Environ Monit Assess (2020) 192: 32
https://doi.org/10.1007/s10661-019-7947-5

Heavy metal contamination in urban surface sediments: sources, distribution, contamination control, and remediation

Mohamed Y. Hanfi · Mostafa Y. A. Mostafa · Michael V. Zhukovsky

Received: 5 June 2019 / Accepted: 31 October 2019 / Published online: 11 December 2019
© Springer Nature Switzerland AG 2019

Abstract Urban road sediments act as large basins for heavy metal contaminants produced as a result of natural processes and anthropogenic activities. This study is aimed at reviewing research over recent decades on heavy metal contamination in different cities around the world. The study reviews literature from Google Scholar, Web of Science, and Scopus journal publications. Cr, Cu, Pb, Zn, Ni, and Cd levels vary from one city to another. Based on the collected results, the pollution level and geoaccumulation index are estimated in each city. The levels of pollution in these cities range from low to extremely high, depending on the sources of pollution at each site (geogenic and anthropogenic sources, etc.) and factors like the distribution of industrial activities, population, and traffic emissions. This review shows that the development of modern cities and rapid urbanization are the major causes of heavy metal contamination in the environment. The contamination of the urban environment has different sources, both natural and anthropogenic in character. Solving the problem of heavy metal contamination in the urban environment requires the use of different techniques such as urban road control treatment and soil remediation.

Keywords Heavy metal · Urban geoaccumulation · Contamination · Sediment · Remediation

M. Y. Hanfi · M. Y. A. Mostafa · M. V. Zhukovsky
Ural Federal University, Mira Street 19, Ekaterinburg, Russia 620002

M. Y. Hanfi (✉)
Nuclear Materials Authority, Maadi, Cairo 520, Egypt
e-mail: m.nuc2012@gmail.com

M. Y. A. Mostafa
Physics Department – Faculty of Science, Minia University, Minia 520, Egypt

M. V. Zhukovsky
Institute of Industrial Ecology UB RAS, Sophy Kovalevskoy St. 20, Ekaterinburg, Russia 620990

Introduction

Heavy metal contamination of the environment can be defined as an increase in the natural background of toxic heavy metals in the urban surface sediment caused by human activities. An urban surface sediment is composed of a wide range of particle sizes: dust, fine sand, and coarse sand. Heavy metal contents in the urban surface sediment on some metals are significantly of biological toxicity, such as chromium (Cr), lead (Pb), cadmium (Cd), and arsenic (As), zinc (Zn), copper (Cu), nickel (Ni), stannum (Sn), and vanadium (V).

In recent years, with the continuous development of the urban environment, the content of heavy metal in the urban surface sediment has increased and cause the adverse effect to the environment, such as disease and illness in humans. (Chao et al. 2014; Davis et al. 2002; Han et al. 2002; Jean-Philippe et al. 2012; Venkatesha Raju et al. 2013; Prajapati and Meravi 2014; Sayadi and Rezaei 2014; Sayyed and Sayadi 2011; Taylor and Owens 2009a; Yang et al. 2016; Zojaji 2014; Hanfi et al. 2019). These heavy metals are commonly found in the environment and diet. In small amounts, they are required for maintaining good health but in larger amounts, they can become toxic or dangerous. Heavy metal toxicity can lower energy levels and damage the functioning of the brain, lungs, kidney, liver, blood composition, and other important organs. Long-term exposure can lead to gradually progressing physical, muscular, and neurological degenerative processes that imitate diseases such as multiple sclerosis, Parkinson's disease, Alzheimer's disease, and muscular dystrophy. Repeated long-term exposure of some metals and their compounds may even cause cancer (Järup 2003)

Distribution and sources of heavy metal in the urban surface

With the extended development of the urban environment, the distribution of heavy metals in the urban environment is almost a serious threat to the countries. (Yang and Sun 2009; Su et al. 2014). The chemical characteristics of heavy metals play the main role in the spread distribution in the urban environment. Heavy metal contamination is difficult to be observed. A short period is not enough to damage the environment. Probably, when the environmental and the chemical conditions have changed, heavy metals may be activated and cause environmental deterioration.

In the last decades, many studies of the urban surface sediment in different cities around the world were carried out to evaluate the heavy metal contamination volume. The quantitative data on heavy metal concentrations, their contamination levels, and their sources have been gathered and intercompared.

Sources of heavy metal in the urban surface

Heavy metals are significant environmental pollutants and their toxicity is a problem of increasing significance for ecological, evolutionary, nutritional, and environmental reasons (Jaishankar et al. 2014)

Urban surfaces serve as a sink of deposits, which originated from different sources. In an urban area, the contamination build-up is the process by which contaminants of natural and anthropogenic origin are deposited on urban impact surfaces such as roofs, roads, and driveways over a period of dry weather (Ma et al. 2016; Wijesiri et al. 2015). The main urban surfaces were included the urban surface road (road-deposited sediment) and urban soil. Several studies have conducted on the details of the heavy metal sources in the urban surface roads.

Urban surface road

The sources of sediments and the heavy metal contaminants in the urban surface roads (road-deposited sediment) are explained in the urban sediment cascade which is presented by Taylor 2007 (Perry and Taylor 2007) and reproduced with the permission of Willey-Blackwell, as shown in Fig.1.

Heavy metals in the urban surface roads originate from a wide range of sources which include intrinsic and extrinsic sources. Intrinsic sources are an anthropogenic source that include the emissions that are associated with vehicular traffic (vehicle exhaust particles, tire wear particles, weathered urban surface particles, brake lining wear particles), industrial (power plants, coal combustion, metallurgical industry, auto repair shop, chemical plant, etc.), and residential areas as well as domestic emission, weathering of building facades, pavement surface, and precipitation of previously suspended particles (atmospheric aerosols), and so on. (Akhter and Madany 1993; De Silva et al. 2016; Zereni and Alt 2006; Ferreira-Baptista and De Miguel 2005; Gibson and Farmer 1986; Harrison 1979; Harrison et al. 1981; Hjortenkrans et al. 2006, 2007; Hopke et al. 1980; Khairy et al. 2011; Winther and Slento 2010; Ravindra 2004; Schwar et al. 1988; Whiteley and Murray 2003; Wichmann et al. 2007).

Urban soil

Water and air contamination in the environment had been reported in several studies as opposed to soil contamination. Soil contamination was with wide range of distribution and it is more difficult to be controlled and governed than air and water contamination. Consequently, in recent years, the soil contamination in the world is becoming too serious. It is paid the ecological authorities in the developed countries to make soil contamination as an important topic of environmental protection (Chao et al. 2014).

The deposition of heavy metals in the soil depends on the environmental factors and the soil properties: soil texture, geological origin, soil chemical and physical

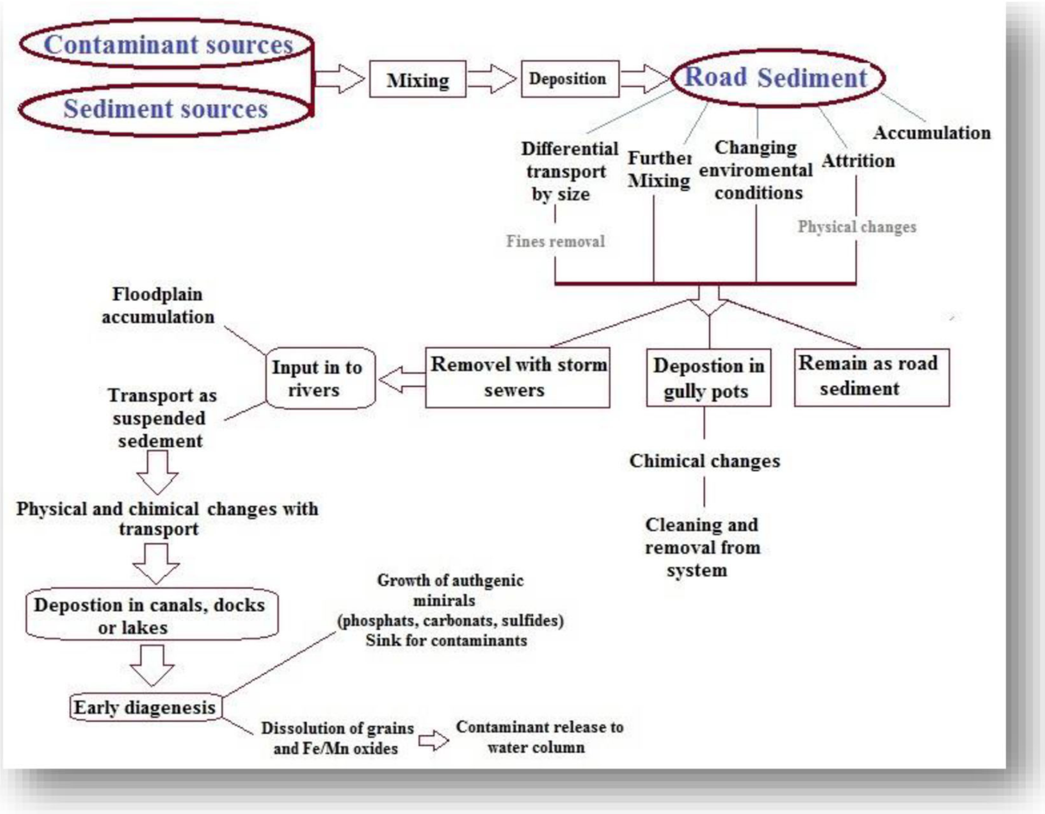

Fig. 1 The urban sediment cascade (from Taylor 2007; reproduced with the permission of Wiley-Blackwell)

properties, and horizontal and ventral distances from other roads (Bak et al. 1997; Wong et al. 2006; Yassoglou et al. 1987; Zheng et al. 2008) as well as human activities (Ahmadi Doabi et al. 2019; Nagajyoti et al. 2010).

In agricultural soils, the main sources of heavy metal are due to human activities such as wastewater, livestock manure, disposal of urban and industrial wastes, pesticides, mining, smelting processes, application of mineral fertilizers, and atmospheric deposition from the traffic emissions such as motor vehicles and the combustion fuels (Ahmadi Doabi et al. 2019; Esmaeili et al. 2014; Hani and Pazira 2011; Li et al. 2008; Montagne et al. 2007; Qishlaqi and Moore 2007; Romic and Romic 2003; Sridhara Chary et al. 2008; Yang et al. 2009) Heavy metal contamination in urban soils may be transferred into the human body through inhalation of dust and skin absorption that cause toxic health effects. They also affect indirectly the human health through the food chain, atmosphere, and water (Wei et al. 2010). Consequently, the heavy metal contamination and sources must be identified to establish the contamination control of heavy metal, soil remediation, and management (Ahmadi Doabi et al. 2019; Yáñez et al. 2002; Lin et al. 2017).

Urban surface sediment does not remain in one place for a long time, but re-suspended back into the atmospheric particles, which it contains metal concentrations or the precipitation washes and dissolved solids in urban road runoff and in receiving water catchments and sewage irrigation (Ahmed and Ishiga 2006; Charlesworth et al. 2003; Ferreira-Baptista and De Miguel 2005; Liang et al. 2018; Lu et al. 2009; Wei et al. 2010)

Aim of this work

This work is a review about heavy metal in the urban surface from different countries around the world. It was based on the collection of published data from the various articles from Web of Science, Scopus, and Google Scholar journal publications. The system of quotation followed the paper by paper citing from through references. The strategy of collecting samples and analytical methods used in different studies is listed in Table 1. The urban surface sediment was collected from roadsides and the center road surface regularly or randomly using sweeping procedures such as a plastic dustpan or brushes and transferred into the laboratories through a polyethylene bag, then dried at different temperatures. The selected samples were sieved at different fractions. The sieved urban surface samples are dissolved with different acids such as HNO_3, $HCLO_4$, H_2SO_4, HF, H_2O_2, and boric acid. Various analytical techniques such as, AAS, ICP-MS, ICP-OES, ICP-OES, and XRF used to determine the heavy metal concentration such as Cr, Cu, Pb, Zn, Cd, and Ni. All the samples analytical techniques are acceptable. The distribution of analytical methods used in heavy metal analysis in the present survey is shown in Fig. 2. The widely used method is atomic absorption spectroscopy although it is considered a destructive technique but has a good reliability and is more precise. Recently, different types of inductively coupled plasma (ICP) are developing and have been used widely.

With the development of economy and society, heavy metal contamination has become increasingly common in the world. It is almost a serious threat to every country. In the world's top ten environmental events, two events have been related to heavy metal contamination (Yang et al. 2009). Numerous studies indicated that the concentration ranges of the heavy metals observed in the urban surface sediment in particles are composed of sediment, soil, leaves, rubbish, and organic and inorganic materials (Biggins and Harrison 1980; Quiñonez-Plaza et al. 2017; Taylor and Owens 2009b).

The contaminants in the urban surface

The majority of heavy metals in the urban environment matrices (air, soil, and water) are contributed from anthropogenic sources.

Chromium

The sources of chromium (Cr) with the most of release are coming from industrial compartments. The industrial compartments include chromate production, ferrochrome and chrome pigment production, metal processing, tannery facilities, and stainless-steel welding. The chromium released from the air and waste water is contributed from metallurgical, chemical industries and refractory (Tchounwou et al. 2012). Before 2005, a few studies are reported to the chromium concentrations. Heavy traffic in Kavala, Greece, was the direct cause of high concentrations of chromium (Christoforidis and Stamatis 2009). Furthermore, the chromium in urban surface is associated with the chrome plating of some motor vehicle parts (Al-shayeb and Seaward 2001).

Lead

In the urban environment, lead (Pb) is derived from natural and anthropogenic sources. The dominant sources of lead are traffic emissions, weathering of materials, and industrial activities such as mining, manufacturing, fossil fuel burning, and different industrial, agricultural, and domestic applications. (Zhang 2003). In the last decades, many studies have been conducted of the lead variation concentrations in the urban surface. Historical deposition of atmospheric Pb has been evaluated using a number of archives such as ice cores, sediments, peat bogs, herbarium plants, and forest soils worldwide (Zhang 2003). Several studies indicated the different sources of lead in the urban environment. In cities such as New York (USA), Seoul (Korea), and Kuala Lumpur (Malaysia), lead concentrations were 200 times higher than the permissible limit, due to vehicles emissions (Fergusson 1984; Ramlan and Badri 1989).

Lead has the most toxicity heavy metals in the urban environment due to effects on the human body especially, the human nervous and circulatory systems. Pb is mainly transferred into the human body through inhalation and ingestion, and enters the blood circulation in the form of soluble salts, protein complexes or ions, etc. The most amount of Pb concentration accumulates in the bones. It can damage many organs and systems such as the liver, kidney, nervous system, urinary system, and the basic physiological processes of cells (Momani 2006). From Fig. 3, the annual variation of Pb decreases despite the increased volume of traffic due to non-use of lead fuel; this is due to the efforts of health care and assurance from different organizations about exposure of dangerous and carcinogenic pollution sources

Cadmium and zinc

Cadmium (Cd) and zinc (Zn) have the same sources in the urban surface and are chemically related elements in

Table 1 Materials and methods of heavy metal contamination in the urban surface sediment in the different cities at the world

No.	City	country	No. of samples	Digestion	Analysis	Ref
1	Lancaster	UK	29	HNO_3+HCL+HF	AAS (Pb, Cu, Zn, Ni, Cr, Cd)	(Harrison 1979)
2	Scotland	Great Britain	6	HCL	AAS (Pb, Zn)	(Wade et al. 1980)
3	Lancaster	England	6	∑ sequential (HNO_3+HF+$HCLO_4$+HCL)	AAS (Pb, Zn, Cu, Cd)	(Harrison et al. 1981)
4	Various sites	Hong Kong	14	HNO_3+H_2SO_4+$HCLO_4$	AAS (Pb, Cu, Zn, Cd)	(Lau and Wong 1982)
6	New York	USA	2	HNO_3+HF+$HCLO_4$	INAA (Zn, Cr) and AAS (Cu, Cd, Pb)	(Fergusson 1984)
6	Various sites	Nigeria	–	HNO_3+HF+HCL	AAS (Pb, Cu, Zn, Ni, Cr, Cd)	(Ndiokwere 1984)
7	Halkyn, North Wales	Great Britain	59	HNO_3	AAS (Pb, Cu, Zn, Cd)	(Davies et al. 1985)
8	Athens	Greece	170	HNO_3+H_2O_2	AAS (Pb, Cd, Zn) + ICP-MS (Ni)	(Yassoglou et al. 1987)
9	London	UK	400	HCL+HNO_3	AAS (Cu, Cd, Pb, Zn)	(Schwaret al 1988)
10	Kuala Lumpur	Malaysia	25	∑ sequential (HNO_3+HF+$HCLO_4$+HCL)	AAS (Zn, Pb, Cu, Cd)	(Ramlan and Badri 1989)
11	Cuenca	Ecuador	83	HNO_3	AAS (Pb, Zn, Cd)	(Nicholas Hewitt and Candy 1990)
12	London	England	-	HNO_3+HCl	AAS (Pb, Zn, Cd)	(Thoronton 1991)
13	Various sites	Bahrain	106	HNO_3+HCL	AAS (Pb, Zn, Cd, Ni, Cr)	(Akhter and Madany 1993)
14	Various areas	Bahrain	76	HNO_3+HCL	AAS+ICP-OES (Cr, Cu, Pb, Zn, Cd)	(Madany and Akhter 1994)
15	Seoul	Korea	29	HCl+HNO_3	ICP-ES (Cu, Pb, Zn, Cd)	(Chon et al. 1995)
16	Sault Ste Marie	Canada	30	∑ sequential (HNO_3+HF+$HCLO_4$+HCL)	ICP-ES (Cu, Pb, Zn, Cd, Ni, Cr)	(Stone and Marsalek 1996)
17	Oslo	Norway	16	HNO_3+$HClO_4$+HF	ICP-MS (Pb, Zn, Cu, Cd)	(Miguel et al. 1997)
18	Taejon	Korea	200	HCl+HNO_3	AAS (Cu, Pb, Zn, Cd)	(Kim et al. 1998)
19	California Bight	USA	248	HNO_3+HCL	ICP-MS (Cd, Cr, Cu, Ni, Pb, Zn)	(Schiff and Weisberg 1999)
20	Seoul	Korea	30	HF+HNO_3+$HClO_4$	ICP-AES (Cu, Pb, Zn, Cd, Cr)	(Yun et al. 2000)
21	Kowloon Peninsular	Hong Kong	45	HNO_3	ICP-AES (Cu, Pb, Zn, Cd)	(Li et al. 2001)
22	Bursa	Turkey	10	HCl+HNO_3	AAS (Pb, Zn, Ni, Cd)	(Arslan 2001)
23	Birmingham	UK	150	$HCLO_4$+HNO_3+H_2SO_4	AAS (Cu, Pb, Zn, Ni, Cd)	(Charlesworth et al. 2003)
24	Istanbul	Turkey	22	HNO_3	AAS (Cn, Pb, Zn, Ni, Cd)	(Sezgin et al. 2004)
25	Krak	Jordan	15	HNO_3	AAS (Cu, Pb, Zn, Ni)	(Al-Khashman 2004)
26	Luanda	Angola	92	HCL+HNO_3	ICP-MS (Cd, Cr, Cu, Ni, Pb, Zn)	(Ferreira-Baptista and De Miguel 2005)
27	Kayseri	Turkey	29	HNO_3	AAS (Pb, Cu, Zn, Cr, Ni, Cd)	(Tokalioğlu and Kartal 2006)
28	Amman	Jordan	120	HNO_3	AAS (Pb, Cu, Zn, Ni, Cd)	(Al-Khashman 2007)
29	Hangzhou	China	25	HF+H_2SO_4+HCL	ICP-MS and AES (Cd, Cr, Cu, Ni, Pb, Zn)	(Mingkui and Hao 2009)
30	Baoji	China	38	Boric acid	XRF (Cu, Ni, Pb, Zn)	(Lu et al. 2009)

Table 1 (continued)

No.	City	country	No. of samples	Digestion	Analysis	Ref
31	Kavala	Greece	96	HNO_3	AAS (Pb, Cu, Zn, Ni, Cr, Cd)	(Christoforidis and Stamatis 2009)
32	Urumqi	China	169	HNO_3+H_2SO_4+HF	ICP-MS (Cd, Cr, Cu, Ni, Pb, Zn)	(Wei et al. 2010)
33	Delta	Egypt	7	HNO_3+$HClO_4$+HF	AAS (Pb, Cu, Zn, Ni, Cr, Cd)	(Khairy et al. 2011)
34	Ulsan	Korea	12	HNO3	AAS (Cd, Cu, Pb, Zn, Ni)	(Duong and Lee 2011)
35	Intertidal Bohai Bay	China	15	HF+HNO_3+$HClO_4$	ICP-MS (Cd, Cr, Cu, Ni, Pb, Zn)	(Gao and Li 2012)
36	Murree	Pakistan	8	HNO_3+H_2O_2	AAS (Pb, Cu, Zn, Ni, Cr, Cd)	(Abbasi et al. 2013)
37	Gorimedu	India	16	HNO_3+HCL	AAS (Cd, Cu, Pb, Zn, Cr)	(Khan and Kathi 2014)
38	Intertidal Laizhou Bay	China	18	HF+HNO_3+$HClO_4$	ICP-MS (Cd, Cr, Cu, Ni, Pb, Zn)	(Zhang and Gao 2015)
39	Intertidal Jiaozhou Bay	China	29	HF+HNO_3+$HClO_4$	ICP-MS (Cd, Cr, Cu, Pb, Zn)	(Xu et al. 2016)
40	Tijuana	Mexico	30	HNO_3+$HCLO_4$	AAS (Pb, Cu, Cr, Cd)	(Quiñonez-Plaza et al. 2017)
41	Jiaozhou Bay	China	9	HNO_3+HF+$HClO_4$	ICP-MS (Cd, Cr, Cu, Ni, Pb, Zn)	(Liang et al. 2018)

the earth materials. Cadmium is distributed in the earth's crust of about 0.1 mg/kg. Various industrial activities are the main source of cadmium in the urban surface. The production of alloys, batteries, and pigments is the major industrial application of cadmium (Tchounwou et al. 2012). Approximately, 33–72% of the local cadmium are distributed in air and transferred by atmospheric transport (Harrison and Williams 1982; Komarnicki 2005; Rashad Yaaqub et al. 1991). From Table 2, the high level of Cd in urban roads in various sites in Bahrain derived from household dust can be attributed to attrition of rubber backing on carpets (Fergusson and Kim 1991; Solomon and Hartford 1976) and from the fragment of car tires.

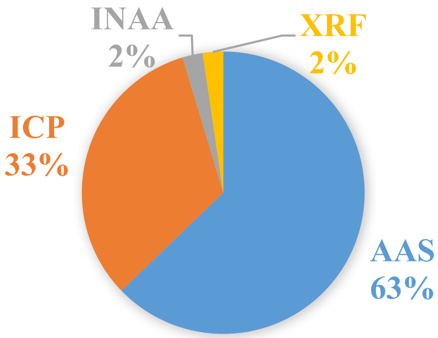

Fig. 2 The distribution of analytical methods used in heavy metal analysis in the present survey

Cadmium is considered the sixth element with a high toxicity that damages the human health according to Agency for Toxic Substances Management Committee. Cadmium can have an effect on the human health and, especially, it can damage the metabolism of calcium, which will cause calcium deficiency and result in bone fractures (Chao et al. 2014).

The existence of zinc in the urban environment is an indicator for human activities and may also be traced to vehicles emissions. Primary, the anthropogenic sources of zinc in the urban environment (air, soil, and water) include the released materials from mining and metallurgic operations and use of commercial products involving zinc such as fertilizers (Davis et al. 2001; Kennedy and Sutherland 2008; Vos and Janssen 2008). The annual variation of Zn concentrations has a wide range, as shown in Fig. 3 because the sources of Zn in the surface urban roads are the metallic parts of cars and automobile exhaust.

Nickel

Nickel (Ni) is one of heavy metals widely distributed in the urban environment. The contribution of nickel is

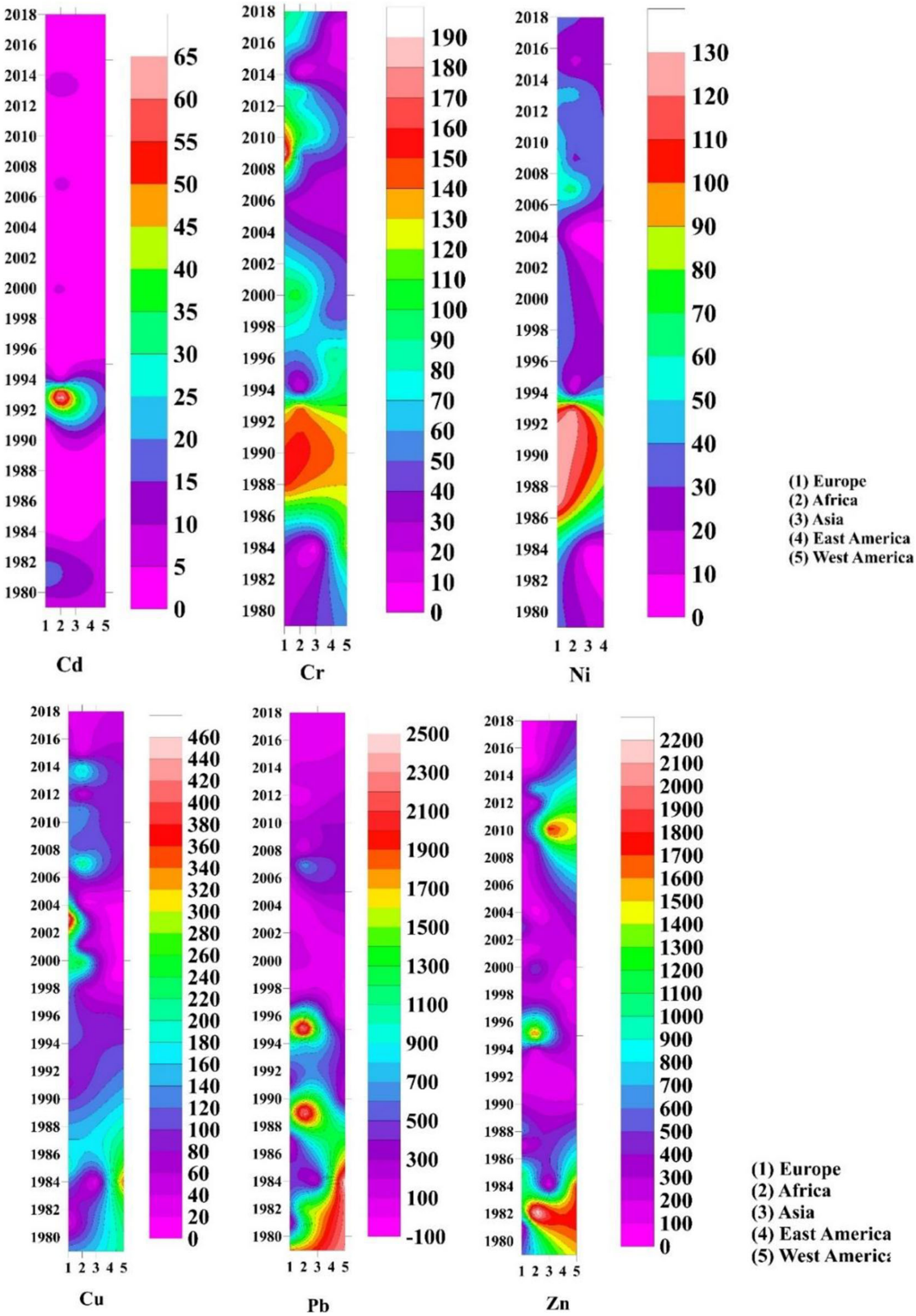

Fig. 3 Heavy metal distributions in the surface urban roads around the world

Table 2 Heavy metal concentrations (mg kg^{-1}) in urban surface sediment in the different cities at the world

City	Country	Cr	Cu	Pb	Zn	Ni	Cd	References
Lancaster	UK	29	143	1880	534	35	4.6	(Harrison 1979)
Scotland	Great Britain	NC	NC	756	422	NC	NC	(Wade et al. 1980)
Lancaster	England	NC	19.9	20	20.2	NC	20	(Harrison et al. 1981)
Various sites	Hong-Kong	NC	91.5	1556	2377	-	14.5	(Lau and Wong 1982)
New York	USA	125	356	2583	1811	NC	8	(Fergusson 1984)
Various sites	Nigeria	1.4	12	111	31	1.9	0.7	(Ndiokwere 1984)
Halkyn, North Wales	Great Britain	NC	200	480	1166	NC	0.8	(Davies et al. 1985)
Athens	Greece	NC	NC	121	125	128.45	2.4	(Yassoglou et al. 1987)
London	UK	155	NC	1030	680	NC	3.5	(Schwar et al. 1988)
Kuala Lumpur	Malaysia	NC	NC	2466	344	NC	3	(Ramlan and Badri 1989)
Cuenca	Ecuador	NC	NC	108	218	NC	0.33	(Nicholas Hewitt and Candy 1990)
London	England	NC	73	294	183	NC	1	(Thoronton 1991)
Various sites	Bahrain	144	NC	697	152	126	72	(Akhter and Madany 1993)
Various areas	Bahrain	9.6	NC	742	67	12	1.5	(Madany and Akhter 1994)
Seoul	Korea	NC	101	2582.5	1811	NC	3	(Chon et al. 1995)
Sault Ste Marie	Canada	92.4	87.3	90.5	227	26.5	0.85	(Stone and Marsalek 1996)
Oslo	Norway	NC	123	182	412	41	1.4	(Miguel et al. 1997)
Taejon	Korea	NC	57	52	214	NC	NC	(Kim et al. 1998)
California Bight	USA	39	15	10.9	59	18.1	0.33	(Schiff and Weisberg 1999)
Seoul	Korea	106	269	144	532	NC	6	(Yun et al. 2000)
Kowloon Peninsular	Hong Kong	NC	24.8	93.4	168	NC	2.8	(Li et al. 2001)
Bursa	Turkey	NC	NC	210	57	NC	3.1	(Arslan 2001)
Istanbul	Turkey	NC	152	184	477	30.36	2.11	(Charlesworth et al. 2003)
Birmingham	UK	NC	466.9	48	534	41.1	1.62	(Sezgin et al. 2004)
Karak	Jordan	NC	11.3	11.2	13.1	4.2	NC	(Al-Khashman 2004)
Luanda	Angola	26	42	315	317	10	1.1	(Ferreira-Baptista and De Miguel 2005)
Kayseri	Turkey	29	36.9	74.8	112	44.9	2.53	(Tokalioğlu and Kartal 2006)
Amman	Jordan	NC	243	737	293	67	6.9	(Al-Khashman 2007)
Hangzhou	China	51.29	116.04	202.16	321.4	25.88	1.59	(Mingkui and Hao 2009)
Baoji	China	NC	123.17	408.41	715.1	48.83	NC	(Lu et al. 2009)
Kavala	Greece	196	124	301	272	58	0.2	(Christoforidis and Stamatis 2009)
Urumqi	China	54.28	94.54	53.53	294.47	43.28	1.17	(Wei et al. 2010)
Delta	Egypt	85.7	102	308	1840	38.5	2.98	(Khairy et al. 2011)
Ulsan	Korea	NC	148	118	NC	NC	1.5	(Duong and Lee 2011)
Intertidal Bohai Bay	China	68.6	24	25.6	73	28	0.12	(Gao and Li 2012)
Murree	Pakistan	93	156.9	145.8	890	47.8	8.4	(Abbasi et al. 2013)
Gorimedu	India	0.85	202.24	156.63	222.46	NC	6.54	(Khan and Kathi 2014)
Intertidal Laizhou Bay	China	32.69	10.99	13.37	50.63	17.38	0.19	(Zhang and Gao 2015)
Intertidal Jiaozhou Bay	China	69.9	38.8	55.2	107.4	NC	0.42	(Xu et al. 2016)
Tijuana	Mexico	17.1	50.2	31.8	NC	NC	0.1	(Quiñonez-Plaza et al. 2017)
Jiaozhou Bay	China	86.17	27.31	38.54	76	32.35	0.304	(Liang et al. 2018)
WHO		50	2	10	250	20	1	(WHO 2008)

NC not counted

about 0.008% of the earth's crust. Sources of nickel in the urban environment are natural and anthropogenic with stationary and mobile. Nature sources of the nickel include wind-blown dust, derived from the weathering of rocks and soils, volcanic emissions, forest fires, and vegetation (Cempel and Nikel 2006). The main anthropogenic sources of nickel emissions to the atmosphere are the burning of residual and fuel oils, municipal waste incineration, and nickel mining and refining. Sulfide ores and the silicate oxide are two commercial classes of nickel origin. Canada and the Russian Federation, the largest producers of nickel from the sulfide ores, account of 20–25% of the total annual production (IARC 1990). The uses of nickel in the environment include as steel production, the production of alloys, and electroplating in the form nickel sulfate account for about 42%, 36%, and 18%, respectively. From Fig. 3, the annual variation of nickel concentrations decreases with subsequent years; and in general, its concentration with the permissible limit according to WHO (2008). Automobile emissions are the main sources in Athens, Greece, and various sites, such as Bahrain (Madany and Akhter 1994; Yassoglou et al. 1987).

Copper

Copper (Cu) is released into the atmosphere from wide distribution of natural and anthropogenic sources. The main sources in nature are windblown dust, volcanoes, decaying vegetation, sea spray, and forest fires (Davies et al. 1985; Georgopoulos 2011). Anthropogenic emissions of copper include vehicles emission, iron and steel production, wood production, coal combustion, nonferrous metal production, industrial application, and phosphate fertilizer manufacture. In general, heavy metals are emitted into the atmosphere and attached with a particulate matter in the form of an oxide, sulfide, or carbonate. For example, copper in fine particles (< 1 μm) resulted from the combustion process and other high-temperature sources, while that with a large particle (> 10 μm) originated from windblown dust and soil (Schroeder et al. 1987). From the literature survey that was shown in table, the copper in Birmingham, UK, originated from the mechanical abrasion of vehicles (Jiries et al. 2001).

In general, the contamination with heavy metal depends on anthropogenic sources of the land-use, the rapid urbanization. Moreover, the significant factors are traffic and the population volume.

Table 2 presents the concentration of heavy metals such as Cr, Cu, Pb, Zn, Ni, and Cd in the urban surface sediment at different cities from different countries based on collected published data from different engines. The results are ordered from the oldest to the newest in the last 40 years (1979–2018). Last raw state the recommended reference value from WHO (2008). A special distribution of each heavy metal element is presented in Fig. 3. The distribution is according to the continent in last 40 years. Compared with the reference value, Pb, Zn, and Cd have a high concentration in different urban roads around the world until now.

From the results, heavy metals in the urban surface sediment having different concentrations in Fig. 3 were found, where a few of cities have high concentrations and other have low concentrations of heavy metal relative to WHO (2008).

From Fig. 3, the annual variation of Pb decreases despite the increased volume of traffic due to non-use of lead fuel; this is due to the efforts of health care and assurance from different organizations about exposure of dangerous and carcinogenic pollution sources.

Contamination levels of heavy metal

Pollution level

It is very important to determine the degree of pollution or environmental planning construction in the urban environment. The integrated pollution index (IPI) can be calculated by (Abbasi et al. 2013):

$$\mathrm{PI} = \frac{C_\mathrm{n}}{B_\mathrm{n}}$$

where C_n and B_n are the measured and the background/reference values of heavy metal in the urban environment, and where the background in this study is related to the CEPA environmental background values (Dandan et al. 2007). The mean value of pollution index is the integrated pollution index IPI classified into: IPI ≤ 1 low level of pollution; 1 < IP ≤ 2 moderate level of pollution; 2 < IPI ≤ 5 high level of pollution; IPI > 5 extreme high level of pollution (Wei and Yang 2010). In this review, the IPI is calculated in different cities around the world. The frequency of IPI is shown in Fig. 4 for each heavy metal element. The results show that the levels of pollution around the world have a range from low level to extremely high level. This result is due to the different sources of pollution in each city.

The analysis of this distributions giving us nearly 56% of Pb IPI is in extreme high level of pollution, 24% high level, 10% moderate, and 10% low level. For Cd, 78% is extreme high level of pollution, 14% high level, and 8% moderate. For Zn, 28% is extreme high level of pollution, 33% high level, 15% moderate, and 23% low level. These distributions in Fig. 4 confirm that the major sources of pollution in the urban environment are due to lead cadmium and zinc sources. It has given us a good indicator about the expected range for each heavy metal element. Besides that, the levels of pollution of each city depend on the geogenic and anthropogenic sources. Moreover, the distribution of industrial activities, population size, and the traffic emissions for each city is affecting the levels of pollution.

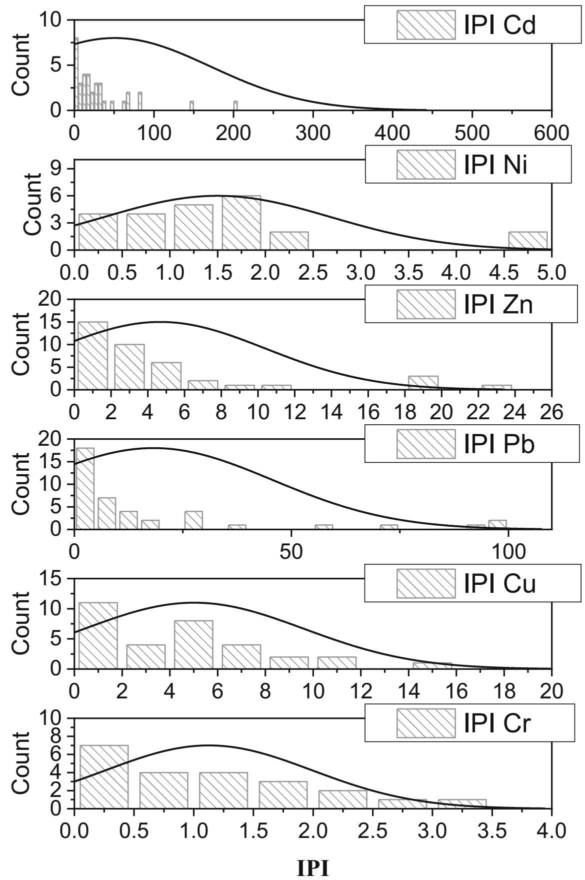

Fig. 4 The integrated pollution index IPI frequency from the used measurements around the world

Geoaccumulation index

The geoaccumulation index has been used to assess the degree of the contamination with heavy metal in urban surface sediment (Faiz et al. 2009; Lu et al. 2009; Quiñonez-Plaza et al. 2017; Wakida 2016). The geoaccumulation index (I_{geo}) calculated by:

$$I_{geo} = \log_2\left(\frac{C_n}{1.5\,B_n}\right)$$

where C_n is the measured heavy metal concentration in the different samples in the urban environment, B_n is the geochemical background values in the soil according to the CEPA environmental background values (Dandan et al. 2007), and the value 1.5 allows us to analyze natural variations in the content of a specified substance in the environment and to detect very small anthropogenic influences. According to Muller (Muller 1969), I_{geo} is classified into six categories: uncontaminated ($I_{geo} \leq 0$); uncontaminated to moderately contaminated ($0 < I_{geo} \leq 1$); moderately contaminated ($1 < I_{geo} \leq 2$); moderately to heavily contaminated ($2 < I_{geo} \leq 3$); heavily contaminated ($3 < I_{geo} \leq 4$); heavily to extremely contaminated ($4 < I_{geo} \leq 5$); extremely contaminated ($I_{geo} \geq 5$). The calculated values of heavy metal in the urban surface sediment for each selected city are presented in Table 3.

The calculated values of I_{geo} can be divided into two groups. The first group as shown in Fig. 5a includes Cr and Ni and is characterized by I_{geo} lowest value in all investigated samples. It is indicated that the urban surface sediment samples are uncontaminated with these metals except a few of cities such as, London (UK), Kavala (Greece), and Athens (Greece) and various cities in Bahrain are in an uncontaminated and moderately contaminated category. The second group including Cu, Pb, Zn, and Cd is presented in Fig. 5b. In this group, I_{geo} values ranged from uncontaminated to extremely contaminated. The I_{geo} values due to Pb and Cd concentrations vary between different contaminated categories, where in relation to Pb concentrations, 10 cities were found extremely contaminated, 4 cities heavily and extremely contaminated, 6 cities heavily contaminated, 8 cities moderately and heavily contaminated, 5 cities moderately contaminated, and the other cities vary between moderately and uncontaminated. Furthermore, for Cd, three cities were extremely contaminated and 5 heavily and extremely contaminated and the other cities vary in the other different contamination categories.

Table 3 Geo-accumulation index of heavy metal in urban surface sediment in the several cities around the world

No	City	Country	Cr	Cu	Pb	Zn	Ni	Cd
1	Lancaster	UK	− 1.66	2.08	5.59	1.83	− 0.21	4.94
2	Scotland	Great Britain	–	–	4.28	1.49	–	–
3	Lancaster	England	–	− 0.77	− 0.96	− 2.89	–	7.06
4	Various sites	Hong Kong	–	1.43	5.32	3.99	–	6.59
5	New York	USA	0.45	3.39	6.05	3.59	− 4.41	5.74
6	Various sites	Nigeria	− 6.03	− 1.50	1.51	− 2.27	–	2.22
7	Halkyn, North Wales	Great Britain	–	2.56	3.62	2.96	–	2.42
8	Athens	Greece	–	–	1.63	− 0.26	1.67	4.00
9	London	UK	0.76	–	4.72	2.18	–	4.54
10	Kuala Lumpur	Malaysia	–	–	5.98	1.20	–	4.32
11	Cuenca	Ecuador	–	–	1.47	0.54	–	1.14
12	London	England	–	1.11	2.91	0.29	–	2.74
13	Various sites	Bahrain	0.65	–	4.16	0.02	1.64	8.91
14	Various areas	Bahrain	− 3.25	–	4.25	− 1.16	− 1.75	3.32
15	Seoul	Korea	–	1.57	6.05	3.59	–	4.32
16	Sault Ste Marie	Canada	0.01	1.36	1.21	0.60	− 0.61	2.50
17	Oslo	Norway	–	1.86	2.22	1.46	0.02	3.22
18	Taejon	Korea	–	0.75	0.42	0.51	–	–
19	California Bight	USA	− 1.23	− 1.18	− 1.84	− 1.35	− 1.16	1.14
20	Seoul	Korea	0.21	2.99	1.88	1.83	–	5.32
21	Kowloon Peninsular	Hong Kong	–	− 0.45	1.26	0.16	–	4.22
22	Bursa	Turkey	–	–	2.43	− 1.40	–	4.37
23	Istanbul	Turkey	–	2.16	2.24	1.67	− 0.41	3.81
24	Birmingham	UK	–	3.78	0.30	1.83	0.03	3.43
25	Karak	Jordan	–	− 1.58	− 1.80	− 3.52	− 3.26	–
26	Luanda	Angola	− 1.82	0.31	3.01	1.08	− 2.01	2.87
27	Kayseri	Turkey	− 1.66	0.12	0.94	− 0.42	0.15	4.08
28	Amman	Jordan	–	2.84	4.24	0.97	0.73	5.52
29	Hangzhou	China	− 0.75	1.48	0.46	0.97	0.10	2.96
30	Baoji	China	− 0.84	1.78	2.37	1.10	− 0.64	3.41
31	Kavala	Greece	–	1.86	3.39	2.25	0.28	–
32	Urumqi	China	1.10	1.87	2.95	0.86	0.52	0.42
33	Delta	Egypt	− 0.09	1.59	2.98	3.62	− 0.07	4.31
34	Ulsan	Korea	–	2.13	1.60	–	–	3.32
35	Intertidal Bohai Bay	China	− 0.42	− 0.50	− 0.61	− 1.04	− 0.53	− 0.32
36	Murree	Pakistan	0.02	2.21	1.90	2.57	0.24	5.81
37	Gorimedu	India	− 6.75	2.58	2.01	0.57	–	5.45
38	Intertidal Laizhou Bay	China	− 1.48	− 1.63	− 1.54	− 1.57	− 1.22	0.34
39	Intertidal Jiaozhou Bay	China	− 0.39	0.19	0.50	− 0.48	–	1.49
40	Tijuana	Mexico	− 2.42	0.57	− 0.29	–	–	− 0.58
41	Jiaozhou Bay	China	− 0.09	− 0.31	− 0.02	− 0.98	− 0.32	1.02

Moreover, with Zn, most of the cities were found moderately contaminated, a few cities were moderately and heavily contaminated, while the highest value was in various sites in Hon Kong, New York (USA), Seoul

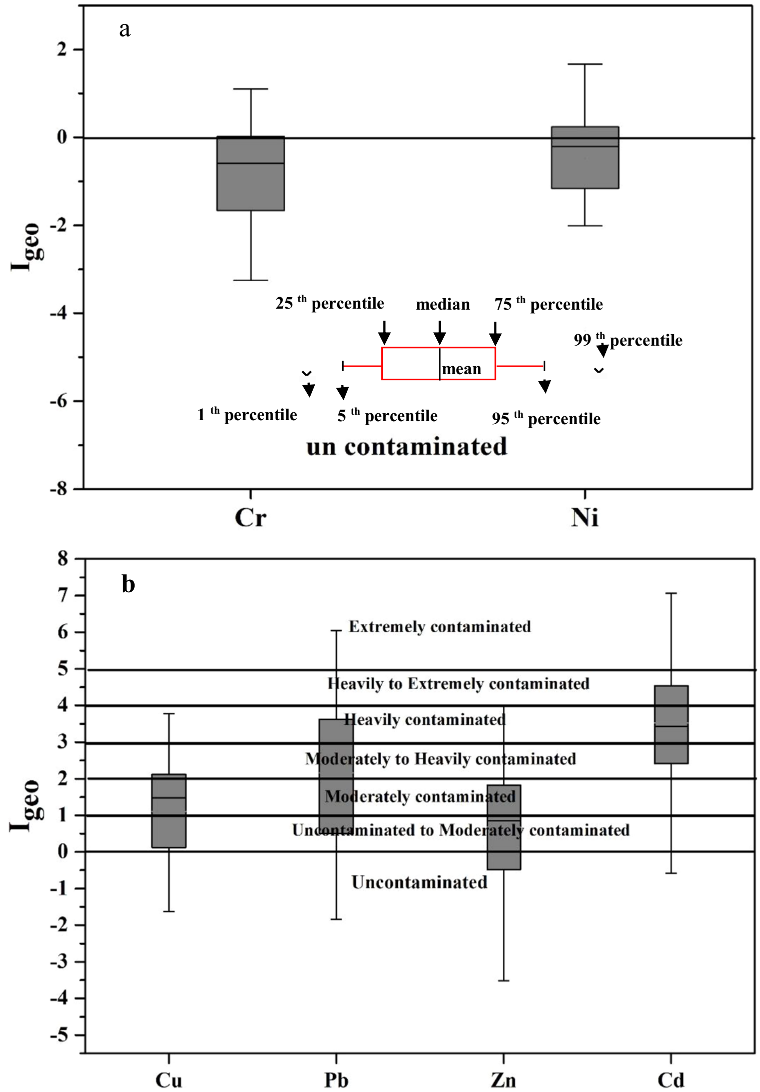

Fig. 5 **a, b** The values of I_{geo} in a several cities at the world

(Korea), and Delta (Egypt); this indicated that it was heavily and extremely contaminated and the other cities were varied in other contaminated categories. However, I_{geo} values for Cu indicated all cities were found in the first four categories of contamination.

The concentrations and I_{geo} values of heavy metal in urban surface sediment and soils indicate that the contamination is widespread in the urban environment in the world. In general, the traffic emission and industrial emission are the main contamination sources of heavy metal in the urban environment. Among cities, there are different contamination sources. As example, the traffic pollution, tire abrasion, fuel and oils that are used for heating system, corrosion of metallic parts of cars, lubricants, incinerator, and industrial emissions are considered the main contamination sources for heavy metal.

Particle size distribution of urban surface sediment and heavy metal

The particle size of particulate matter is a significant property affecting heavy metal (Mudroch and Duncan 1986). Their distribution plays an important role in the urban environment control. Coarse particles (> 1000 μm) are relatively easy to monitor and remove. On the other hand, fine solids are the most dominant fraction in the urban areas due to ease of mobility (Deletic et al.

2000; Goonetilleke et al. 2009; Herngren et al. 2006). They have the ability to stay in suspension longer and are therefore transported a greater distance by urban runoff (Faiz et al. 2009; Herngren et al. 2006). Figure 6 shows the variation of the heavy metal concentrations with the particle fraction size (< 100 μm, 100–500 μm, 500–1000 μm, and 1000–2000 μm) for each element in the urban surface samples from the different literatures. From all the literatures that are chosen, the heavy metal concentrations were determined related to the particle fraction size. So, the results show that the heavy metal concentration in the urban surface sediment decreases with increasing particle size (Duong and Lee 2011). This might be due to the smaller particle size of surface sediment that have an available surface area per unit of mass for covering or deposition of heavy metal. From Fig. 6, it is observed that the fraction size (< 100 μm) has the most concentrations of Cu, Pb, Zn, and Cd in urban sediment in these cities; this is due to the sweeper efficiency in the removal of < 100-μm solid particles (Sartor and Boyd 1972). Consequently, the most pollutants of Pb, Zn, Cu, and Cd are associated with the fine fraction of particles influenced by traffic emissions, tire wearing, and brake abrasion, but the concentration of Cr and Ni in sediment associated in the coarse grain size (500–1000 μm) was derived from diesel exhaust emissions and the corrosion of vehicles (Beckwith et al. 1986; McBride 1994).

Contamination control and treatment

Contamination management in urban surface road

The contaminant control in the urban surface depends on the volume of deposited sediments, their contaminant concentrations, and their transport mechanism. Any approach used to reduce pollutants in urban surface must be based on the methods appropriate for each urban environment.

The volume of deposited sediments in the urban surface road can be reduced by mitigation strategies and adopting preventive treatment. Adopting preventive treatment is used to evaluate the enhancement of roads and road traffic restrictions (Kadioğlu et al. 2010; Loganathan et al. 2013). Mitigating process is used to remove the deposited sediments on the urban surface road by the mechanical and manual techniques such as sweeping, water flushing, and chemical suppressants (Amato et al. 2010). The deposited sediments in the urban surface consisted of different fraction sizes; fine particles (100–250 μm) that are attached in the atmosphere and coarse particles are bonded with the surface. Consequently, the cleaning of roads from the deposited sediments had been used the different categories of street sweepers; mechanical broom, vacuum-assisted broom, and regenerative-air units. Several studies are concluded that the mechanical street sweepers are used to remove the coarse particles followed by a regenerative air street cleaner to remove the finer particles (Amato et al. 2010; Perry and Taylor 2007; Loganathan et al. 2013; Brinkmann and Tobin 2001). Also, they recommended that after the sweeping processes, a washing process could be practice to remove most of the deposited sediments. The removal of deposited sediments in the urban surface roads depends on some of the factors such as the location of the city, weather, the volume of traffic, road pavement, and the frequency of sweepings and washing. The most effective method to remove the deposited sediments in the urban surface roads was weekly sweeping (Brinkmann and Tobin 2001).

Remediation and treatment of soil

In the last years, soil contamination was not considered as important as air and water pollution, because soil contamination was often with wide range and was more difficult to be controlled and governed than air and water pollution. However, in recent years, the soil contamination in developed countries is becoming too serious. It is thus paid more and more attention and became a hot topic of environmental protection worldwide. Therefore, remediation and treatment of urban environment of heavy metals is a suitable way for environmental protection (Rulkens et al. 1998).

The dilution and self-purification techniques are used to eliminate the heavy metal contamination in the urban environment after closing the contamination sources. Nevertheless, the remediation of heavy metal contamination in the urban environment is difficult to be remediated, due to its needs to have a relatively high cost and a relatively long time. The avoidance of heavy metals contaminated soil is not only needed to control the sources, but also improve the remediation of contaminated soil (Yao et al. 2012).

Soil remediation techniques can be widely classified into three categories: physical, chemical, and biological. Physical remediation techniques include (1) soil replacement, (2) soil isolation, (3) vitrification, and (4)

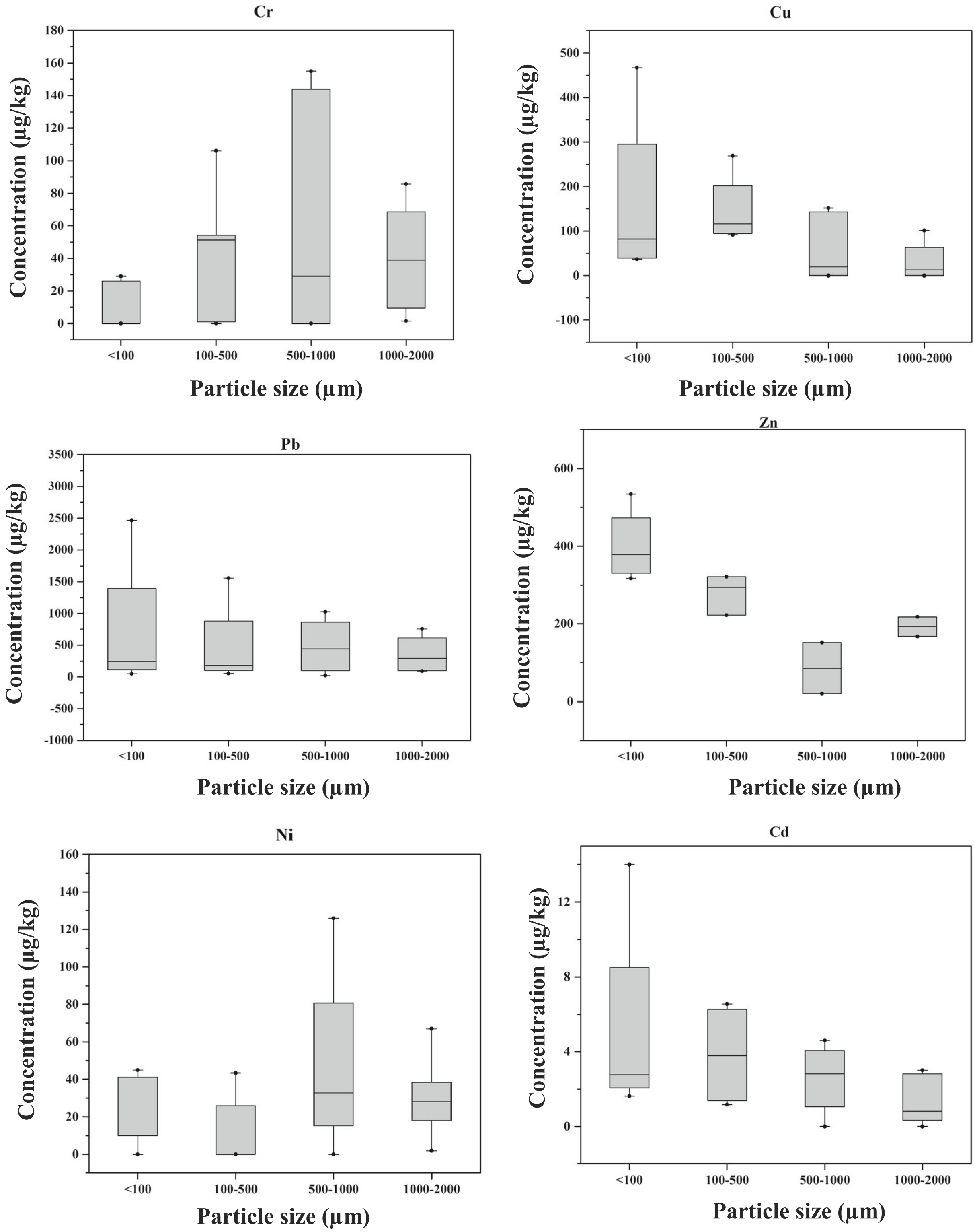

Fig. 6 The variation of heavy metal concentration with different fraction size in the surface urban sediment

electrokinetic; biological methods generally include (5) phytostabilization, (6) phytoevaporation, and (7) phytoextraction; and chemical methods include (8) immobilization and (9) soil washing, as shown in Fig. 7 and adapted by Khalil et al. 2016 (Khalid et al. 2017).

Physical remediation

The physical remediation includes replacement of contaminated soil and thermal desorption.

Replacement of contaminated soil Replacement of contaminated soil can be classified into three types. In the first type, the contaminated soil can be removed and inserted into a new soil. This method is unsuitable for contaminated soil with a large area. The removed soil must be treated to avoid the second contamination. In the second type, to isolate the contaminated soil, the cover of clean soil will add to the contaminated surface or to blend with the latter. The isolation of contaminated soil can be decreasing its effects on the urban environment. In the third type, the contamination spread can go deeply into the soil and the degrading treatment and the dilution will be achieved remediation. These methods can be applied to small areas due to material sources and the large cost (Yao et al. 2012).

Thermal desorption (verification) Thermal desorption is the engineering physical process that can be used to remove the contaminants in the urban soil by evaporation and heating. The evaporation of heavy metal in the soil can be achieved by using the vacuum negative pressure or carrier gas. The heating technique is a simple process that had been remediated in the soil contamination. This method depends on the temperature desorption and is classified into high-temperature desorption and low-temperature desorption (Aresta et al. 2008; Gan et al. 2009; Mallampati et al. 2015; Yao et al. 2012). Essentially, the way it works is by baking the soil causing contaminates to evaporate. The extracted material is captured and cooled for subsequent disposal. The treated soil is then cooled and removed from the remediation

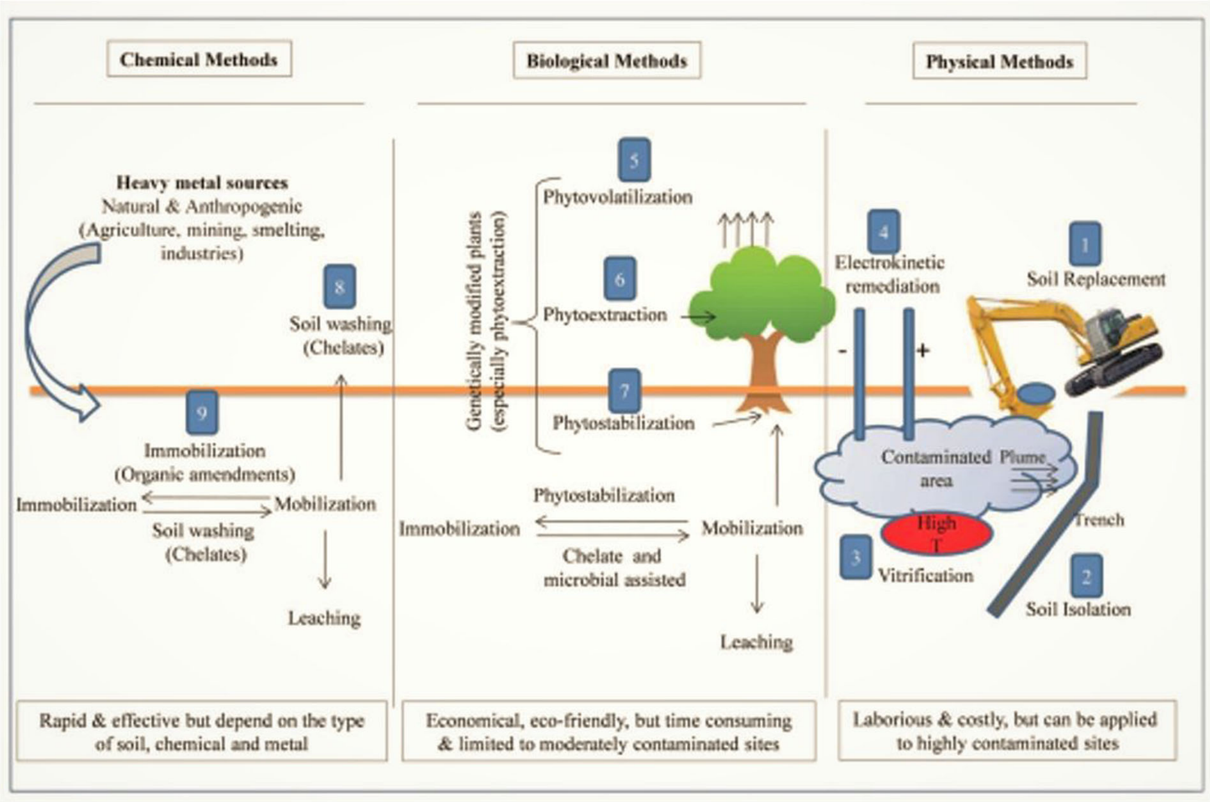

Fig. 7 Comparison of different soil remediation methods (adapted from Khalil 2016)

mechanism across the carrier system. Once the process is complete, the soil is ready for recycling or further testing (Rulkens et al. 1998; Semple et al. 2001).

Electrokinetic remediation Electrokinetic remediation is suitable for sandy and clay soils contaminated with heavy metals. This technique depends on an electric current applied between a cathode and anode of tank which contains the contaminated soil (Acar and Alshawabkeh 1993; Cox et al. 1996; Luo et al. 2005; Sabatini and School 1992).

Chemical remediation

Soil leaching Soil leaching method is used to wash the contaminated soil with fresh water and a specific reagent that can leach the contamination from soil. In this method, the heavy metal in soil was separated by adsorption, precipitation, and ion exchange and then recycled from extraction solution (Tampouris et al. 2001).

Adsorption Adsorption technique is depending on the chemical fixation with adding the specific reagents and other materials into the contaminated soil. These reagents are suitable to form insoluble or hardly movable thus avoiding the diffusion of heavy metal in the environment media and achieving the leaching of soil (Austruy et al. 2014; Ashraf et al. 2016; Castelo-Grande et al. 2010; Khalid et al. 2017; Shahid et al. 2014).

Bioremediation

Biological remediation is a suitable technique to treat the contaminated soil. This technique depends on the optimum conditions created for microbiological degradation. This can occur by influencing such factors as pH, temperature, soil moisture, oxygen concentration, and bioavailability of the contaminants to the microorganisms (Abdel-Aziz et al. 1997; Prakash et al. 2013; Watanabe 1997; Wołejko et al. 2016). This method includes phytostabilization, photoevaporation, and phytoextraction.

Conclusion

The several cities in the world are distinguished with the volume population and rapid urbanization. The different sources of heavy metal were common to the urban and industrial environments. The distribution and intensities of heavy metal depend on the nature properties of each city. The most results show that the heavy metal concentrations were higher than the maximum limit. The concentrations of Cu, Pb, Zn, and Cd in the urban surface sediment are mainly derived from anthropogenic sources but the Cr and Ni come from geogenic sources. The highest concentrations of heavy metal in the urban environment are influenced by the population size, industrial activities, and heavy traffic emissions. On the other hand, the lowest concentrations are found in the locations with low automobiles traffic and low population volume such as rural areas. This indicates, according to the values of I_{geo} in several cities, that the contamination levels in these cities varied from uncontaminated to extremely contaminated. The contamination levels with Pb, Cd, and Zn are higher than that of other heavy metals. In spite of the efforts to reduce this level through the nearest past years, Pb, Cd, and Zn are stilling higher than the permissible limits. The effective way for environmental protection of heavy metal contamination in the urban is remediation and treatment. There exist several important factors which can affect the selection and applicability of available soil clean-up technologies. These factors include (i) cost involved, (ii) time required, (iii) effectiveness under high metal(loid) s contamination, (iv) general acceptance and commercial availability, (v) long-term effectiveness, and (vi) applicability to multi-metal contaminated sites.

Compliance with ethical standards

Conflict of interest The authors declare that they have no conflict of interest.

References

Abbasi, M. N., Tufail, M., & Chaudhry, M. M. (2013). Assessment of heavy elements in suspended dust along the murree highway near Capital City of Pakistan. *World Applied Sciences Journal, 21*(9), 1266–1275. https://doi.org/10.5829/idosi.wasj.2013.21.9.155.

Abdel-Aziz, R. A., Radwan, S. M. A., & Dahdoh, M. S. (1997). Reducing the heavy metals toxicity in sludge amended soil using VA mycorrhizae. *Egyptian Journal of Microbiology, 32*(2), 217–234.

Acar, Y. B., & Alshawabkeh, A. N. (1993). Principles of electrokinetic remediation. *Environmental Science and Technology, 27*(13), 2638–2647. https://doi.org/10.1021/es00049a002.

Ahmadi Doabi, S., Karami, M., & Afyuni, M. (2019). Heavy metal pollution assessment in agricultural soils of Kermanshah province, Iran. *Environmental Earth Sciences, 78*(3), 70–12. https://doi.org/10.1007/s12665-019-8093-7.

Ahmed, F. A., & Ishiga, H. (2006). Trace metal concentrations in street dusts of Dhaka city. *Bangladesh, 40*, 3835–3844. https://doi.org/10.1016/j.atmosenv.2006.03.004.

Akhter, M., & Madany, I. (1993). Heavy metals in street and house dust in Bahrain. *Water Air Soil Pollut 66*, 111–119. https://doi.org/10.1007/BF00477063

Al-Khashman, O. A. (2004). Heavy metal distribution in dust, street dust and soils from the work place in Karak Industrial Estate, Jordan. *Atmospheric Environment, 38*(39), 6803–6812. https://doi.org/10.1016/j.atmosenv.2004.09.011.

Al-Khashman, O. A. (2007). Determination of metal accumulation in deposited street dusts in Amman, Jordan. *Environmental Geochemistry and Health, 29*(1), 1–10. https://doi.org/10.1007/s10653-006-9067-8.

Al-shayeb S. M and Seaward M. R. D. (2001). Heavy metal content of roadside soils ring road in Riyadh (Saudi Arabia). *Asian Journal of Chemistry*, 13, 407–723.

Amato, F., Querol, X., Johansson, C., Nagl, C., & Alastuey, A. (2010). A review on the effectiveness of street sweeping, washing and dust suppressants as urban PM control methods. *Science of the Total Environment, 408*(16), 3070–3084. https://doi.org/10.1016/j.scitotenv.2010.04.025.

Aresta, M., Dibenedetto, A., Fragale, C., Giannoccaro, P., Pastore, C., Zammiello, D., & Ferragina, C. (2008). Thermal desorption of polychlorobiphenyls from contaminated soils and their hydrodechlorination using Pd- and Rh-supported catalysts. *Chemosphere, 70*(6), 1052–1058. https://doi.org/10.1016/j.chemosphere.2007.07.074.

Arslan, H. (2001). Heavy metals in street dust in bursa, turkey. *Journal of Trace and Microprobe Techniques, 19*(3), 439–445. https://doi.org/10.1081/TMA-100105058.

Ashraf, A., Bibi, I., Niazi, N. K., Ok, Y. S., Murtaza, G., Shahid, M., et al. (2016). Chromium(VI) sorption efficiency of acid-activated banana peel over organo-montmorillonite in aqueous solutions Anam, (Vi), 1–32.

Austruy, A., Shahid, M., Xiong, T., Castrec-Rouelle, M., Payre, V., Niazi, N. K., & Muhammad Sabir, C. D. (2014). Mechanisms of metal-phosphates formation in the rhizosphere soils of pea and tomato: environmental and sanitary consequences. *Journal of Soils and Sediments, 14*(4), 666–678. https://doi.org/10.1007/s11368-014-0862-z.

Bak, J., Jensena, J., Larsenb, M. M., & Pritzl, G. (1997). A heavy metal monitoring-programme in Denmark, *207*, 179–186.

Beckwith, P. R., Ellis, J. B., Revitt, D. M., & Oldfield, F. (1986). Heavy metal and magnetic relationships for urban source sediments, *42*, 67–75.

Biggins, D. E., & Harrison, R. M. (1980). Chemical speciation of lead compounds in street dusts, (6).

Brinkmann, R. and Tobin G.. (2001). *Urban sediment removal*.

Castelo-Grande, T., Augusto, P. A., & Monteiro, P. (2010). Remediacion Del Suelo Contaminado Con Pesticidas. *International Journal of Environmental Analytical Chemistry*, (April 2013), 37–41. doi:https://doi.org/10.1080/03067310903374152.

Cempel, M., & Nikel, G. (2006). Nickel: a review of its sources and environmental toxicology. *Polish Journal of Environmental Studies, 15*(3), 375–382. https://doi.org/10.1109/TUFFC.2008.827.

Chao, S., LiQin, J., & WenJun, Z. (2014). A review on heavy metal contamination in the soil worldwide: situation, impact and remediation techniques. *Environmental Skeptics & Critics, 3*(2), 24–38. https://doi.org/10.1037/a0036071.

Charlesworth, S., Everett, M., McCarthy, R., Ordóñez, A., & de Miguel, E. (2003). A comparative study of heavy metal concentration and distribution in deposited street dusts in a large and a small urban area: Birmingham and Coventry, West Midlands, UK. *Environment International, 29*(5), 563–573. https://doi.org/10.1016/S0160-4120(03)00015-1.

Chon, H. T., Kim, K. W., & Kim, J. Y. (1995). Metal contamination of soils and dusts in Seoul metropolitan city, Korea. *Environmental Geochemistry and Health, 17*(3), 139–146. https://doi.org/10.1007/BF00126082.

Christoforidis, A., & Stamatis, N. (2009). Heavy metal contamination in street dust and roadside soil along the major national road in Kavala's region, Greece. *Geoderma, 151*(3–4), 257–263. https://doi.org/10.1016/j.geoderma.2009.04.016.

Cox, C. D., Shoesmith, M. A., & Ghosh, M. M. (1996). Electrokinetic remediation of mercury-contaminated soils using iodine/iodide lixiviant. *Environmental Science and Technology, 30*(6), 1933–1938. https://doi.org/10.1021/es950633r.

Dandan, W., Huixin, L., Feng, H., & Xia, W. (2007). Role of earthworm-straw interactions on phytoremediation of Cu contaminated soil by ryegrass. *Acta Ecologica Sinica, 27*(4), 1292–1298. https://doi.org/10.1016/S1872-2032(07)60030-4.

Davies, B. E., Elwood, P. C., Gallacher, J., & Ginnever, R. C. (1985). The relationships between heavy metals in garden soils and house dusts in an old lead mining area of North Wales, Great Britain. *Environmental Pollution. Series B: Chemical and Physical, 9*(4), 255–266. https://doi.org/10.1016/0143-148X(85)90002-3.

Davis, A. P., Shokouhian, M., & Ni, S. (2001). Loading estimates of lead, copper, cadmium, and zinc in urban runoff from specific sources. *Chemosphere, 44*(5), 997–1009. https://doi.org/10.1016/S0045-6535(00)00561-0.

Davis, D. L., Bell, M. L., & Bates, D. (2002). Guest editorials a look back at the London smog of 1952 and the half century since a half century later. *Environmental Health Perspectives, 110*(12), 734–735.

De Silva, S., Ball, A. S., Huynh, T., & Reichman, S. M. (2016). Metal accumulation in roadside soil in Melbourne, Australia: effect of road age, traffic density and vehicular speed. *Environmental Pollution, 208*, 102–109. https://doi.org/10.1016/j.envpol.2015.09.032.

Deletic, A. N. A., Ashley, R., & R. D. (2000). Modelling input of fine granular sediment into drainage systems via gully-pots. *Water Research, 34*(15), 3836–3844.

Duong, T. T. T., & Lee, B. K. (2011). Determining contamination level of heavy metals in road dust from busy traffic areas with different characteristics. *Journal of Environmental Management, 92*(3), 554–562. https://doi.org/10.1016/j.jenvman.2010.09.010.

Esmaeili, A., Moore, F., Keshavarzi, B., Jaafarzadeh, N., & Kermani, M. (2014). A geochemical survey of heavy metals in agricultural and background soils of the Isfahan industrial zone, Iran. *Catena, 121*, 88–98. https://doi.org/10.1016/j.catena.2014.05.003.

Faiz, Y., Tufail, M., Javed, M. T., & Chaudhry, M. M. (2009). Road dust pollution of Cd , Cu , Ni , Pb and Zn along Islamabad Expressway, Pakistan. *Microchemical Journal, 92*(2), 186–192. https://doi.org/10.1016/j.microc.2009.03.009.

Fergusson, J. E. (1984). The elemental composition of street dust from large.pdf. *The Science of the Total Environment, 34*, 101–116.

Fergusson, J. E., & Kim, N. D. (1991). Trace elements in street and house dusts : sources and speciation of the three materials , soil , sediment and dust , which derive primarily from the earth ' s crust , and with which h u m a n beings come into contact , dust is the most pervasive . It is, *100*, 125–150.

Ferreira-Baptista, L., & De Miguel, E. (2005). Geochemistry and risk assessment of street dust in Luanda, Angola: a tropical urban environment. *Atmospheric Environment, 39*(25), 4501–4512. https://doi.org/10.1016/j.atmosenv.2005.03.026.

Gan, S., Lau, E. V., & Ng, H. K. (2009). Remediation of soils contaminated with polycyclic aromatic hydrocarbons (PAHs). *Journal of Hazardous Materials, 172*(2–3), 532–549. https://doi.org/10.1016/j.jhazmat.2009.07.118.

Gao, X., & Li, P. (2012). Concentration and fractionation of trace metals in surface sediments of intertidal Bohai Bay, China. *Marine Pollution Bulletin, 64*(8), 1529–1536. https://doi.org/10.1016/j.marpolbul.2012.04.026.

Georgopoulos. (2011). *Journal of Toxicology and Environmental Health , Part B: Critical Reviews Environmental Copper: its Dynamics and Human*, (September 2013), 37–41. doi: https://doi.org/10.1080/109374001753146207.

Gibson, M. J., & Farmer, J. G. (1986). Multi-step sequential chemical extraction of heavy metals from urban soils. *Environmental Pollution. Series B: Chemical and Physical, 11*(2), 117–135. https://doi.org/10.1016/0143-148X(86)90039-X.

Goonetilleke, A., Egodawatta, P., & Kitchen, B. (2009). Evaluation of pollutant build-up and wash-off from selected land uses at the Port of Brisbane, Australia. *Marine Pollution Bulletin, 58*(2), 213–221. https://doi.org/10.1016/j.marpolbul.2008.09.025.

Han, F. X., Banin, A., Su, Y., Monts, D. L., Plodinec, M. J., Kingery, W. L., & Triplett, G. E. (2002). Industrial age anthropogenic inputs of heavy metals into the pedosphere. *Naturwissenschaften, 89*(11), 497–504. https://doi.org/10.1007/s00114-002-0373-4.

Hanfi, M. Y., Yarmoshenko, I. V., Seleznev, A. A., & Zhukovsky, M. V. (2019). The gross beta activity of surface sediment in different urban landscape areas. *Journal of Radioanalytical and Nuclear Chemistry, 0123456789*, 831–839. https://doi.org/10.1007/s10967-019-06657-9.

Hani, A., & Pazira, E. (2011). Heavy metals assessment and identification of their sources in agricultural soils of Southern Tehran, Iran. *Environmental Monitoring and Assessment, 176*(1–4), 677–691. https://doi.org/10.1007/s10661-010-1612-3.

Harrison, R. M. (1979). Toxic metals in street and household dusts. *Science of the Total Environment, 11*(1), 89–97. https://doi.org/10.1016/0048-9697(79)90036-6.

Harrison, R. M., & Williams, C. R. (1982). Airborne cadmium, lead and zinc at rural and urban sites in north-west England. *Atmospheric Environment (1967), 16*(11), 2669–2681. https://doi.org/10.1016/0004-6981(82)90349-3.

Harrison, R. M., Laxen, D. P. H., & Wilson, S. J. (1981). Chemical associations of lead, cadmium, copper, and zinc in street dusts and roadside soils. *Environmental Science and Technology, 15*(11), 1378–1383. https://doi.org/10.1021/es00093a013.

Herngren, L., Goonetilleke, A., & Ayoko, G. A. (2006). Analysis of heavy metals in road-deposited sediments. *571*, 270–278. doi:https://doi.org/10.1016/j.aca.2006.04.064

Hjortenkrans, D., Bergbäck, B., & Häggerud, A. (2006). New metal emission patterns in road traffic environments. *Environmental Monitoring and Assessment, 117*, 85–98. https://doi.org/10.1007/s10661-006-7706-2.

Hjortenkrans, D. S. T., Bergback Bo, G., & Haggurd, A. V. (2007). Metal emissions from brake linings and tires: case studies of Stockholm, Sweden 1995/1998 and 2005. *Environmental Science & Technology, 41*(15), 5224–5230.

Hopke, P. K., Lamb, E. R., & Natusch, D. F. S. (1980). Multielemental characterization of urban roadway dust. *Environmental Science and Technology, 14*(2), 164–172. https://doi.org/10.1021/es60162a006.

IARC. (1990). *will-~ IARC monograhs on the evaluation of carcinogenic evaluation of carcinogenic risks to rumans, which met in Lyon*.

Jaishankar, M., Mathew, B. B., Shah, M. S., Krishna Murthy T.P., Sangeetha Gowda K.R. (2014). Biosorption of few heavy metal ions using agricultural wastes biosorption of few heavy metal ions using agricultural wastes, (March). doi:https://doi.org/10.12691/jephh-2-1-1.

Järup, L. (2003). Hazards of heavy metal contamination. *68*, 167–182. doi:https://doi.org/10.1093/bmb/ldg032.

Jean-Philippe, S. R., Labbé, N., Franklin, J. A., & Johnson, A. (2012). Detection of mercury and other metals in mercury contaminated soils using mid-infrared spectroscopy. *Proceedings of the International Academy of Ecology and Environmental Sciences, 2*(8), 139–149.

Jiries, A. G., Hussein, H. H., & Halaseh, Z. (2001). The quality of water and sediments of street runoff in Amman. *Jordan, 824*, 815–824. https://doi.org/10.1002/hyp.186.

Kadioğlu, Y. K., Üstündağ, Z., Solak, A. O., & Karabiyikoğlu, G. (2010). Sources of environmental pollution in Ankara (Turkey): geochemistry and traffic effects-PEDXRF Applications. *Spectroscopy Letters, 43*(3), 247–257. https://doi.org/10.1080/00387010903329391.

Kennedy, P., Sutherland, S. (2008). *Urban sources of copper, lead and zinc* (Vol. 0504).

Khairy, M. A., Barakat, A. O., Mostafa, A. R., & Wade, T. L. (2011). Multielement determination by flame atomic absorption of road dust samples in Delta Region, Egypt. *Microchemical Journal, 97*(2), 234–242. https://doi.org/10.1016/j.microc.2010.09.012.

Khalid, S., Shahid, M., Niazi, N. K., Murtaza, B., Bibi, I., & Dumat, C. (2017). A comparison of technologies for remediation of heavy metal contaminated soils. *Journal of Geochemical Exploration, 182*, 247–268. https://doi.org/10.1016/j.gexplo.2016.11.021.

Khan, A. B., & Kathi, S. (2014). Evaluation of heavy metal and total petroleum hydrocarbon contamination of roadside surface soil. *International journal of Environmental Science and Technology, 11*(8), 2259–2270. https://doi.org/10.1007/s13762-014-0626-8.

Kim, K. W., Myung, J. H., Ahn, J. S., & Chon, H. T. (1998). Heavy metal contamination in dusts and stream sediments in the Taejon area, Korea. *Journal of Geochemical Exploration, 64*(1-3–3 pt 1), 409–419. https://doi.org/10.1016/S0375-6742(98)00045-4.

Komarnicki, G. J. K. (2005). Lead and cadmium in indoor air and the urban environment. *Environmental Pollution, 136*(1), 47–61. https://doi.org/10.1016/j.envpol.2004.12.006.

Lau, W. M., & Wong, H. M. (1982). An ecological survey of lead contents in roadside dusts and soils in Hong Kong. *Environmental Research, 28*(1), 39–54. https://doi.org/10.1016/0013-9351(82)90152-9.

Li, X., Poon, C. S., & Liu, P. S. (2001). Heavy metal contamination of urban soils and street dusts in Hong Kong. *Applied Geochemistry, 16*(11–12), 1361–1368. https://doi.org/10.1016/S0883-2927(01)00045-2.

Li, Y., Gou, X., Wang, G., Zhang, Q., Su, Q., & Xiao, G. (2008). Heavy metal contamination and source in arid agricultural soil in central Gansu Province, China. *Journal of Environmental Sciences, 20*(5), 607–612. https://doi.org/10.1016/S1001-0742(08)62101-4.

Liang, X., Song, J., Duan, L., Yuan, H., Li, X., Li, N., et al. (2018). Source identification and risk assessment based on fractionation of heavy metals in surface sediments of Jiaozhou Bay, China. *Marine Pollution Bulletin, 128*, 548–556. https://doi.org/10.1016/j.marpolbul.2018.02.008.

Lin, Y., Han, P., Huang, Y., Yuan, G. L., Guo, J. X., & Li, J. (2017). Source identification of potentially hazardous elements and their relationships with soil properties in agricultural soil of the Pinggu district of Beijing, China: multivariate statistical analysis and redundancy analysis. *Journal of Geochemical Exploration, 173*, 110–118. https://doi.org/10.1016/j.gexplo.2016.12.006.

Loganathan, P., Vigneswaran, S., & Kandasamy, J. (2013). Road-deposited sediment pollutants: a critical review of their characteristics, source apportionment, and management. *Critical Reviews in Environmental Science and Technology, 43*(13), 1315–1348. https://doi.org/10.1080/10643389.2011.644222.

Lu, X., Wang, L., Lei, K., Huang, J., & Zhai, Y. (2009). Contamination assessment of copper, lead, zinc, manganese and nickel in street dust of Baoji, NW China. *Journal of Hazardous Materials, 161*(2–3), 1058–1062. https://doi.org/10.1016/j.jhazmat.2008.04.052.

Luo, Q., Zhang, X., Wang, H., & Qian, Y. (2005). Mobilization of phenol and dichlorophenol in unsaturated soils by non-uniform electrokinetics. *Chemosphere, 59*(9), 1289–1298. https://doi.org/10.1016/j.chemosphere.2004.11.043.

Ma, Y., Egodawatta, P., Mcgree, J., Liu, A., & Goonetilleke, A. (2016). Science of the total environment human health risk assessment of heavy metals in urban stormwater. *Science of the Total Environment, 557–558*, 764–772. https://doi.org/10.1016/j.scitotenv.2016.03.067.

Madany, I. M., & Akhter, M. S. (1994). THE correlations between heavy metals in residential indoor dust and, *20*(4), 483–492.

Mallampati, S. R., Mitoma, Y., Okuda, T., Simion, C., & Lee, B. K. (2015). Dynamic immobilization of simulated radionuclide 133Cs in soil by thermal treatment/vitrification with nanometallic Ca/CaO composites. *Journal of Environmental Radioactivity, 139*, 118–124. https://doi.org/10.1016/j.jenvrad.2014.10.006.

McBride, M. B. (1994). *Environmental chemistry of soils*. New York: Oxford University Press.

Miguel D. E., Llamas, J. F., Chacon, E., Berg, T., Larssen, S., Røyset, O., Vadset, M. (1997). Origin and patterns of distribution of trace elements in street dust: unleaded petrol and urban lead. *31*(17), 2733–2740.

Mingkui, Z., & Hao, W. (2009). Concentrations and chemical forms of potentially toxic metals in road-deposited sediments from di ff erent zones of Hangzhou, China. *Journal of Environmental Sciences, 21*(5), 625–631. https://doi.org/10.1016/S1001-0742(08)62317-7.

Momani, K. (2006). Partitioning of lead in urban street dust based on the particle size distribution and chemical environments. *Soil and Sediment Contamination, 15*(2), 131–146. https://doi.org/10.1080/15320380500506289.

Montagne, D., Cornu, S., Bourennane, H., Baize, D., Ratié, C., & King, D. (2007). Effect of agricultural practices on trace-element distribution in soil. *Communications in Soil Science and Plant Analysis, 38*(3–4), 473–491. https://doi.org/10.1080/00103620601174411.

Mudroch, A., & Duncan, G. A. (1986). Distribution of metals in different size fractions of sediment from the Niagara River. *Journal of Great Lakes Research, 12*(2), 117–126. https://doi.org/10.1016/S0380-1330(86)71706-1.

Muller. (1969). Index of geoaccumulation in sediments of the Rhine River. *Journal of Geology, 2*, 108–118.

Nagajyoti, P. C., Lee, K. D., & Sreekanth, T. V. M. (2010). Heavy metals, occurrence and toxicity for plants: a review. *Environmental Chemistry Letters, 8*(3), 199–216. https://doi.org/10.1007/s10311-010-0297-8.

Ndiokwere, C. L. (1984). A study of heavy metal pollution from motor vehicle emissions and its effect on soil in Iskenderun, north-east Mediterranean. *Environmental Pollution, 7*(1), 35–42. https://doi.org/10.1016/0143-148X(84)90035-1.

Nicholas Hewitt, C., & Candy, G. B. B. (1990). Soil and street dust heavy metal concentrations in and around Cuenca, Ecuador. *Environmental Pollution, 63*(2), 129–136. https://doi.org/10.1016/0269-7491(90)90063-I.

Perry, C. and Taylor, K. (2007). *Environmental Sedimentology.*

Prajapati, S., & Meravi, N. (2014). Heavy metal speciation of soil and Calotropis procera from thermal power plant area. *Proceedings of the International Academy of Ecology and Environmental Sciences, 4*(2), 68–71 http://www.iaees.org/publications/journals/piaees/articles/2014-4(2)/heavy-metal-speciation-of-soil.pdf.

Prakash, D., Gabani, P., Chandel, A. K., Ronen, Z., & Singh, O. V. (2013). Bioremediation: a genuine technology to remediate radionuclides from the environment. *Microbial Biotechnology, 6*(4), 349–360. https://doi.org/10.1111/1751-7915.12059.

Qishlaqi, A., & Moore, F. (2007). Statistical analysis of accumulation and sources of heavy metals occurrence in agricultural soils of Khoshk River Banks, Shiraz, Iran. *Environmental Sciences, 2*(5), 565–573.

Quiñonez-Plaza, A., Wakida, F. T., Temores-Peña, J., Rodriguez-Mendivil, D. D., Garcia-Flores, E., Pastrana-Corral, M. A., & Melendez-Lopez, S. G. (2017). Total petroleum hydrocarbons and heavy metals in road-deposited sediments in

Tijuana, Mexico. *Journal of Soils and Sediments, 17*(12), 2873–2886. https://doi.org/10.1007/s11368-017-1778-1.

Ramlan, M. N., & Badri, M. A. (1989). Heavy metals in tropical city street dust and roadside soils: a case of Kuala Lumpur, Malaysia. *Environmental Technology Letters, 10*(4), 435–444. https://doi.org/10.1080/09593338909384759.

Rashad Yaaqub, R., Davies, T. D., Jickells, T. D., & Miller, J. M. (1991). Trace elements in daily collected aerosols at a site in southeast England. *Atmospheric Environment Part A, General Topics, 25*(5–6), 985–996. https://doi.org/10.1016/0960-1686(91)90140-3.

Ravindra, K. (2004). Platinum group elements in the environment and their health risk. *318*(03), 1–43. doi:https://doi.org/10.1016/S0048-9697(03)00372-3

Romic, M., & Romic, D. (2003). Heavy metals distribution in agricultural topsoils in urban area. *Environmental Geology, 43*(7), 795–805. https://doi.org/10.1007/s00254-002-0694-9.

Rulkens, W. H., Tichy, R., & Grotenhuis, J. T. C. (1998). Remediation of polluted soil and sediment: perspectives and failures. *Water Science and Technology, 37*(8), 27–35. https://doi.org/10.1016/S0273-1223(98)00232-7.

Sabatini, R. C. K. and School, D. A. (1992). Transport and remediation of subsurface contaminants. In *American Chemical Society.* doi:https://doi.org/10.1016/0304-3894(93)85090-2.

Sartor, J. D. and Boyd, G. B.. (1972). *Water pollution aspects of street surface contaminants*. Washington.

Sayadi, M. H., & Rezaei, M. R. (2014). Impact of land use on the distribution of toxic metals in surface soils in Birjand city, Iran. *Proceedings of the International Academy of Ecology and Environmental Sciences, 4*(1), 18–29.

Sayyed, M. R. G., & Sayadi, M. H. (2011). Variations in the heavy metal accumulations within the surface soils from the Chitgar industrial area of Tehran. *Proceedings of the International Academy of Ecology and Environmental Sciences, 1*(1), 36–46.

Schiff, K. C., & Weisberg, S. B. (1999). Iron as a reference element for determining trace metal enrichment in Southern California coastal shelf sediments. *Marine Environmental Research, 48*(2), 161–176. https://doi.org/10.1016/S0141-1136(99)00033-1.

Schroeder, W, Dobson, H. M., & Kane, D. M. (1987). Toide Traes Elsinein is associated wiili, 1267–1285.

Schwar, M. J. R., Moorcroft, J. S., Laxen, D. P. H., Thompson, M. A. C. (1988). Baseline metal-in-dust concentrations in greater London sampling strategy. *68*, 25–43.

Semple, K. T., Reid, B. J., & Fermor, T. R. (2001). Impact of composting strategies on the treatment of soil contaminated with diesel fuel.pdf. *Environmental Pollution, 112*, 269–283.

Sezgin, N., Ozcan, H. K., Demir, G., Nemlioglu, S., & Bayat, C. (2004). Determination of heavy metal concentrations in street dusts in Istanbul E-5 highway. *Environment International, 29*(7), 979–985. https://doi.org/10.1016/S0160-4120(03)00075-8.

Shahid, M., Xiong, T., Masood, N., Leveque, T., Quenea, K., Austruy, A., et al. (2014). Influence of plant species and phosphorus amendments on metal speciation and bioavailability in a smelter impacted soil: a case study of food-chain contamination. *Journal of Soils and Sediments, 14*(4), 655–665. https://doi.org/10.1007/s11368-013-0745-8.

Solomon, R. L., & Hartford, J. W. (1976). Lead and cadmium in dusts and soils in a small urban community, *10*(8), 773–777.

Sridhara Chary, N., Kamala, C. T., & Samuel Suman Raj, D. (2008). Assessing risk of heavy metals from consuming food grown on sewage irrigated soils and food chain transfer. *Ecotoxicology and Environmental Safety, 69*(3), 513–524. https://doi.org/10.1016/j.ecoenv.2007.04.013.

Stone, M., & Marsalek, J. (1996). Trace metal composition and speciation in street sediment: Sault Ste. Marie, Canada. *Water, Air, and Soil Pollution, 87*(1–4), 149–169. https://doi.org/10.1007/BF00696834.

Su, Chao & Jiang, LiQin & Zhang, Wenjun. (2014). A review on heavy metal contamination in the soil worldwide: Situation, impact and remediation techniques. Environ. Skept. Crit.. 3. 24–38.

Tampouris, S., Papassiopi, N., & Paspaliaris, I. (2001). Removal of contaminant metals from fine grained soils, using agglomeration, chloride solutions and pile leaching techniques. *Journal of Hazardous Materials, 84*(2–3), 297–319. https://doi.org/10.1016/S0304-3894(01)00233-3.

Taylor, K. G., & Owens, P. N. (2009a). Sediments in urban river basins: a review of sediment – contaminant dynamics in an environmental system conditioned by human activities, 281–303. doi:https://doi.org/10.1007/s11368-009-0103-z

Taylor, K. G., & Owens, P. N. (2009b). Sediments in urban river basins: a review of sediment-contaminant dynamics in an environmental system conditioned by human activities. *Journal of Soils and Sediments, 9*(4), 281–303. https://doi.org/10.1007/s11368-009-0103-z.

Tchounwou, P. B., Yedjou, C. G., Patlolla, A. K., & Sutton, D. J. (2012). Molecular, clinical and environmental toxicology. *National Institutes of Health Public Access, 101*(August), 133–164. https://doi.org/10.1007/978-3-7643-8338-1.

Thoronton, I. (1991). Metal contamination of soils in urban areas. In Soils in the Urban Environment (eds P. *Bullock and P. J. Gregory), Chap.*, *4pp*(c), 47–75.

Tokalioğlu, Ş., & Kartal, Ş. (2006). Multivariate analysis of the data and speciation of heavy metals in street dust samples from the Organized Industrial District in Kayseri (Turkey). *Atmospheric Environment, 40*(16), 2797–2805. https://doi.org/10.1016/j.atmosenv.2006.01.019.

Venkatesha Raju, K., Somashekar, R. K., & Prakash, K. L. (2013). Spatio-temporal variation of heavy metals in Cauvery River basin. *Proceedings of the International Academy of Ecology and Environmental Sciences, 3*(1), 80.

Vos, H., & Janssen, M. (2008). EU-wide control measures to reduce pollution from WFD relevant substances copper and zinc in the Netherlands EU-wide control measures to reduce pollution from WFD relevant substances Copper and zinc in the Netherlands. *Public Health.*

Wade, K. J., Flanagan, J. T., Currie, A., & Curtis, D. J. (1980). Roadside gradients of lead and zinc concentrations in surface-dwelling invertebrates. *Environmental Pollution. Series B: Chemical and Physical, 1*(2), 87–93. https://doi.org/10.1016/0143-148X(80)90029-4.

Wakida, F. T. (2016). Soil mercury levels in the area surrounding the Cerro Prieto geothermal complex, Mexico. *Environmental Monitoring and Assessment, 188*, 1–11. https://doi.org/10.1007/s10661-016-5474-1.

Watanabe, M. E. (1997). Phytoremediation on the Brink of Commericialization. *Environmental Science & Technology, 31*(4), 182A–186A. https://doi.org/10.1021/es972219s.

Wei, B., & Yang, L. (2010). A review of heavy metal contaminations in urban soils, urban road dusts and agricultural soils from China. *Microchemical Journal, 94*(2), 99–107. https://doi.org/10.1016/j.microc.2009.09.014.

Wei, B., Jiang, F., Li, X., & Mu, S. (2010). Heavy metal induced ecological risk in the city of Urumqi, NW China. *Environmental Monitoring and Assessment, 160*(1–4), 33–45. https://doi.org/10.1007/s10661-008-0655-1.

Whiteley, J. D., & Murray, F. (2003). Anthropogenic platinum group element (Pt , Pd and Rh) concentrations in road dusts and roadside soils from Perth, Western Australia. *Science of the Total Environment, 317*(x), 121–135. https://doi.org/10.1016/S0048-9697(03)00359-0.

WHO. (2008). *Food standard programme codex Alimentarius commission 13th session.*

Wichmann, H., Anquandah, G. A. K., Schmidt, C., Zachmann, D., & Bahadir, M. A. (2007). Increase of platinum group element concentrations in soils and airborne dust in an urban area in. *Germany, 388*(x), 121–127. https://doi.org/10.1016/j.scitotenv.2007.07.064.

Wijesiri, B., Egodawatta, P., McGree, J., & Goonetilleke, A. (2015). Process variability of pollutant build-up on urban road surfaces. *Science of the Total Environment, 518–519*, 434–440. https://doi.org/10.1016/j.scitotenv.2015.03.014.

Winther, M., & Slento, E. (2010). In M. Winther & E. Slento (Eds.), *Heavy metal emissions for danish road transport*. Denmark: National Environmental Research Institute www.neri.dk.

Wołejko, E., Wydro, U., & Łoboda, T. (2016). The ways to increase efficiency of soil bioremediation. *Ecological Chemistry and Engineering S, 23*(1), 155–174. https://doi.org/10.1515/eces-2016-0011.

Wong, C. S. C., Li, X., & Thornton, I. (2006). Urban environmental geochemistry of trace metals. *142*. doi:https://doi.org/10.1016/j.envpol.2005.09.004

Xu, F., Qiu, L., Cao, Y., Huang, J., Liu, Z., Tian, X., Li, A., & Yin, X. (2016). Trace metals in the surface sediments of the intertidal Jiaozhou Bay, China: sources and contamination assessment. *Marine Pollution Bulletin, 104*(1–2), 371–378. https://doi.org/10.1016/j.marpolbul.2016.01.019.

Yáñez, L., Ortiz, D., Calderón, J., Batres, L., Carrizales, L., Mejía, J., Martínez, L., García-Nieto, E., & Díaz-Barriga, F. (2002). Overview of human health and chemical mixtures: problems facing developing countries. *Chemical Mixtures, 110*(suppl 6), 901–909. https://doi.org/10.1289/ehp.110-1241270.

Yang, P. G., Mao, R. Z., Shao, H. B., & Gao, Y. F. (2009). The spatial variability of heavy metal distribution in the suburban farmland of Taihang Piedmont Plain, China. *Comptes Rendus Biologies, 332*(6), 558–566. https://doi.org/10.1016/j.crvi.2009.01.004.

Yang, Nam, T., Nam, K., & Kim, Y. J. (2016). Characteristics of heavy metal contamination by anthropogenic sources in artificial lakes of urban environment. *KSCE Journal of Civil Engineering, 20*(1), 121–128. https://doi.org/10.1007/s12205-015-0534-6.

Yao, Z., Li, J., Xie, H., & Yu, C. (2012). Review on remediation technologies of soil contaminated by heavy metals. *Procedia Environmental Sciences, 16*, 722–729. https://doi.org/10.1016/j.proenv.2012.10.099.

Yassoglou, N., Kosmas, C., Asimakopoulos, J., & Kallianou, C. (1987). Heavy metal contamination of roadside soils in the Greater Athens area. *Environmental Pollution, 47*(4), 293–304. https://doi.org/10.1016/0269-7491(87)90149-7.

Yun, S. T., Choi, B. Y., & Lee, P. K. (2000). Distribution of heavy metals (cr, cu, zn, pb, cd, as) in roadside sediments, seoul metropolitan city, korea. *Environmental Technology (United Kingdom), 21*(9), 989–1000. https://doi.org/10.1080/09593332108618045.

Zereni, F. and Alt, F. (Ed.). (2006). *Palladium emissions in the environment*. Germany.

Zhang, Y. (2003). 100 years of Pb Deposition And Transport in soils in. *Transport*, 197–210.

Zhang, J., & Gao, X. (2015). Heavy metals in surface sediments of the intertidal Laizhou Bay, Bohai Sea, China: distributions, sources and contamination assessment. *Marine Pollution Bulletin, 98*(1–2), 320–327. https://doi.org/10.1016/j.marpolbul.2015.06.035.

Zheng, Y., Chen, T., & He, J. (2008). Relationship between heavy metals and soil minerals (Subject Editor: Stefan Norra) Multivariate Geostatistical Analysis of Heavy Metals in Topsoils from. *Soils, Section 2 Heavy Metals and Soil Minerals, 8*(1), 51–58. https://doi.org/10.1065/jss2007.08.245.

Zojaji, F. (2014). Bioaccumulation of chromium by Zea mays in wastewater-irrigated soil: an experimental study. *Proceedings of the International Academy of Ecology and Environmental Sciences, 4*(2), 62–67. https://doi.org/10.0000/issn-2220-8860-piaees-2014-v4-0007.

Publisher's note Springer Nature remains neutral with regard to jurisdictional claims in published maps and institutional affiliations.