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RESEARCH ARTICLE

Heavy Metal Concentrations In Particulate Matter In The Air: Toxicity, Health Risks And Sustainable Mitigation

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There are several air pollutants in the environment that include HM, O_3, VOCs, PM 10, PM 2. 5, CO, SO_2, and NO_x. PM10 particles are less than 10 m in diameter and have adverse effects on the human body as well as the environment and cause ecological consequences such as vision impairment and acid rain. Monitoring of HM in ambient air is vital due to their adverse effects on human health with some of them being classified as carcinogens including Ni, Cd, As, and Cr. The Government of India brought the National Clean Air Program (NCAP) to address the deteriorating quality of air. Continuous exposure to HM pollution is a significant threat to life as it gets accumulated in the food chain and leads to health risks. Bioremediation, especially using microbial biosorbents is a viable and sustainable approach for remediating HM contamination in areas and environments. Microbes use different metal sequestrations to improve metal biosorption to remove metals and metalloids from solutions by using the constituents of the biomass.

Keywords: Heavy Metals, Particulate Matters, Air Pollution, PM 10, PM 2.5, Toxic, Health Risks, biosorbent

1. Introduction

HM contamination is a serious environmental and public health hazard. HMs are high atomic weight and toxicity, and they are found in rocks, soils and water naturally but human activities, particularly industrial and commercial ones, also contribute to their release into the environment. It is well known that HMs are toxic for a long time. Other HMs such as zinc, copper, and nickel are crucial for human health even though they are also common in the environment [1]. Manganese is a representative of HMs since it composes about 0. 1% of the earth's crust.

HMs may be harmful when they come into contact with environmental factors and the food chain; for instance, methylmercury from mercury in water is particularly poisonous [2]. Chromium, a widely used metal in industry, is a carcinogen [3]. However, the benefits of some HMs are often outweighed by the risks they pose in physiological activities. Some of these HMs enter the human body through water, air, and food, and regulate different biological processes [4].

Lead, antimony, cadmium and thallium are all toxic HMs that are commonly used in industrial processes and contribute a lot of pollution to the atmosphere. Thallium in particular is associated with alopecia and has more serious effects when compared to other HMs [5].

Antimony and chromium exposures also enhance carcinogenicity [6] while lead exposure affects children's intellectual function [7]. Mercury leads to Minamata disease and cadmium results in itai-itai disease. HM toxicity affects several human body systems such as the cardiovascular system, skin, liver, and kidney systems, and the nervous system. People should minimize exposure to high HM emission areas to prevent health impacts.

1.1 HM in the Environment

Heavy metals are naturally present in the environment and essential for life, but their accumulation in organisms like lead, copper, nickel, chromium, arsenic, cadmium, and mercury can be harmful. [8]. Thallium is one of the most toxic HMs that occurs naturally and is also an industrial pollutant that puts a significant health burden on humans [9][10]. Antimony is highly toxic and is released through natural events and industrial activities at nanogram levels and causes respiratory disorders and other health effects [11][12]. In the form of Zn2+, it is an essential cofactor in many

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enzymes while higher levels are toxic depending on exposure; mining and smelting are the highest emitters of zinc [13]. Copper is essential for plant metabolism but toxic to plants in excess [14]. Nickel that is emitted into the environment from natural and man-made sources has several adverse effects on human body including cardiovascular and respiratory diseases [15][16]. Cobalt, while having some beneficial effects in smaller quantities, is highly toxic in large emissions [17]. The two forms of chromium are chromium (VI) which is highly toxic compared to chromium (III) and that industrial activities mainly release it [18]. Manganese is also present in the environment in sufficient amounts and is essential for life but may be toxic in high concentrations especially as used as petrol additive [19]. Lead is one of the non-biodegradable substances that are being introduced into the environment due to human activities and more so to children [20]. Mercury is highly toxic and is increasing due to human activities; in the marine environment it is methylated resulting in a potent neurological toxin [21][22]. Cadmium, released through natural and industrial processes, enters the water and food chain and has no useful function but causes human health hazards [23].

2. Literature Review

The atmosphere envelops the Earth, allowing life-sustaining solar energy to penetrate the planet's surface or water [24]. However, industrialization and urbanization during the Industrial Revolution led to a significant increase in particulate matter (PM) and heavy metals (HM) emissions, altering the natural atmosphere [25]. Swift industrialization and urbanization increased emissions from biomass burning and fossil fuel combustion [26].

Primary particles in the environment, such as organic and elemental carbon and soil-related particles, originate from biomass products and fossil fuel combustion and are relatively easier to identify and quantify than secondary particles [27]. HM, hazardous metallic elements with high densities, primarily enter the atmosphere through metal mining operations, sewage effluent discharge, metal-enriched sewage sludge, and air particulate deposition [28].

Environmental metals stem from both anthropogenic (industrial and vehicle emissions) and natural sources (volcanic activity, vegetation emissions, and dust resuspension) Iron and lead are common metals found in airborne particles, with sources including oil burning, re-suspended soil, and vehicular emissions [29].

PM pollution is a significant environmental concern due to its composition of liquid and solid components, including allergens, nitrates, sulfates, heavy metals, and polycyclic aromatic hydrocarbons (PAHs), which can lead to gene mutations and cancer [30]. PM is categorized based on size, with PM2.5 and PM10 being the main groups [31].

Road dust acts as a sink for contaminants from various sources, accumulating on road surfaces due to forces such as particle inertia, electrical charge impacts, Brownian diffusion, particle drag, and gravity [32]. PM sources include farming produce burning, transportation, construction, trash burning, coal mining, and incomplete fuel combustion, with transportation emissions being a significant contributor [33].

Urbanization and industrialization have led to a surge in vehicle numbers, contributing to high PM levels in urban environments [34]. PM adversely affects air quality, visibility, climate, and radiation forces [35]. HM associated with PM in road dust and ambient air poses significant health risks, with finer particles accumulating more HM due to their larger surface area [36].

Although HM constitutes only a small percentage of PM,[37] they can cause severe health impacts through inhalation, ingestion, and skin absorption [38]. HM has a propensity for bioaccumulation across the food chain, leading to cancer, immunological toxicity, neurotoxicity, and cardiotoxicity [39,40]. Given the harmful effects of HM in urban environments, analyzing HM concentrations in environmental PM and road dust is crucial for addressing related health concerns [41]. Similar studies have been conducted in India, China, and other countries [42].

2.1 Size distribution of PM and environmental concentrations of pollutants

PM10 concentration in Indian cities varies from 100 – 400 µg /m3 [44]. According to EPA in Lahore Pakistan the mean level of TSP is 606-678µg/m^3 [45]. The average annual TSP concentration in major cities in China is between 300 and 500 µg/m^3. TSP and PM10 concentration in Southeast Asia are high with annual mean concentrations between 100 and 400 µg/m^3 and 100 and 300 µg/m^3 respectively. On the other hand, yearly mean TSP concentrations in the region of Western Pacific, North America, and Western Europe (excluding China) are significantly lower and range from 20 to 80 µg/m^3 while PM10 amounts are from 10 to 55 µg/m^3 [46]. The concentrations of HM in PM vary between 30-35 µg/m^3 [47]. Potential soil contaminants include Sr, Se, As, Ba, V, Ca, K, Ni, Fe, Cr, Cd, Zn, Cu, and Mn.

2.2 Impacts of PM

Long-range transport of pollutants affects both the environment and human health, leading to issues like acid rain, climate change, and ozone formation. HMs such as Zn, Cd, Pb, along with base cations like Mg (2+), Ca (2+), K (+), Na (+), NH (4) +, NO (3-), SO$_4$

(2-), are deposited via wet and dry processes into ecosystems. While NH_4^+, NO_3^-, and SO_4^{2-} contribute to eutrophication and acidification, base cations help alleviate acidification and enhance nutrient cycling in soil. Despite their importance, HMs are toxic [48].

PM10 has been associated with respiratory health problems and coronary artery disease [49]. PM2. 5 is more dangerous and can even reach the inner part of the lungs [50]. Increased concentrations of coarse particles (PM2. 5-10) have also been shown to contribute to death [51]. Allergens are also present in some of the constituents in the road particles that are re-suspended [52]. The results indicate that small particles have a greater effect than large particles per unit mass [53]. Research in Finland and Germany highlights greater health impacts of fine and ultrafine particles on asthmatics [54]. Particle effects vary based on chemical composition.

2.3 PM pollution prevention and air quality oversight

2.3.1 Models of meteorology and air pollution dispersion

The Weather Research and Forecasting (WRF) modeling system, Regional Atmospheric Modeling System (RAMS), and MM5 modeling system are commonly used for weather forecasting [55].

MM5 is a non-hydrostatic, limited-area model designed to simulate mesoscale atmospheric circulation, while RAMS is a flexible numerical system developed by Colorado State University for predicting meteorological events [56].

2.3.2Methodology of remote sensing

Remote sensing is another approach with a wide range of applications regarding ecological contamination. It entails gathering data on the earth's surface without obtaining a physical sample or contacting it by employing sensors mounted on a platform at some distance from them [57]. A sensor detects the energy the earth reflects, and the data obtained can be presented as a computer image or a photograph. It was founded on the notion that the atmosphere impacts satellite photographs of the earth's surface in the solar spectrum, and the signal received by the satellite sensor was the sum of these impacts [58].

2.3.3Application of global positioning systems (GPS) and Geographic information systems (GIS)

GIS and GPS are essential for air quality monitoring. GIS gathers, analyzes, and disseminates geographic data, aiding in assessing quality of life. GPS receivers help fill spatial coordinate gaps in inventory data, determining emission points' precise positions [59]. GIS evaluates quality of life, informing local individuals and organizations, optimizing resource distribution for community growth [60]. GPS receivers are another beneficial instrument that state and local government organizations can utilize to remedy spatial coordinate gaps in point source inventory data [61]. It comprises satellite, control, and receiver parts, and the GPS receivers can be utilized to determine the precise position of emission-releasing points if access to the site is provided.

2.3.4Air Quality Monitoring Measures

Environmental authorities employ various regulatory methods to incentivize industrial facilities to reduce pollutants, including control and command strategies, pollution taxes, tradable permits, voluntary engagement programs, ecological performance ratings, and public disclosure programs.

2.3.5Implementation of the source apportionment technique

Identifying the sources of suspended particles is critical for efficient air quality management.

Receptor-oriented modeling is a widely used method for identifying the sources of suspended particles in the air [62].

The process includes developing a conceptual model, identifying possible sources, acquiring and examining particulate matter samples, and ensuring source classes with receptor models. It also quantifies source contributions, calculates profile modifications and precursor gases for secondary aerosols, and reconciles outcomes with source models and receptor information.

Effects of PM on human body

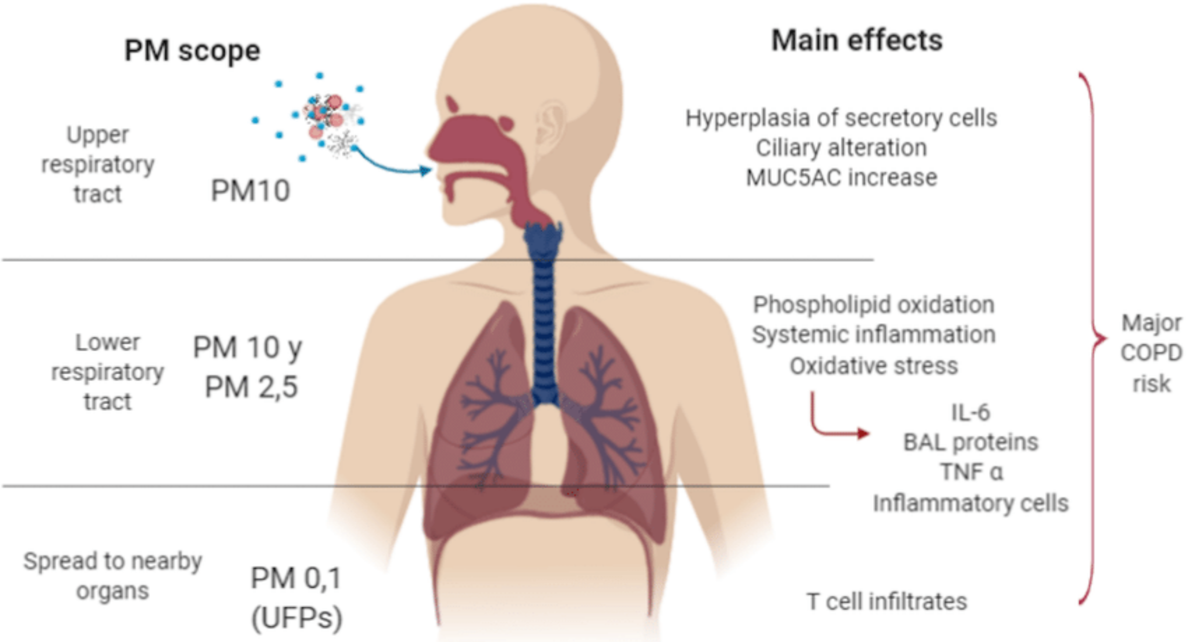


Figure 2 The effects of PM in human body.

Outdoor air pollution, including ozone and particulate matter (PM0, PM2, PM10), poses health risks, leading to respiratory diseases. Living in highly polluted areas increases hospitalization due to flu or respiratory syncytial virus (RSV). Recurrent exposure causes inflammation in immune cells, reducing functionality, and increasing susceptibility to respiratory infections.

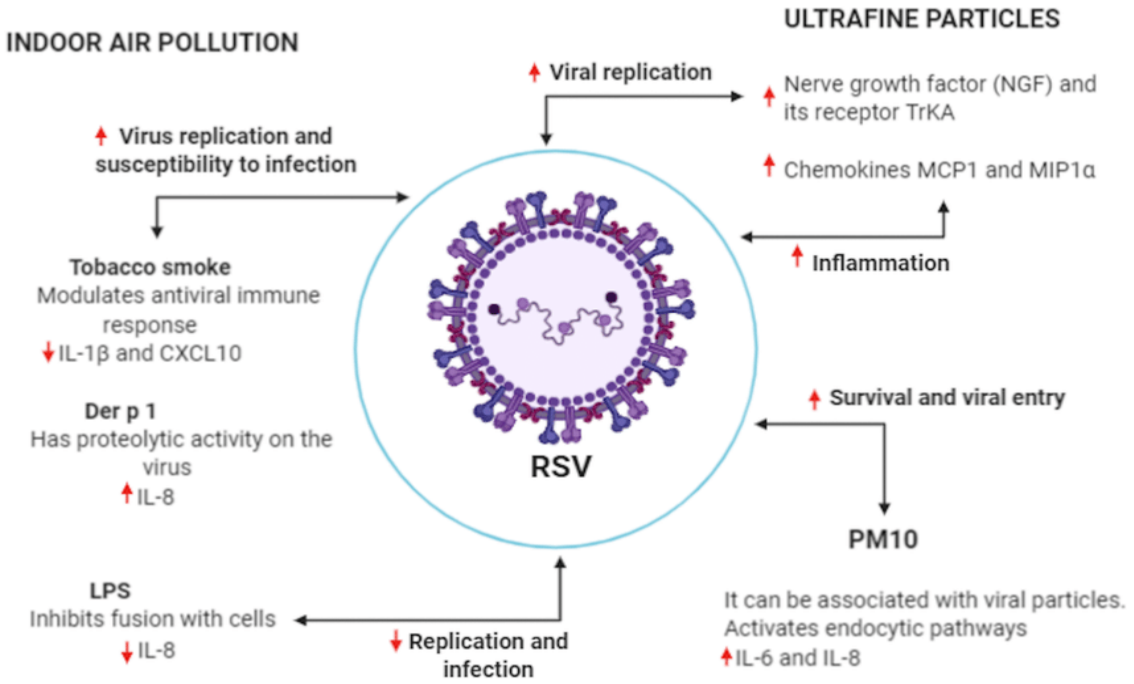


Figure 3 The impact air pollutant (PM) on Respiratory syncytial virus (RSV).

PM, categorized by size, can be deposited in the respiratory system, increasing vulnerability to COPD. Air pollutants like indoor pollution and PM10 affect respiratory tissues, influencing immune responses and promoting RSV infection. PM2.5, PM10, indoor pollution, and ozone adversely affect immune responses and cytokine production, promoting influenza infection.

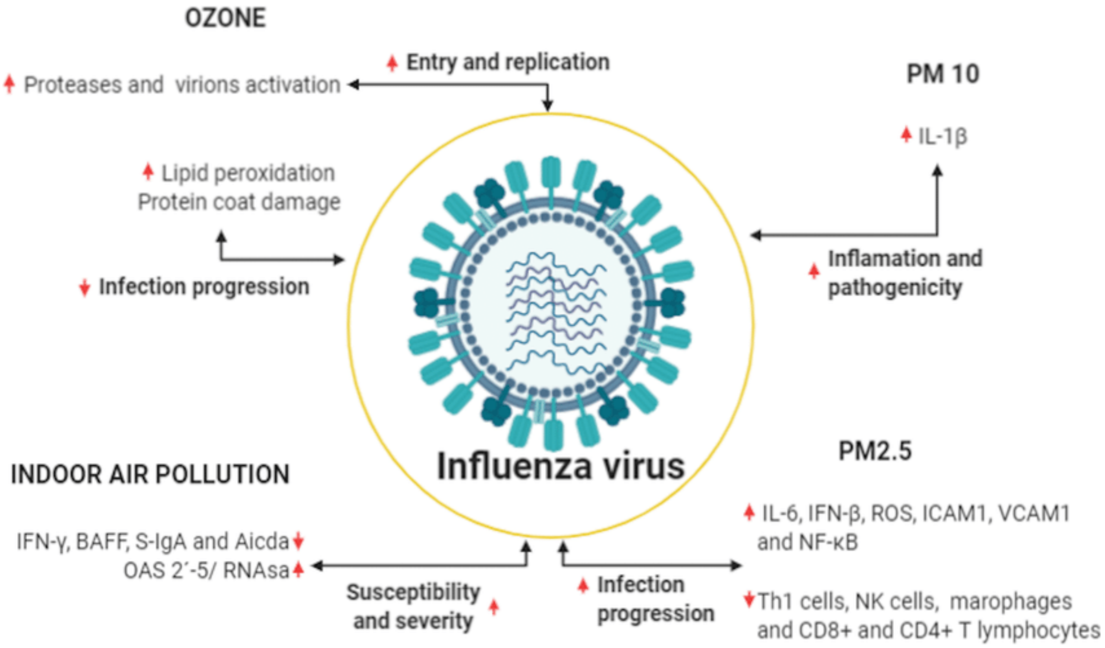


Figure 4 The impact air pollutant (PM) on influenza virus.

3. Effects of HM on human body

Chromium (VI) is a highly toxic compound, difficult to metabolize, and more toxic than chromium (III) [63, 64]. It enters cells through the membrane, leading to ROS generation and cellular damage [65, 66]. Associated with cancers and organ toxicity, particularly affecting kidneys, and liver [70, 71], it induces chromosomal abnormalities, DNA damage, and lung carcinogenesis [72].

Cadmium (II) causes acute and chronic damage to pulmonary and olfactory functions through inhalation or ingestion [73, 74]. Symptoms of ingested Cd (II) include abdominal pain, diminished consciousness, nausea, vomiting, and hepatic damage [75]. It's linked to lung adenocarcinomas, DNA strand breakage, and disruption of protein and nucleic acid synthesis [76].

Lead (II) emitted by natural and anthropogenic processes affects children through dust and chips in packaged food, impacting organs like the liver, kidneys, heart, and brain [77, 78]. It significantly impacts the neurological system, causing symptoms like memory loss, irritability, headaches, and poor attention. Table 1 shows the HM's source and impacts on health.

Table 1 The HM's source and Health impacts

HM	Source	Health impacts	References
Sb	Electronic device, smelting and mining activities, Abrasion of vehicle brake linings	loss of sleep, abdominal pain, nausea and vomiting, dizziness, headache,	**[79]**
Ba	Internal combustion engines	tremors, paralysis and even death, muscle weakness, irregular heartbeat, diarrhea, vomiting, nausea,	**[80]**
Ag	Sewage sludge, biocide, Photographic processing effluents	Coma or death, unconsciousness, confusion, staggering, drowsiness, respiratory irritation, headaches, breathing difficulty, dizziness	**[81]**
Fe	Automobile	Retinitis, choroiditis, conjunctivitis	**[82]**
Mn	Gasoline combustion, electroplating industries, auto workshops, automobile part corrosion, and Industrial dumping areas	Inhalation or contact causes damage to central nervous system	**[83]**
Co	motor vehicle tire wheel, Traffic emissions	Cause cancer, rhinitis and asthma, allergic dermatitis, toxic to the heart muscle.	**[84]**
Cr	Automobile part corrosion, industry dumping areas, power plant	Respiration problem, Rapid hair loss	**[85]**
V	Power plant	May cause liver or kidney damage, nausea, vomiting, abdominal pain and greenish discoloration of the tongue.	**[86]**
Sn	waste combustion, nonferrous metallurgy of Cu–Ni, coal burning, Combustion of liquid fuels	Stomachache, anemia, and liver and kidney problems. neurotoxicity, interstitial pneumonia, Mutagenicity/genotoxici ty:	**[87]**
As	Power plant, Copper metallurgy	Dermatitis (Skin irritation), Bronchitis	**[88]**

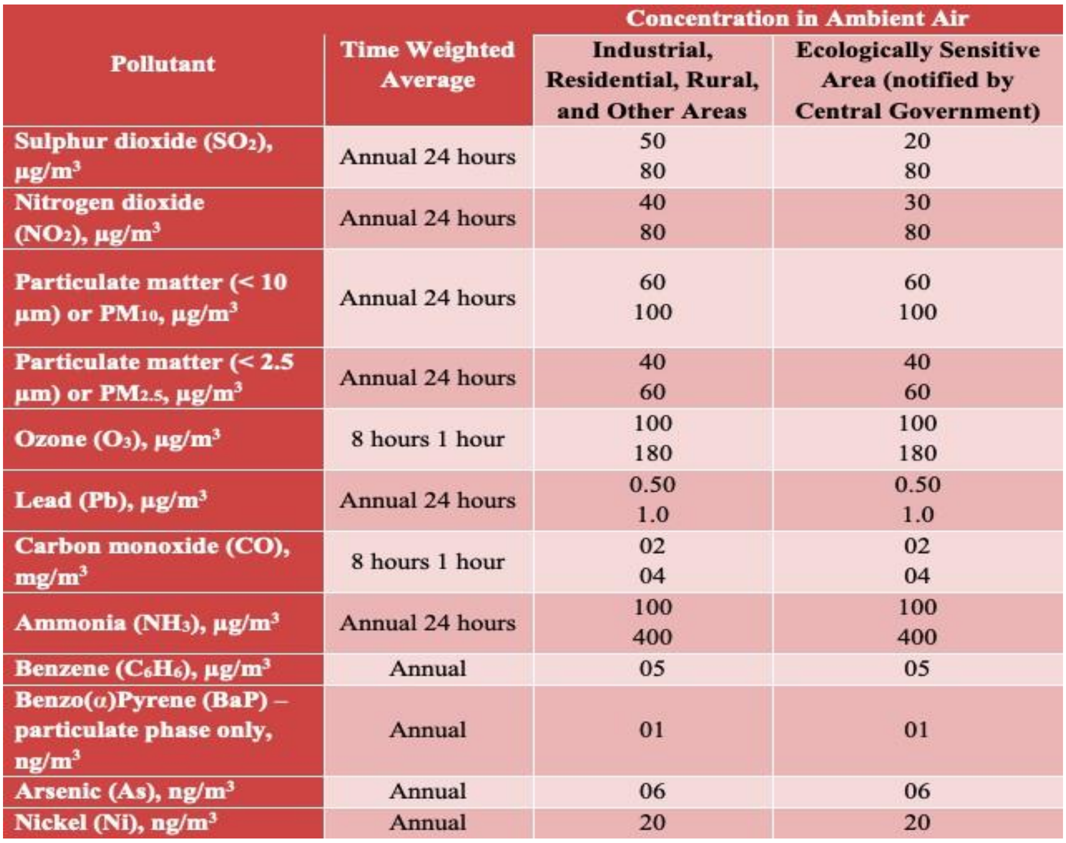
Bi	Nonferrous metallurgy of copper	hepatotoxicity, nephrotoxicity, gastrointestinal toxicity, neurotoxicity,	**[89]**
Ni	automobile part corrosion, industry dumping areas, power plant, fossil fuel combustion, brake linings, Abrasion of tire treads	Rapid hair fall, Throat and Stomach cancers, Lungs, Hepatotoxic, Genotoxic, Neurotoxic, mmunotoxic,	**[90]**
Cd	brake linings, Abrasion of tire treads	Cancer in bone marrow, Gastrointestinal disorder, Bronchitis, Kidney damage,	**[91]**
Zn	lubricating motor oil, and tires, fossil fuel combustion, tire and brake wear, Traffic exhaust,	cause damage to nervous membrane, Zinc fumes have corrosive effect on skin	**[92]**
Cu	tire and brake wear, Traffic exhaust	Intestinal irritation, Severe anaemia, Failure of kidney and Brain	**[93]**
Pb	Pigments, pesticides, fertilizers, mining and Pb ore smelting, brake linings, abrasion of tire treads, automobile emissions, Gasoline.	Mental retardation in children, Gastrointestinal damage, kidney, Liver	**[94]**
Hg	industrial uses, and mining, waste incineration, coal combustion,	Damage to nervous system	**[95]**

4. Allowable HM levels in ambient air-WHO air quality guidelines

Table 2. World Health Organization (WHO) air quality guidelines.

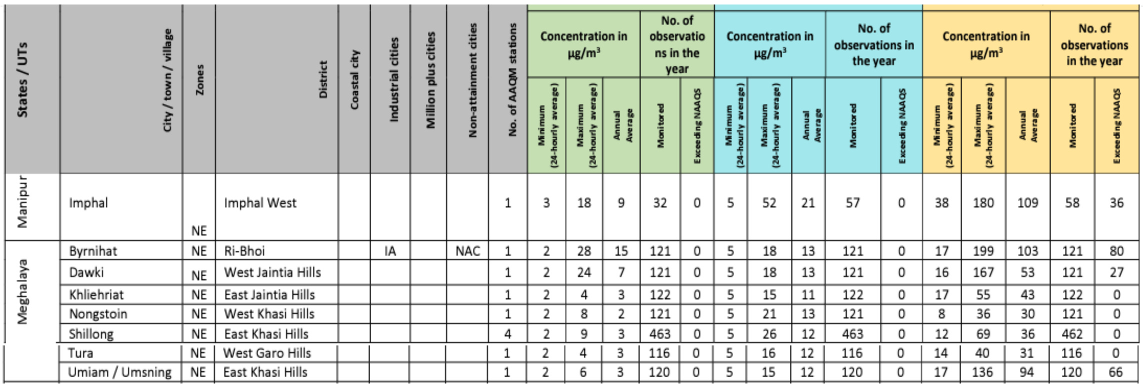
Table 2 shows the World Health Organization (WHO) air quality guidelines [96].

HM	Summer μgm^{-3}	Winter μgm^{-3}	Limit Value μgm^{-3}
Pb	0.5	0.5	0.5
Ni	0.061	0.067	0.00024
Fe	3.4	4.3	10000
Cu	0.2	0.2	100
Cr	0.309	0.354	0.012
Cd	0.022	0.026	0.0002
As	0.07	0.035	0.0006



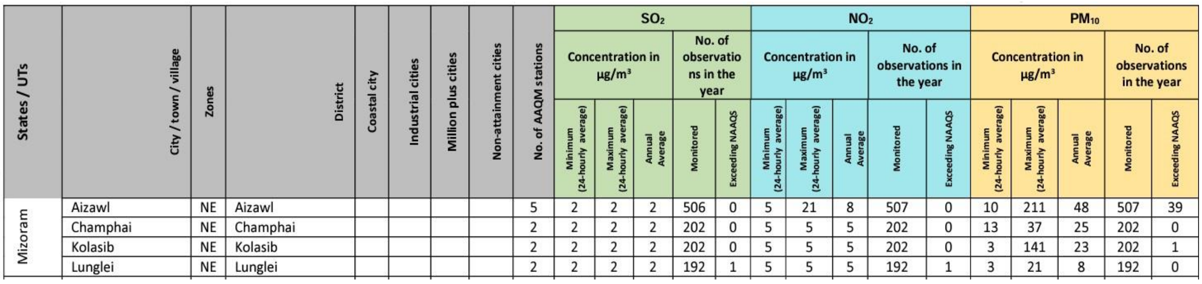
Pollutant	Time Weighted Average	Concentration in Ambient Air	
		Industrial, Residential, Rural, and Other Areas	Ecologically Sensitive Area (notified by Central Government)
Sulphur dioxide (SO_2), $\mu g/m^3$	Annual 24 hours	50 80	20 80
Nitrogen dioxide (NO_2), $\mu g/m^3$	Annual 24 hours	40 80	30 80
Particulate matter (< 10 µm) or PM_{10}, $\mu g/m^3$	Annual 24 hours	60 100	60 100
Particulate matter (< 2.5 µm) or $PM_{2.5}$, $\mu g/m^3$	Annual 24 hours	40 60	40 60
Ozone (O_3), $\mu g/m^3$	8 hours 1 hour	100 180	100 180
Lead (Pb), $\mu g/m^3$	Annual 24 hours	0.50 1.0	0.50 1.0
Carbon monoxide (CO), mg/m^3	8 hours 1 hour	02 04	02 04
Ammonia (NH_3), $\mu g/m^3$	Annual 24 hours	100 400	100 400
Benzene (C_6H_6), $\mu g/m^3$	Annual	05	05
Benzo(α)Pyrene (BaP) – particulate phase only, ng/m^3	Annual	01	01
Arsenic (As), ng/m^3	Annual	06	06
Nickel (Ni), ng/m^3	Annual	20	20

Figure 8 National Ambient Air Quality Standards (NAAQS) Revised in Relation to WHO Standards



States / UTs	City / town / village	Zones	District	Coastal city	Industrial cities	Million plus cities	Non-attainment cities	No. of AAQM stations	Concentration in $\mu g/m^3$			No. of observations in the year		Concentration in $\mu g/m^3$			No. of observations in the year		Concentration in $\mu g/m^3$			No. of observations in the year	
									Minimum (24-hourly average)	Maximum (24-hourly average)	Annual Average	Monitored	Exceeding NAAQS	Minimum (24-hourly average)	Maximum (24-hourly average)	Annual Average	Monitored	Exceeding NAAQS	Minimum (24-hourly average)	Maximum (24-hourly average)	Annual Average	Monitored	Exceeding NAAQS
Manipur	Imphal	NE	Imphal West					1	3	18	9	32	0	5	52	21	57	0	38	180	109	58	36
Meghalaya	Byrnihat	NE	Ri-Bhoi		IA		NAC	1	2	28	15	121	0	5	18	13	121	0	17	199	103	121	80
	Dawki	NE	West Jaintia Hills					1	2	24	7	121	0	5	18	13	121	0	16	167	53	121	27
	Khliehriat	NE	East Jaintia Hills					1	2	4	3	122	0	5	15	11	122	0	17	55	43	122	0
	Nongstoin	NE	West Khasi Hills					1	2	8	2	121	0	5	21	13	121	0	8	36	30	121	0
	Shillong	NE	East Khasi Hills					4	2	9	3	463	0	5	26	12	463	0	12	69	36	462	0
	Tura	NE	West Garo Hills					1	2	4	3	116	0	5	16	12	116	0	14	40	31	116	0
	Umiam / Umsning	NE	East Khasi Hills					1	2	6	3	120	0	5	15	12	120	0	17	136	94	120	66

Figure 6 The Ambient Air quality in selected cities for an example Manipur, Meghalaya, states of India (2019) [97].



States / UTs	City / town / village	Zones	District	Coastal city	Industrial cities	Million plus cities	Non-attainment cities	No. of AAQM stations	SO_2					NO_2					PM_{10}				
									Concentration in $\mu g/m^3$			No. of observations in the year		Concentration in $\mu g/m^3$			No. of observations in the year		Concentration in $\mu g/m^3$			No. of observations in the year	
									Minimum (24-hourly average)	Maximum (24-hourly average)	Annual Average	Monitored	Exceeding NAAQS	Minimum (24-hourly average)	Maximum (24-hourly average)	Annual Average	Monitored	Exceeding NAAQS	Minimum (24-hourly average)	Maximum (24-hourly average)	Annual Average	Monitored	Exceeding NAAQS
Mizoram	Aizawl	NE	Aizawl					5	2	2	2	506	0	5	21	8	507	0	10	211	48	507	39
	Champhai	NE	Champhai					2	2	2	2	202	0	5	5	5	202	0	13	37	25	202	0
	Kolasib	NE	Kolasib					2	2	2	2	202	0	5	5	5	202	0	3	141	23	202	1
	Lunglei	NE	Lunglei					2	2	2	2	192	1	5	5	5	192	1	3	21	8	192	0

Figure 7 shows the Ambient Air quality in selected city for an example Mizoram state of India (2019) [97].

The CPCB regulates ambient air quality standards through the NAAQS, first issued in 1982 and updated in 1994, 1998, and 2009, significantly reducing contaminants across the country.

NAAQS standards cover pollutants like Nickel, Arsenic, Benzopyrene, Benzene, Lead (Pb), Ammonia, Ozone (O_3), Carbon Monoxide (CO), Sulphur Dioxide (SO_2), Nitrogen Dioxide (NO_2), PM10, and PM2.5, monitored by the NAMP.

The National AQI, introduced in 2014, categorizes air quality into six levels, aiding public understanding. It focuses on eight pollutants, unlike NAAQS's twelve, calculating the highest concentration to reflect air quality directly.

5. HM biosorption by various microbial biosorbents

Unprocessed waste, water, or sludge from industrial or human activities release these toxins, posing risks like allergies, infections, and diseases to living beings. To combat this pollution, eco-friendly methods like biosorption using microbial biomass are crucial. Unlike traditional methods that generate chemical waste, biosorption is safer, cost-effective, and utilizes microbial metal sequestration systems for HM removal.

6. Conclusion

Several efficient and readily available biosorbents effectively remove HM pollutants at minimal cost. However, further research is necessary to identify the most suitable biosorbent for different applications, such as industrial wastewater treatment and soil remediation. Sustainable strategies are needed to optimize biosorbent selection, operational conditions, and HM removal techniques. Additionally, more research on biosorbent characteristics, like particle size and surface properties, is essential to improve biosorption studies. Furthermore, exploring the potential of microbial biomass for metal adsorption, particularly in wastewater and air industries, remains crucial.

References

1. Mohsen Soleimani, Nasibeh Amini, Babak Sadeghian, Dongsheng Wang, Liping Fang, Heavy metals and their source identification in particulate matter (PM2.5) in Isfahan City, Iran, Journal of Environmental Sciences, Volume 72,2018, Pages 166-175.
2. K.M. Rice, E.M. Walker, M. Wu, C. Gillette, E.R. Blough, Environmental mercury and its toxic effects, J. Prev. Med. Public Heal., 47 (2) (2014), pp. 74-83.
3. J.J. Coetzee, N. Bansal, E.M.N. Chirwa, Chromium in environment, its toxic effect from chromite-mining and ferrochrome industries, and its possible bioremediation, Expo. Heal. 12 (1) (2020), pp. 51-62.
4. N. Roohani, R. Hurrell, R. Kelishadi, R. Schulin, Zinc and its importance for human health: An integrative review, J. Res. Med. Sci., 18 (2013), pp. 144-157.
5. B. Karbowska, Presence of thallium in the

environment: sources of contaminations, distribution and monitoring methods, Environ. Monit. Assess. 188 (11) (2016).

6. H. Sun, J. Brocato, M. Costa, Oral chromium exposure and toxicity, Curr. Environ. Heal. Rep., 2 (3) (2015), pp. 295-303.
7. S. Hou, L. Yuan, P. Jin, B. Ding, N.a. Qin, L.i. Li, X. Liu, Z. Wu, G. Zhao, Y. Deng, A clinical study of the effects of lead poisoning on the intelligence and neurobehavioral abilities of children, Theor. Biol. Med. Model., 10 (1) (2013).
8. Hazrat Ali et al. Environmental Chemistry and Ecotoxicology of Hazardous Heavy Metals: Environmental Persistence, Toxicity, and Bioaccumulation, Journal of chemistry, vol. 2019, Article ID 6730305, 2019.
9. A.L.J. Peter, T. Viraraghavan, Thallium: a review of public health and environmental concerns, Environ. Int., 31 (4) (2005), pp. 493-501.
10. G. Kazantzis, Thallium in the environment and health effects, Environ. Geochem. Health, 22 (2000), pp. 275-280.
11. M. He, N. Wang, X. Long, C. Zhang, C. Ma, Q. Zhong, A. Wang, Y. Wang, A. Pervaiz, J. Shan, Antimony speciation in the environment: Recent advances in understanding the biogeochemical processes and ecological effects, J. Environ. Sci. (China), 75 (2019), pp. 14- 39.
12. S. Sundar, J. Chakravarty, Antimony toxicity, Int. J. Environ. Res. Public Health, 7 (2010), pp. 4267-4277.
13. X. Zhang, L. Yang, Y. Li, H. Li, W. Wang, B. Ye. Impacts of lead/zinc mining and smelting on the environment and human health in China, Environ. Monit. Assess. 184 (4) (2012), pp. 2261-2273.
14. G.G. Schwartz, D. Il'yasova, A. Ivanova, Urinary cadmium, impaired fasting glucose, and diabetes in the NHANES III, Diabetes Care, 26 (2) (2003), pp. 468-470.
15. M. Li, H. Pi, Z. Yang, R.J. Reiter, S. Xu, X. Chen, C. Chen, L. Zhang, M. Yang, Y. Li, P. Guo, G. Li, M. Tu, L.i. Tian, J. Xie, M. He, Y. Lu, M. Zhong, Y. Zhang, Z. Yu, Z. Zhou, Melatonin antagonizes cadmium-induced neurotoxicity by activating the transcription factor EB-dependent autophagy–lysosome machinery in mouse neuroblastoma cells, J. Pineal Res., 61 (3) (2016), pp. 353-369,
16. G. Genchi, A. Carocci, G. Lauria, M.S. Sinicropi, A. Catalano, Nickel: Human health and environmental toxicology, Int. J. Environ. Res. Public Health, 17 (3) (2020), p. 679.
17. J.L. Domingo, Cobalt in the environment and its toxicological implications, Rev. Environ. Contam. Toxicol., 108 (1989), pp. 105-132.
18. J.J. Coetzee, N. Bansal, E.M.N. Chirwa, Chromium in environment, its toxic effect from chromite-mining and ferrochrome industries, and its possible bioremediation, Expo. Heal., 12 (1) (2020), pp. 51-62.
19. S.L. O'Neal, W. Zheng, Manganese toxicity upon overexposure: a decade in review, Curr. Environ. Heal. Reports, 2 (3) (2015), pp. 315-328.
20. N. Loh, H.-P. Loh, L.K. Wang, M.-H.-S. Wang, Health effects and control of toxic lead in the environment, Nat. Resour. Control Process. 233–284 (2016).
21. K.M. Rice, E.M. Walker, M. Wu, C. Gillette, E.R. Blough, Environmental mercury and its toxic effects, J. Prev. Med. Public Heal., 47 (2) (2014), pp. 74-83.
22. B. Gworek, W. Dmuchowski, A.H. Baczewska-Dąbrowska, Mercury in the terrestrial environment: a review, Environ. Sci. Eur., 32 (1) (2020).
23. M.T. Hayat, M. Nauman, N. Nazir, S. Ali, N. Bangash, Environmental hazards of cadmium: past, present, and future, Cadmium Toxic. Toler. Plants Physiol. Remediat., 163–183 (2018).
24. Critchfield HJ (1987) General climatology. Prentice Hall of India Pvt. Ltd., New Delhi.
25. Ashton TS (1948) The industrial revolution: 1760–1830. Oxford University Press, London.
26. Chowdhury Z, Hughes LS, Salmon LG, Cass GR (2001) Atmospheric particle size and composition measurements to support light extinction calculations over the Indian ocean. J Geophys Res 106(22):28597.
27. Duffus JH (2002) Heavy metals: A meaningless term? Pure Appl Chem 74(5):793–807.
28. Shrivastav R (2001) Atmospheric heavy metal pollution: development of chronological records and geochemical monitoring. Resonance 2:62–68.
29. Harris FS (1976) Atmospheric aerosols: a literature survey of their physical characteristics and chemical composition. Report NASA CR-2626, National Aeronautics and Space Administration, Washington.
30. Sielicki P, Janik H, Guzman A, Namieśnik J. The Progress in Electron Microscopy Studies of Particulate Matters to Be Used as a Standard Monitoring Method for Air Dust Pollution. Critical Rev Analyt Chem. 2011;41(4):314–334.
31. Tuyen LH, Tue NM, Suzuki G, et al. Aryl hydrocarbon receptor mediated activities in road dust from a metropolitan area, Hanoi—Vietnam: Contribution of polycyclic aromatic hydrocarbons (PAHs) and human risk assessment. Sci Total Environ. 2014;491–492:246– 254.
32. Qadeer A, Saqib ZA, Ajmal Z, et al. Concentrations, pollution indices and health risk assessment of heavy metals in road dust from

two urbanized cities of Pakistan: Comparing two sampling methods for heavy metals concentration. Sustainable Cities and Society. 2020; 53:101959.

33. Aluko O, Noll KE. Deposition and Suspension of Large, Airborne Particles. Aerosol Science and Technology. 2006;40(7):503–513.
34. Hooftman N, Messagie M, Van Mierlo J, Coosemans T. A review of the European passenger car regulations – Real driving emissions vs local air quality. Renewable and Sustainable Energy Reviews. 2018;86:1–21.
35. Srimuruganandam B, Shiva Nagendra SM. Analysis and interpretation of particulate matter – PM10, PM2.5 and PM1 emissions from the heterogeneous traffic near an urban roadway. Atmos Pollut Res. 2010;1(3):184–194.
36. Choi DY, Jung S-H, Song DK, et al. Al-Coated Conductive Fibrous Filter with Low Pressure Drop for Efficient Electrostatic Capture of Ultrafine Particulate Pollutants. ACS Appl Mater Interfaces. 2017;9(19):16495–16504.
37. Du Y, Gao B, Zhou H, Ju X, Hao H, Yin S. Health Risk Assessment of Heavy Metals in Road Dusts in Urban Parks of Beijing, China. Procedia Environmental Sciences. 2013;18:299–309.
38. Li H, Qian X, Wang Q. Heavy Metals in Atmospheric Particulate Matter: A Comprehensive Understanding Is Needed for Monitoring and Risk Mitigation. Environ Sci Technol. 2013;47(23):13210–13211.
39. Najmeddin A, Keshavarzi B, Moore F, Lahijanzadeh A. Source apportionment and health risk assessment of potentially toxic elements in road dust from urban industrial areas of Ahvaz megacity, Iran. Environ Geochem Health. 2018;40(4):1187–1208.
40. Hu B, Xue J, Zhou Y, et al. Modelling bioaccumulation of heavy metals in soil-crop ecosystems and identifying its controlling factors using machine learning. Environ Poll. 2020;262:114308.
41. Roy S, Gupta SK, Prakash J, Habib G, Baudh K, Nasr M. Ecological and human health risk assessment of heavy metal contamination in road dust in the National Capital Territory (NCT) of Delhi, India. Environ Sci Pollut Res. 2019;26(29):30413–30425.
42. Wu Y, Lu B, Zhu X, et al. Seasonal Variations, Source Apportionment, and Health Risk Assessment of Heavy Metals in PM2.5 in Ningbo, China. Aerosol Air Qual Res. 2019;19(9):2083–2092.
43. Safiur Rahman M, Khan MDH, Jolly YN, Kabir J, Akter S, Salam A. Assessing risk to human health for heavy metal contamination through street dust in the Southeast Asian Megacity: Dhaka, Bangladesh. Sci Total Enviro. 2019;660:1610–1622.
44. Sharma M, Pandey R, Maheshwari M, Sengupta B, Misra A, Shukla BP (2003) Air quality index and its interpretation for city of Delhi. Int J Energy Clean Environ 3(4):67–75.
45. Smith DJT, Harrison Roy M, Luhana L, Pio Casimiro A, Castro LM, Tariq MN, Hayat S, Quraishi T (1996) Concentrations of particulate airborne polycyclic aromatic hydrocarbons and metals collected in Lahore, Pakistan. Atmos Environ 30(23):4031–4040.
46. Sivertsen B (2002) Presenting air quality data. NILU-F 6/2002, National training course on air quality monitoring and management, Norwegian Institute for Air Research, Kjeller, Norway
47. Schroeder WH, Dohson M, Kane DM, Johnson ND (1987) Toxic trace elements associated with air borne particulate matter: a review. J Air Pollut Control Assoc 33:1267–1285.
48. Schwartz SE, Slinn WGN (1992) Precipitation scavenging and atmosphere-surface exchange processes. Hemisphere Publication, Washington.
49. Abbey DE, Nishino N, McDonnell WF, Burchette RJ, Knutsen SF, Beeson WL, Yang JX (1999) Long-term inhalable particles and other air pollutants related to mortality in non-smokers. AM J Resp Crit Care Med 159:373–382.
50. Schwartz J, Dockery DW, Neas LM (1996) Is daily mortality associated specifically with fine particles? J Air Waste Manage Assoc 46:927–939
51. Castillejos M, Borja-Aburto VH, Dockery DW, Gold DR, Loomis D (2000) Airborne coarse particles and mortality. Inhal Toxicol 12:61–72
52. Miguel AG, Cass GR, Glovsky MM, Weiss J (1999) Allergens in paved road dust and airborne particles. Environ Sci Technol 33:4159–4168
53. Oberdörster G (2001) Pulmonary effects of inhaled ultrafine particles. Int Arch Occup Environ Health 74:1–8
54. Wichmann HE, Peters A (2000) Epidemiological evidence of the effects of ultrafine particle exposure. Philos Trans R Soc Lond A 358:2751–2769.
55. Grell GA, Dudhia J, Staufer DR (1995) A description of the fifth-generation Penn State/NCAR Mesosscale Model (MM5), NCAR Technical Note, 6-1995.
56. Yerramilli A, Rao Dodla VB, Yerramilli S (2011) Air pollution, modeling and GIS based decision support systems for air quality risk assessment. In: Farhad N (ed) Advanced air pollution, vol. 2. Cambridge: MIT Press, Massachusetts, pp 23–47.
57. Liu CH, Chen AJ, Liu GR (1996) An image-based retrieval algorithm of aerosol

characteristics and surface reflectance for satellite images. Int J Remote Sens 17(17):3477–3500

58. King MD, Kaufman YJ, Tanre D, Nakajima T (1999) Remote sensing of tropospheric aerosol from space: past, present and future. Bull Am Meterol Soc 80:2229–2259
59. Dueker KJ, Kjerne D (1989) Multipurpose cadastre: terms and definitions. American Society for Photogrammetry and Remote Sensing, Falls Church, p 12.
60. Hein L, Van Koppen K, De Groot RS, Van Ierland EC (2006) Spatial scales, stakeholders and the valuation of ecosystem services. J Ecol Econ 57(2):209–228.
61. Alexis A (2002) Use of GIS and GPS as a QA tool in emission inventory. In: International emission inventory conference, Atlanta, GA
62. Ke L, Liu W, Wang Y, Russell AG, Edgerton ES, Zheng M (2008) Comparison of PM2.5 source apportionment using positive matrix factorization and molecular marker-based chemical mass balance. Sci Total Environ 394:290–302.
63. Singh, V.; Singh, J.; Mishra, V. Development of a cost-effective, recyclable and viable metal ion doped adsorbent for simultaneous adsorption and reduction of toxic Cr (VI) ions. J. Environ. Chem. Eng. 2021, 9, 105124.
64. Bokare, A.D.; Choi, W. Advanced oxidation process based on the Cr(III)/Cr(VI) redox cycle. Environ. Sci. Technol. 2011, 45, 9332–9338.
65. Singh, V.; Mishra, V. Sustainable reduction of Cr (VI) and its elemental mapping on chitosan coated citrus limetta peels biomass in synthetic wastewater. Sep. Sci. Technol. 2021, 57, 1609–1626.
66. Singh, V.; Singh, M.P.; Mishra, V. Bioremediation of toxic metal ions from coal washery effluent. Desalination Water Treat. 2020, 197, 300–318.
67. Singh, V.; Singh, N.; Yadav, P.; Mishra, V. Removal of Hexavalent Chromium from Aqueous Media Using Eco-Friendly and Cost-Effective Biological Methods. In Biosorption for Wastewater Contaminants; Selvasembian, R., Singh, P., Eds.; John Wiley & Sons: Hoboken, NJ, USA, 2021; pp. 246–268.
68. Wakeel, A.; Xu, M.; Gan, Y. Chromium-Induced Reactive Oxygen Species Accumulation by Altering the Enzymatic Antioxidant System and Associated Cytotoxic, Genotoxic, Ultrastructural, and Photosynthetic Changes in Plants. Int. J. Mol. Sci. 2020, 21, 728.
69. Cohen, M.D.; Kargacin, B.; Klein, C.B.; Costa, M. Mechanisms of chromium carcinogenicity and toxicity. Crit. Rev. Toxicol. 1993, 23, 255–281.
70. Kim, E.; Na, K.J. Nephrotoxicity of sodium dichromate depending on the route of administration. Arch. Toxicol. 1991, 65, 537–541.
71. Gumbleton, M.; Nicholls, P.J. Dose-response and time-response biochemical and histological study of potassium dichromate-induced nephrotoxicity in the rat. Food Chem. Toxicol. 1988, 26, 37–44.
72. Wise, S.S.; Holmes, A.L.; Ketterer, M.E.; Hartsock, W.J.; Fomchenko, E.; Katsifis, S.P.; Thompson, W.D.; Wise, J.P. Chromium is the proximate clastogenic species for lead chromate-induced clastogenicity in human bronchial cells. Mutat. Res. 2004, 560, 79–89.
73. Genchi, G.; Sinicropi, M.S.; Lauria, G.; Carocci, A.; Catalano, A. The Effects of Cadmium Toxicity. Int. J. Environ. Res. Public Health 2020, 17, 3782.
74. Rahimzadeh, M.R.; Rahimzadeh, M.R.; Kazemi, S.; Moghadamnia, A.K. Cadmium toxicity and treatment: An update. Caspian J. Intern. Med. 2017, 8, 135–145.
75. Baselt, R.C.; Cravey, R.H. Disposition of Toxic Drugs and Chemicals in Man, 4th ed.; Year Book Medical Publishers: Chicago, IL, USA, 1995; pp. 105–107.
76. Waalkes, M.P.; Berthan, G. (Eds.) Handbook on Metal-Ligand Interactions of Biological Fluids; Marcel Dekker: New York, NY, USA, 1995; Volume 2, pp. 471–482.
77. Lanphear, B.P.; Matte, T.D.; Rogers, J.; Clickner, R.P.; Dietz, B.; Bornschein, R.L.; Succop, P.; Mahaffey, K.R.; Dixon, S.; Galke, W.; et al. The contribution of lead-contaminated house dust and residential soil to children's blood lead levels. A pooled analysis of 12 epidemiologic studies. Environ. Res. 1998, 79, 51–68.
78. Flora, S.J.S.; Flora, G.J.S.; Saxena, G. Environmental occurrence, health effects and management of lead poisoning. In Lead: Chemistry, Analytical Aspects, Environmental Impacts and Health Effects; Cascas, S.B., Sordo, J., Eds.; Elsevier Publication: Amsterdam, The Netherlands, 2006; pp. 158–228.
79. Bech J, Corrales I, Tume P, Barceló J, Duran P, Roca N, Poschenrieder C (2012) Accumulation of antimony and other potentially toxic elements in plants around a former antimony mine located in the Ribes Valley (Eastern Pyrenees). J Geochem Explor 113:100–105.
80. Zahri, Khadijah Nabilah Mohd, Claudio Gomez-Fuentes, Suriana Sabri, Azham Zulkharnain, Khalilah Abdul Khalil, Sooa Lim, and Siti Aqlima Ahmad. 2021. "Evaluation of Heavy Metal Tolerance Level of the Antarctic Bacterial Community in Biodegradation of Waste Canola Oil" Sustainability 13, no. 19: 10749.

81. Hajar EWI, Sulaimanb AZB, Sakinahb AMM (2014) Assessment of heavy metals tolerance in leaves, stems and flowers of Stevia rebaudiana plant. Procedia Environ Sci 20:386–393.
82. El-Hasan T, Al-Omari H, Jiries A, Al-Nasir F (2002) Cypress tree (Cupressus Semervirens L.) bark as an indicator for heavy metal pollution in the atmosphere of Amman City, Jordan. Environ Int 28:513–519.
83. Shi G, Chen Z, Teng J, Bi C, Zhou D, Sun C, Li Y, Xu S (2012) Fluxes, variability and sources of cadmium, lead, arsenic and mercury in dry atmospheric depositions in urban, suburban and rural areas. Environ Res 113:28–32.
84. Acosta-Rodríguez, Ismael, Adriana Rodríguez-Pérez, Nancy Cecilia Pacheco-Castillo, Erika Enríquez-Domínguez, Juan Fernando Cárdenas-González, and Víctor-Manuel Martínez- Juárez. 2021. "Removal of Cobalt (II) from Waters Contaminated by the Biomass of Eichhornia crassipes" Water 13, no. 13: 1725.
85. Cucu-Man S, Steinnes S (2013) Analysis of selected biomonitors to evaluate the suitability for their complementary use in monitoring trace element atmospheric deposition, Environ. Monit Assess 185:7775–7791.
86. Altaf, Muhammad Ahsan, Huangying Shu, Yuanyuan Hao, Yan Zhou, Muhammad Ali Mumtaz, and Zhiwei Wang. 2022. "Vanadium Toxicity Induced Changes in Growth, Antioxidant Profiling, and Vanadium Uptake in Pepper (Capsicum annum L.) Seedlings" Horticulturae 8, no. 1: 28.
87. Nriagu J, Pacyna J (1988) Quantitative assessment of worldwide contamination of air, water and soils by trace metals. Nature 333:134–139
88. Chu, Ha T. T., Tu V. Vu, Tam K. B. Nguyen, and Ha T. H. Nguyen. 2019. "Accumulation of Arsenic and Heavy Metals in Native and Cultivated Plant Species in a Lead Recycling Area in Vietnam" Minerals 9, no. 2: 132.
89. He, Ying, Li Ma, Liya Zhou, Guanhua Liu, Yanjun Jiang, and Jing Gao. 2020. "Preparation and Application of Bismuth/MXene Nano-Composite as Electrochemical Sensor for Heavy Metal Ions Detection" Nanomaterials 10, no. 5: 866.
90. Kummer U, Pacyna J, Pacyna E, Friedrich R (2009) Assessment of heavy metal releases from the use phase of road transport in Europe. Atmos Environ 43:640–647.
91. Genchi, Giuseppe, Maria Stefania Sinicropi, Graziantonio Lauria, Alessia Carocci, and Alessia Catalano. 2020. "The Effects of Cadmium Toxicity" International Journal of Environmental Research and Public Health 17, no. 11: 3782.
92. Abedi, Tayebeh, Shahin Gavanji, and Amin Mojiri. 2022. "Lead and Zinc Uptake and Toxicity in Maize and Their Management" Plants 11, no. 15: 1922.
93. Fujiwara FG, Gómez DR, Dawidowskia L, Perelman P, Faggi A (2011) Metals associated with airborne particulate matter in road dust and tree bark collected in a megacity (Buenos Aires, Argentina). Ecol Indic 11:240–247.
94. Ungureanu, Elena L., Andreea L. Mocanu, Corina A. Stroe, Denisa E. Duță, and Gabriel Mustățea. 2023. "Assessing Health Risks Associated with Heavy Metals in Food: A Bibliometric Analysis" Foods 12, no. 21: 3974.
95. Abd Elnabi, Manar K., Nehal E. Elkaliny, Maha M. Elyazied, Shimaa H. Azab, Shawky A. Elkhalifa, Sohaila Elmasry, Moustafa S. Mouhamed, Ebrahim M. Shalamesh, Naira A. Alhorieny, Abeer E. Abd Elaty, and et al. 2023. "Toxicity of Heavy Metals and Recent Advances in Their Removal: A Review" Toxics 11, no. 7: 580.
96. Morakinyo, Oyewale Mayowa, Murembiwa Stanley Mukhola, and Matlou Ingrid Mokgobu. 2021. "Health Risk Analysis of Elemental Components of an Industrially Emitted Respirable Particulate Matter in an Urban Area" International Journal of Environmental Research and Public Health 18, no. 7: 3653.
97. National ambient air quality status and trends 2019, Central pollution control board, Government of India., 2020.
98. Gupta V., Rastogi A. Biosorption of lead from aqueous solutions by green algae Spirogyra species: Kinetics and equilibrium studies. J. Hazard. Mater. 2008; 152:407–414.
99. Ungureanu G., Santos S., Boaventura R., Botelho C. Biosorption of antimony by brown algae S. muticum and A. nodosum. Environ. Eng. Manag. J. 2015; 14:455–463.
100. Hansen H.K., Ribeiro A., Mateus E. Biosorption of arsenic (V) with Lessonia nigrescens. Miner. Eng. 2006; 19:486–490.
101. Yalçın S., Sezer S., Apak R. Characterization and lead (II), cadmium (II), nickel (II) biosorption of dried marine brown macro algae Cystoseira barbata. Environ. Sci. Pollut. Res. 2012;19:3118–3125
102. Romera E., González F., Ballester A., Blázquez M., Munoz J. Comparative study of biosorption of heavy metals using different types of algae. Bioresour. Technol. 2007;98:3344– 3353
103. Fu Y.Q., Li S., Zhu H.Y., Jiang R., Yin L.F. Biosorption of copper(II) from aqueous solution by mycelial pellets of Rhizopus oryzae. Afr. J. Biotechnol. 2012; 11:1403–1411.
104. Das D., Das N., Mathew L. Kinetics, equilibrium and thermodynamic studies on biosorption of

AG(I) from aqueous solution by macrofungus Pleurotus platypus. J. Hazard. Mater. 2010; 1:765–774.

105. Iqbal M., Edyvean R. Biosorption of lead, copper and zinc ions on loofa sponge immobilized biomass of Phanerochaete chrysosporium. Miner. Eng. 2004; 17:217–223.

106. Akar T., Tunali S., Kiran I. Botrytis cinerea as a new fungal biosorbent for removal of Pb(II) from aqueous solutions. Biochem. Eng. J. 2005; 25:227–235.

107. Dursun A., Uslu G., Cuci Y., Aksu Z. Bioaccumulation of copper (II), lead (II) and chromium (VI) by growing Aspergillus niger. Process Biochem. 2003; 38:1647–1651.

108. Teclu D., Tivchev G., Laing M., Wallis M. Bioremoval of arsenic species from contaminated waters by sulphate-reducing bacteria. Water Res. 2008; 42:4885–4893.

109. Rajkumar M., Freitas H. Influence of metal resistant-plant growth-promoting bacteria on the growth of Ricinus communis in soil contaminated with heavy metals. Chemosphere. 2008; 71:834–842.

110. Kang S., Lee J., Kim K. Metal removal from wastewater by bacterial sorption: Kinetics and competition studies. Environ. Technol. 2005; 26:615–624.

111. Puyen Z.M., Villagrasa E., Maldonado J., Diestra E., Esteve I., Solé A. Biosorption of lead and copper by heavy-metal tolerant Micrococcus luteus de2008. Bioresour. Technol. 2012; 126:233–237.

112. Haq F., Butt M., Ali H., Chaudhary H.J. Biosorption of cadmium and chromium from water by endophytic Kocuria rhizophila: Equilibrium and kinetic studies. Desalination Water Treat. 2015; 2015:1–13.

113. Kang C.-H., Oh S.J., Shin Y., Han S.-H., Nam I.-H., So J.-S. Bioremediation of lead by ureolytic bacteria isolated from soil at abandoned metal mines in South Korea. Ecol. Eng. 2015; 74:402–407.

114. Kim I.H., Choi J.-H., Joo J.O., Kim Y.-K., Choi J.-W., Oh B.-K. Development of a microbe-zeolite carrier for the effective elimination of heavy metals from seawater. J. Microbiol. Biotechnol. 2015; 25:1542–1546.

115. Zouboulis A., Loukidou M., Matis K. Biosorption of toxic metals from aqueous solutions by bacteria strains isolated from metal-polluted soils. Process Biochem. 2004; 39:909–916.

116. Sinha A., Pant K.K., Khare S.K. Studies on mercury bioremediation by alginate immobilized mercury tolerant Bacillus cereus cells. Int. Biodeterior. Biodegrad. 2012; 71:1–8.