental geochemistry information from around the world, with a focus on the effectiveness of various pollution and risk assessment indices in urban environmental and medical geochemistry studies. It is obvious that the environmental geochemistry of soil, street dust, water, and air contain a wealth of information about the state of urban environments. The majority of metals detected in the urban environment exceeded the local soil background values, upper continental crust, or average shale values. Depending on a number of variables, including industrial layout, local geology, land use, natural disasters, and population distribution, these chemical anomalies differ from city to city. In summary, the build-up of these metals in soil, water, air, and street dust can cause bioaccumulation and biomagnification, which can be extremely dangerous for both people and wildlife. Furthermore, through contaminated water and food sources, this pollution affects biodiversity and poses a threat to public health and food security. The relationships between urban geochemistry and public health can be effectively understood using geochemical indices. More urban environmental and medical geochemistry studies that can continuously monitor the level, distribution, sources, morphology, and risks of chemicals are needed to protect the environment and people. Assessing the level and spatial distribution of harmful metals can help determine the health risks associated with them and support appropriate urban environmental management. To reduce heavy metal contamination in urban areas, a comprehensive strategy that includes source management, pollution prevention, soil remediation, land-use planning, regulatory enforcement (i.e., stricter industrial regulations, community monitoring programs), public education, community empowerment, and stakeholder engagement is required. Future research should use big data analytics and machine learning such as Random Forest, Gradient Boosting Machines and others to significantly improve geochemical indices' predictive capabilities and enable real-time monitoring and evaluation. Interdisciplinary collaboration among urban planners, statisticians, geologists, health scientists, environmental scientists, and policymakers will be critical for advancing the field of medical geology and addressing real-world challenges.

Author Contributions

All authors have made significant contribution to the study. Data collection, analysis, and writing of the manuscript was done by I.M. and S.A.O. All authors have proof read the manuscript and approved its submission to the journal.

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Data Availability Statement

All the data used in this study are included in the manuscript.

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Conflicts of Interest

No conflict of interest.

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