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Review

Environmental pollution indices: a review on concentration of heavy metals in air, water, and soil near industrialization and urbanisation

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Abstract
Current industrial operations pollute the world's land, water, and air with heavy metals. Metals' environmental behaviour and geographical distribution near the industrial production. Heavy metal contamination potential was assessed using geoaccumulation index, enrichment factor, and other criteria. Heavy metal concentrations have increased due to industrial waste, geochemical shifts, agriculture, and mining. Modifying cell structure, heavy metals can harm and cause cancer. We need to develop and conduct comprehensive monitoring to determine if industrial production and mining is causing elevated heavy metal levels nearby area in the zone. This review shares contemporary heavy metal contamination on its nature, origin, and extent.

Keywords Environmental · Contamination criteria · Heavy metals · Toxicity · Indices

1 Introduction

Increased industrialization, exploitation of natural and mineral resources, and unsustainable societal behaviours have resulted in widespread environmental degradation on a global scale. Polluting the environment and subsoil pollution is a result of the direct disposal of urban and industrial pollutants into pits dug in the ground [1–3]. Water pollution has emerged as a major concern due to the importance of having access to clean drinking water for both the environment and human well-being [3–6]. Heavy metals from rapid industrialization and urbanisation have accumulated in urban soil, water, sediment, roadway dust, and creatures [7–9]. The toxicity and perceived permanency of heavy metal contaminations in the environment have sparked growing concern [10, 11]. High concentrations of these indestructible and non-biodegradable metals are hazardous to all forms of life. Cadmium (Cd), Chromium (Cr), Lead (Pb), Zinc (Zn), Iron (Fe) and Copper (Cu) are common heavy metals to potential dangers and occurrences in polluted soils [3–12]. Heavy metals may accumulate to dangerous concentrations under specific environmental conditions, causing ecological damage [13–15]. Several indices have been established over the past few decades to evaluate geochemical accumulation and pollution intensities in soil and sediment [16, 17]. Most of the indices evaluate soil buildup or contamination relative to some standard metal content. Soil erosion, the greenhouse effect, and heavy metal contamination are only some of the environmental problems that have resulted from agriculture's excessive use of its resources. Heavy metal contamination of agricultural soils has long been recognised as a major problem in this field [18].

Air, noise, and water pollution are the principal environmental pollutants. Point and non-point water pollution exist. Factory, sewage, power plant, underground coalmine, and oil well water pollution sources may be monitored and tracked. Non-point sources, on the other hand, arise from many contaminating activities that are hard to control. Non-point

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sources include storm water drainage from lawns, parking lots, streets, etc. that ultimately reaches major water sources, agricultural runoff of fertilisers from farm animals and crop land, urban runoffs, air pollutants washed or deposited to earth, and so on. Similarly, the main cause of air pollution is fossil fuel burning which emit sulphur dioxide and particulates. Ozone is produced in the troposphere by nitrogen oxides and organic vapours reacting with sunlight [19].

Urban regions have considerable environmental pollution due to the large number of pollutants and polluted. Air pollution causes illness, pain, and cognitive and physical decline. Urban air pollution may harm children and immunocompromised individuals. Urban air pollution harms buildings and materials, increasing maintenance costs and reducing aesthetics. Human health is harmed by water pollution. The water dilemma involves groundwater contamination. Groundwater provides drinking water in many areas. The upper soil layers of the aquifers cleaned the groundwater. Surface storage facilities, particularly those that leak trash or large volumes of liquids like gasoline, contaminate groundwater. Earth's chemical waste pollutes subsurface water. Fertilizer and pesticide leaching harms groundwater. Human Development Index (HDI) Report (2011) outlines research technique that loss of 8% from the baseline would be "environmental disaster" with the biggest drops in South Asia and Sub-Saharan Africa. Climate change affects agriculture, clean water and pollution, making it a "environmental issue". From mining and processing raw materials to assembling and delivering finished goods, manufacturing worsens environmental circumstances. Manufacturing energy generation, agricultural and forestry production, and others may be divided down into even more pollution-causing subsectors. Consumption, which includes residential, commercial, and societal usage of manufacturing products, pollutes second only to production. Thus, production and consumption cause pollution. Not all manufacturing and consumption waste was recycled, polluting the environment.

National long-term policy themes require the commitment of society and decision-makers to strengthen and apply strategies to check the pollution. As such country where without check or strict impose of law the fresh water is being highly polluted i.e. Romania is poor in freshwater resources (Europe ranked13th) and is dependent on precipitation. Climate warming leads to decreased river runoff due to increasing air temperature, which, in turn, accelerates evapotranspiration [20].

2 Metals that are toxic found in the water supply

Heavy metals (HMs) are often distributed unevenly between the water and the sediments of the riverbed. To what extent metals are transported across the sediment–water interface depends on the physical and chemical properties of the water as well as the sediment. The accumulation of HMs in river environments leads to harmful amounts that biota can absorb because these contaminants are neither biodegradable nor thermodegradable [21]. Extreme hydrometeorology provides a window into the ever-changing balance between HMs in sediments and water flow. River flows are rising due to climate change, which is washing silt from riverbeds into the higher reaches of rivers. Because of this, the composition and quality of the water can be altered over time by pollution deposits that are buried deep underground [22, 23].

The increasing number of megacities, together with urbanization's other effects such as population increase and migration, provide a problem for clean water supplies [24]. Emerging concerns to the supply of safe drinking water pose serious dangers to human health and have broad public health implications [25, 26]. Polluted urban waters affect the quality of drinking water and pose a threat to urban residents since these metal contaminants are carried throughout the city via the air, surface runoffs, and groundwater flow [25]. The correct methods and equipment can be used to control water contamination from point sources such factories, sewage systems, power plants, underground coalmines, and oil wells.

Heavy metal contamination surrounding mines can range from mild to severe, depending on factors including mineralization of tailings and geochemical properties. Generation of millions of tons of sulfide-rich tailings by opencast mining activities has a significant negative effect on soils and water streams, according to [27–29]. There is a high probability that wind and water will distribute, incorporate into particle matter, or dissolve trace elements in mining and metallurgical waste following disposal. When the transportation process was on then the pollution can arise from three sources: primary contamination, which is caused by residues near the sources of contamination; secondary contamination, which occurs when trace elements spread out from their production areas through water and wind and tertiary contamination, which signifies the mobilization of trace elements [30, 31].

Heavy metals can enter the aquatic environment in one of two ways: naturally or artificially. Indirect channels include dry and wet deposition and land run-off in addition to direct discharges into fresh and marine habitats [32]. Significant natural sources also come from forest fires, continental weathering, and volcanic activity. Either high, intermittent emissions from explosive volcanism or low, continuous emissions from processes like geothermal heat flow or magma degassing can be attributed to volcanic activity [32]. Groundwater contamination is a major environmental issue. Groundwater has always been safe to drink because the land above the aquifer filters it. Surface leaks from trash or bulk liquid storage (like gasoline) are the main source of groundwater contamination. Chemical wastes dumped on the ground may contaminate the underlying groundwater over time. The pollution of groundwater is also worsened by the leaching of fertilisers and pesticides from the agriculture sector too [33].

3 Root cause: soil contamination from heavy metals

High heavy metal content in soils is related to the latter's geo- and bioaccumulation ability [34] as well as the transport rate within the soil profile [35]. Distribution of heavy metals within the soil profile could provide information about their origin [36, 37]. Soil enrichment with heavy metals could reflect historical human activities [38–41]. The present anthropogenic pollution sources, such as industry and agriculture, have an undoubted influence on heavy metal accumulation in the soil [42–44]. Heavy metals can be derived from both local and distant sources of emissions, and therefore can be deposited in situ or due to their ability to be bound by dust can be transported over long distances [38, 45]. Most anthropogenic pollutants are emitted into the atmosphere and then are deposited on the soil surface [46, 47]. Heavy metals are considered substantial constituents of the Earth's crust [48, 49] hence, the nature of the parent material and pedogenesis at the site can create favourable or unfavourable conditions for heavy metal accumulation. Furthermore, weathering of the parent material is a natural process affecting the number of heavy metals in the soil [36, 50]. The problem of high concentrations of heavy metals, especially in agricultural soils, creates a global environmental issue due to the crucial importance of food production and security [26, 36, 51]. Incorporation of heavy metals into the trophic chain may affect animal and human health [26, 52, 53].

Growing awareness of ever-expanding industrialization as well as intensive agricultural soil use and their influence on the content of heavy metals in the soil necessitates the appropriate evaluation as well as determination of their ecological risk [54, 55]. Heavy metal pollution is visible in urban centres and farmland located in the vicinity of pollution sources [20, 52]. Analysis of studies of time trends of heavy metal content in soils allows the tracing back of the development of industrialization as well as the use of fertilizers in the last decades. Numerous geochemical studies have contributed to the creation of an extensive database of heavy metal background values that can now be used for the evaluation of environmental quality [56, 57]. However, analysis of the total contents of heavy metals in the soil may not always be a sufficient method of assessment [55, 58]. The key to the effective assessment of soil contamination with heavy metals lies in the use of pollution indices.

4 Evaluation of heavy metal using a range of parameters

Heavy metals in soil can be measured using pollution indices which was developed one of the earliest indices [17]. For a thorough geochemical assessment of the soil environment, pollution indices can be used as a tool and guidance [2, 38, 55]. In order to determine soil pollution indices, it is necessary to first evaluate the soil's geochemical context (GB). Soil heavy metal concentration is a term that was coined to differentiate between normal and excessive levels of heavy metals in the ground [48, 59]. Based on [60–62] stated that GB "is a relative metric to discern between natural element or compound concentrations and anthropogenically-influenced concentrations in a given environmental sample." The ability to evaluate environmental risk and the level of soil deterioration is further evidence of the all-encompassing nature of measuring soil quality using indices [60]. These indexes are useful for distinguishing between heavy metal accumulations attributable to natural processes and those attributable to human activity [58, 63]. In the case of agro-ecosystems in particular, it is crucial to keep an eye on soil quality and the pollution indices that measure it [47]. Physical properties (texture, structure, and porosity), chemical properties (fixed residues, petroleum products, extractible substances in organic solvents, and heavy metals) and specific soil quality indicators (active and potential pH, total organic carbon TOC, oil compounds, extractible substances in organic solvents, and heavy metals) are the four groups into which the various parameters used to assess soil quality can be sorted.

5 Measures of air, water and soil contamination

Heavy metal contamination can be evaluated using a number of different approaches and criteria [64]. The enrichment factor (EF), contamination factor (CF), Geo-accumulation index (Igeo), and pollution load index (PLI) are among the identified environmental pollution factors can used for measurement.

5.1 Selected indices and overall analysis

Indicators of pollution can be split into two categories from a modelling standpoint: single-indicator indices and composite indices [58]. Enrichment factor (EF), contamination factor (CF), contamination degree (CD), pollution load index (PLI), metal pollution index (MPI), and geo accumulation index (I-geo) are all indices for quantifying soil contamination. Many authors choose to express the metal contamination relative to the average shale when attempting to estimate the level of pollution (Table 1).

5.2 Degree of Enrichment factor (EF)

In scientific studies, the amount of an element's or compound's enrichment over its background concentration is evaluated using a metric called the Enrichment Factor. The EF was developed by researchers [66] is widely used to quantify the effects of human activity on sediments and soils. Sample concentrations are compared to background concentrations of the same element in non-polluted locations to determine this factor [64, 66, 67]. In order to evaluate natural or anthropogenic sources of heavy metal content in samples, an enrichment factor is calculated as follows:

$$EF_{El} = \frac{\frac{[El]_{sample}}{[X]_{sample}}}{\frac{[El]_{crust}}{[X]_{crust}}} \tag{1}$$

where "El" refers to the element under consideration, the square brackets indicate concentrations (usually in mass/ mass units, such as mg/kg), and "X" is selected reference element. Crust subscription in Eq. 1 refer to Clarke of Earth's crust, most often Continental.

5.3 Contamination Factor (CF)

Contamination factor is an indicator of soil and sediment heavy metals contamination ratio and is obtained by dividing the concentration of the element in the sample taken by the concentration of the same element in the background [64, 68].

$$C = \frac{C_{Sample}}{C_{Background}} \tag{2}$$

where "C" sample is the concentration of an element in the sample and C background is the concentration of the element in global shale. If CF is higher than 1, indicating the increased concentration of pollutant due to human factors.

Table 1 Potential industrial and agricultural sources for metals in the environment (Source: Li et al. [65])

Metal	Sources
Iron	Minig areas, fuel, refineries, textile
Lead	Materials used in the production of batteries, electricity, paint, glass, fertilizer, gasoline, and plastic
Cadmium	Products such as batteries, electricity, colorants, solid alloys, gasoline, polymers, and fertilizers
Zinc	Batteries, electricity, paint, solder, glass, fertilizer, gasoline and insecticides
Nickel	Batteries and electrical; pigments and paints; alloys and catalysts; fertilizers
Cupper	Materials used in the production of batteries, electricity, paint, solid alloys, fuel, and insecticides
Chromium	Pigments; fertilizers; textile

5.4 Geoaccumulation index

According to research, geoaccumulation index was first introduced by Muller and was initially named as the Muller index [64, 69]. The Muller index is used to measure the amount of contamination with heavy metals in the soil. This assessment index was used in soil and sediment contamination studies [70, 71]. Geoaccumulation index is used for classification of soils, from non-contaminated to heavily contaminate and is calculated using the following formula [71]:

$$I_{geo} = log_2^{\left[\frac{C_n}{1.5B_n}\right]} \tag{3}$$

In Eq. 3, Cn is the measured concentration of the element in the collected sample and Bn represents the concentration of the element in the background sample. The coefficient of 1.5 is used to eliminate possible changes in the background due to the geological effects.

5.5 Pollution load index (PLI)

Soil and sediment pollution is commonly assessed using pollution load index. This index calculates the coefficient of each soil element by dividing its concentration by its concentration [72]. Therefore, PLI may be determined for a collection of contaminating metals as the geometric mean of all metal concentrations. PLI readings above 1 indicate soil contamination, while those close to 1 suggest background concentration [72]. The total heavy metal contamination in the region is obtained using this indicator, and by Eq. 4:

$$PLI = \sqrt[n]{CF_1 \times CF_2 \times CF_3 \times \cdots \times CF_n} \tag{4}$$

Soil pollution caused by certain heavy metals can be evaluated with the help of the instruments included in the separate indices group (Table 2). Different pollution indicators are more or less applicable for certain types of soil uses [38, 57, 73]. Pollution indices can be used to get a sense of how bad things are at a certain location, but picking the right one depends on factors like how dangerous it would be to use it [36, 53, 55, 74]. Environmental management is aided by knowing how polluted farmland soils are [51, 75, 76]. Protecting precious ecosystems and limiting human exposure to harmful substances requires an understanding of soil pollution [77]. Soil and groundwater are enriched with heavy metals due to widespread agricultural practices [75, 78]. Since EF may pinpoint the origin of contamination, it is recommended that it be included in the set of individual pollution indices used to evaluate agricultural soils [55]. Complex pollution indices are also useful for gauging the level of pollution in an area and estimating the possible ecological danger [36, 52, 56].

5.6 Combined pollution index (PI) based on production and consumption

The Pollution Index (PI) is the sum of two sub-indices, Production and Consumption. Pollution from both production and consumption will be factored into a composite index. Symbolically,

$$PI_{it} = PI_{it}^{P} + PI_{it}^{C} \tag{5}$$

where I and t indicate countries and time as stated before; PI_{it} = Combined pollution index

PI_{it}^{P} = Production based pollution Index; PI_{it}^{C} = Consumption based pollution Index;

5.7 Ecological risk assessment

Several variables, including the correction factor for the metal, ecological risk factors, and toxicological response factors, are accounted for in the calculation of the risk index (RI) (Tables 2, 3). For instance, Zn and Mn both have a value of 1, while Cr has a value of 2. According to [79], Co, Cu, and Ni are all given a value of 5, whereas Cd is given a value of 30. The RI is calculated by taking into account a number of elements, such as the toxicological response factor (Tri) of each element as published by [79], the contamination factor (CFi) of each metal, and possible ecological risk factor (Eir) associated with each metal [64]. The RI or modified risk index (MRI), shorthand for the prospective and modified ecological risk index grades, is a measure of the danger posed by a specific ecological situation. When the enrichment factor (EF) is used, an index is calculated that measures the possible ecological danger to the environment; this index is called the

Table 2 Heavy metal contamination indices offered in the literature, their breadth, shortcomings and strengths

Index	Application scope	Strengths	Shortcomings	Authors
I_{geo}	Heavy metal contamination in soil: a quantitative analysis	Facilitates analysis of past and present levels of contamination In common usage Method of Simple Numbers Utilization of GB The potential for variance in lithogenic effects is reduced by a factor of 1.5	Thin the GB could fluctuate due to natural causes Leaving out the potential of metals that are heavy and ignores the geochemical fluctuations that occur naturally	Liu et al. (2016) Chen et al. (2015)
PI	Heavy metal pollution in topsoil: a quantitative assessment	The ratio between topsoil concentration and GB values allows for a quick and accurate application, and the scale is extensively utilized	Doesn't rely on fluctuations in the environment excludes heavy metals' potential use	Al-anbari et al. (2015) Chen et al. (2015)
EF	Comparative analysis of heavy metal content Origin of Heavy Metals Determination	Estimated anthropogenic impact Assessment of heavy metal origin Reduces metal variability Standardization of the element measured against one that is used for low occurrence variability of elements Assessment of the pollution by individual heavy metals Precise scale	Relative to some standard or norm Analyse beyond the concentration of pure elements	Omatoso and ojo (2015) Sayadi et al. (2015)
PIN	Metals, in general, are evaluated	Easy to calculate All contamination is integrated into a single value Precise scale Based on PI values	Rarely employed Doesn't take into account natural geochemical processes The PI class must be calculated	Gong et al. (2008)
MEC	Permits extensive evaluation, including analysis for a range of metals	Easy to apply Give information about heavy metal origin Takes into consideration all studied heavy metals	The values from Kloke (1979) are mandatory Doesn't take into account natural geochemical processes There is no reliable measuring device	Adamu and Nganje (2010) and Pejman et al. (2015)

I geo Geo accumulation Index, *PI* single pollution index, *EF* enrichment factor, *PIN* background enrichment factor, *MEC* multi-element contamination

Table 3 Classifications of soil contamination based on model type

Model	Description	Contamination degree	Sources
Enrichment Factor	To calculate the abundance of metals in samples, EF was taken into account. By comparing the Concentration of each tested metal with that of a reference metal, EF was computed. Mn, Al, and Fe are the reference metals that are typically employed	Inadequate to insufficient enrichment mildly enriched major enlargement Extremely enriched Highest possible enrichment	Rubio and Vilas (2000)
Contamination Factor	The CF is calculated by dividing the total soil metal concentration by the concentration in uncontaminated soil	Minimal contamination Level: Moderate Significant levels of pollution Extremely contaminated state	Tippie (1984)
Geo-accumulation Index	Metal contamination in soils was determined using the geo-accumulation index (i-geo), which compares present-day amounts to those seen before industrialization	High levels of contamination highly contaminated to terribly polluted strongly polluted clean to slightly polluted uncontaminated	Sutherland (2000)
Degree of contamination	Contamination levels may classify based on their intensities in a scale	Low Moderate Considerable Very high	Aksu et al. (1998)
Pollution Load Index	PLI provides simple but comparative means for assessing site quality	Perfection Base line level of pollution	Usero and Garcia (2000)
Metal Pollution Index	Metal Presentation Index was developed to overcome the challenges associated with the application and comprehension of rigorous statistical analysis while allowing for the presentation of the data from the metal concentrations as a single value	Quality decline of the site Non-polluted Polluted	Jorgensen and Pedersen (1994)
Potential Ecological Risk Index	PERI offers a quick and easy quantitative measure for ecological evaluation	Low moderate significant extremely high	Hakanson (1980)

modified risk index. In order to compute MRI, we must first determine both the modified potential ecological risk factor (mEir) and EF for each metal. The equation for calculating the RI as proposed by [80] Hakanson (1980) is presented below:

$$RI = \sum_{i=1}^{n} Er^{i} \quad (6)$$

where "Er".

$Er = \sum_{i=1}^{n} Tr^{i} \times Cf^{i}$, is the Ecological risk index potential of a certain element, Tri is the individual element's biological toxicity response factor and Cf i the contamination factor refers to the level of contamination for each individual constituent.

6 Sources of environmental pollution

Energy is a key factor in achieving sustainable development. When using non-renewable resources, the energy generation process can produce substantial pollution. This happens frequently in third-world countries. The appropriate interpretation of soil conditions is aided by the identification or construction of a sound theoretical framework that may be computed using indices that reflect varied attributes. Sustainable development risk is greatly influenced by environmental pollution. It's possible that the causes of environmental degradation, and the degrees to which they manifest, vary across economically developed and economically developing countries. Risk variables that contribute to a rise or decrease in environmental pollution, and their interrelationships, must be analysed in the context of environmental pollution risk management. To a large extent, pollution may be traced back to the production process, which includes everything from the mining of raw materials to the distribution of finished items. Manufacturing, electricity generation, transportation (road, rail, and air), agriculture, and forestry are all primary production sectors that contribute to environmental pollution. Numerous industries and sub-industries exist within each of these broad categories. The second major contributor to environmental degradation is the domestic, commercial, and societal use of manufactured products (Table 3). As a result, the manufacturing, distribution, retail, and service sectors all add to pollution levels [26].

7 Global pollution index assessment of economic activities and environmental impact

The development of effective policies that aim to mitigate negative impacts and maximize positive ones has been aided by the creation of integrated or strategic impact assessment techniques in economic, environmental, and social domains [81, 82] lend credence to the claim. The cumulative environmental implications of a proposed action can be evaluated with the help of tools for Cumulative Impact Assessment (CIA) [83], which take into account the past, present, and future activities. The potential effects of new endeavours or ongoing commercial operations on the natural environment must be evaluated, and this requires following a structured environmental assessment method. It is generally accepted that the CIA plays a crucial role in environmental planning. However, details on environmental state regulations, administrative processes, and criteria for assessing cumulative consequences are scant. Scales, baselines, notable criteria, and coordination protocols were often used in CIA investigations. Romania relies on the International Pollution Index (IGP) as its primary tool for assessing environmental impacts. This index can be used to evaluate the overall effects on the environment. Collecting data on the technological process, economic and social needs, air emissions, water resources, soil, and noise levels at the analysed area is a crucial part of the approach. The procedure also includes anticipatory thought and identification of potential outcomes, as well as impact evaluation at a comparable scale using the worldwide pollution index as an alternative methodology. This generalization holds true for any approach used to calculate the sum of an environment's influences [84–86].

One of the primary factors contributing to the deterioration of the health of the population is air pollution. The polycyclic aromatic hydrocarbons (PAHs) that are found in particulate matter (PM) contribute significantly to the health risk due to the fact that they are both mutagenic and carcinogenic. The PM2.5 particulate matter is primarily connected with combustion sources, such as engine exhaust and the burning of biomass. On the other hand, the PM2.5–10 particulate matter is primarily associated with suspended particles and mechanical phenomena [20]. There are impacts on the immune system that can be caused by exposure to lead contamination. As a result of Pb toxicity, neurotransmitter levels are disrupted, and major health problems can be evident due to organ damage (Table 4) [26]. According to the

Table 4 Impact of Pollution on human health

Pollutant	Major source of emission	Health impacts	References
PM2.5 and PM 10	Pollutant Air Released from Vehicles, Factory Fires, and Other Sources	CNS, Respiratory, and Cardiovascular Illnesses Cancer, failure of reproductive organs	[89, 90]
Ozone	Pollution from cars and factories	Disruption of breathing, irregular heartbeat, and aggravated eyes	[91, 92]
Carbon monoxide	Pollution from vehicles, burning fossil fuels and forest products, and manufacturing operations	Brain and heart problems	[93, 94]
Sulfur dioxide	Combustion of fuel and coal burning	Eye irritation, central nervous system (CNS) involvement	[95, 96]
Nitrogen dioxide	Combustion of fuels and vehicle emissions	Injury to the Heart, Kidneys, Liver, and Blood	[97, 98]
Lead	Smelting lead, industry, leaded gas,	Disorders of the central nervous system, blood, and the eyes	[99, 100]
Polycyclic aromatic hydrocarbon	Combustion, motors, and motorized wood stoves	Lung disease and cancer	[101, 102]

comparison between Cr(VI) and Cr(III), Cr(VI) is a carcinogen. It is possible for it to trigger asthmatic responses when it is inhaled, in addition to all of the hazardous consequences that it has. Additionally, exposure to Cr can result in the development of some genetic alterations that are detrimental to human health [26]. Heavy metals can have detrimental effects on several cellular components and organelles. Recent research has shown that metal ions can damage human DNA through interactions with DNA and nuclear proteins. This, in turn, can cause cell cycle regulation, apoptosis, and possibly cancer [87]. It has been found that heavy metals cause site-specific damage to human DNA and nuclear proteins when they interact. Many other impacts of Pollution took place on human health (Table 4). The metal causes direct harm by inducing conformational changes in the biomolecules. The production of reactive oxygen and nitrogen species, such as hydroxyl and superoxide radicals, hydrogen peroxide, nitric oxide, and other endogenous oxidants, is responsible for the "indirect" damage [88] caused by heavy metal exposure (Table 4).

8 Policy suggestions

Economic factors (businesses, households, etc.) need energy for production and consumption, making it a crucial resource for development. The end of the world would occur if the fuels used to generate electricity ran out. There is also a reciprocal relationship between pollution and progress; for example, in developing nations where there is little or no rules in place to ensure that manufacturing processes are ecologically benign, there is a strong correlation between human development and pollution levels. Organic farming is a method that can help reduce the amount of toxic metal entering our bodies. No pesticides are used, and only pure water with no detectable levels of pollutants is used in the treatment process [103, 104]. The use of biodiversity in pest management has the additional benefit of increasing the number of native plant and animal species. Temperature, pH, ionic strength, and the presence of natural organic matter are all significant elements in the removal of heavy metals from water. Heavy metals can be effectively removed using agricultural by-products and wastes such dairy manure and rice and peanut hulls. Mineral deposits and natural soil, on the other hand, appear to be less effective at removing heavy metals [104]. Sustainable development is only possible when all three economic actors are involved in policy formulation and all three actors contribute to the achievement of the goal. The government may use either voluntary or mandatory measures to achieve this end. Voluntary efforts include raising awareness about the risks of pollution and resource depletion, supporting responsible waste management at all stages of the production and consumption chains, and providing incentives for good behaviour. Regulations to limit pollutant emissions and waste, progressive levies on emissions and waste, and the maintenance of pollution standards are all examples of voluntary measures adopted to minimize pollution [104, 105]. The government will be able to fund waste management and recycling initiatives with the tax revenue it receives. The government should facilitate the widespread availability and affordable pricing of energy-efficient solutions in order to motivate a shift in consumer preferences toward product categories that use less energy and resources. Therefore, not just individuals but also corporations and governments need to work toward more sustainable consumption habits. Both national governments and multilateral organizations need to work together to create policies that protect the environment and stimulate the economy.

9 Conclusion

Economic growth is being stifled by pollution and environmental degradation caused by rising industrialization, urbanisation, mechanisation, use of fertiliser and pesticides in agriculture, and improper disposal of human waste, particularly in developing countries where environmental laws typically do not exist or are relatively less strict. By identifying the variables and technologies that contribute to pollution during the growth process and replacing them with less harmful alternatives, it is possible to simultaneously reduce pollution and increase productivity. These problems call for increasingly global remedies, making international cooperation essential. This research adds to the growing body of international strategies.

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Data availability All data generated or analysed during this study are included in this published article. Data sharing is not applicable to this article as no datasets were generated or analyzed during the current study.

Declarations

Competing interests The author declares no competing interests is acceptable.

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References

1. Afkhami A, Ghaedi H, Madrakian T, Rezaeivala M. Highly sensitive simultaneous electrochemical determination of trace amounts of Pb(II) and Cd(II) using a carbon paste electrode modified with multi-walled carbon nanotubes and a newly synthesized Schiff base. Electrochim Acta. 2013;89:377–86. https://doi.org/10.1016/j.electacta.2012.11.050.
2. Dufrénot G. New thinking on sustainable development and growth. New Chall Macroecon Policies. 2023. https://doi.org/10.1007/978-3-031-15754-7_4.
3. Yüksel B, Ustaoğlu F, Tokatli C, Islam MS. Ecotoxicological risk assessment for sediments of Çavuşlu stream in Giresun, Turkey: association between garbage disposal facility and metallic accumulation. Environ Sci Pollut Res. 2021;29(12):17223–40. https://doi.org/10.1007/s11356-021-17023-2.
4. Dane H, ŞİŞMAN T. Determination of oxidative, genotoxic, and histopathologic effects of metal pollution on the fish fauna inhabiting Karasu River. Turkey Turk J Zool. 2021;45(7):505–16. https://doi.org/10.3906/zoo-2105-19.
5. Egbueri JC, Mgbenu CN. Chemometric analysis for pollution source identification and human health risk assessment of water resources in Ojoto Province, southeast Nigeria. Water Sci Appl. 2020. https://doi.org/10.1007/s13201-020-01180-9.
6. Kucukosmanoglu AG, Filazi A. Investigation of the Metal Pollution Sources in Lake Mogan, Ankara, Turkey *. Biol Trace Elem Res. 2020;198(1):269–82. https://doi.org/10.1007/s12011-020-02031-z.
7. Chaudhary P, Godara S, Cheeran AN, Chaudhari AK. Fast and accurate method for leaf area measurement. Int J Comput Appl. 2012;49(9):22–5. https://doi.org/10.5120/7655-0757.
8. Hu F, et al. Design of a polarization insensitive multiband terahertz metamaterial absorber. J Phys Appl Phys. 2013;46(19): 195103. https://doi.org/10.1088/0022-3727/46/19/195103.
9. Topaldemir H, Taş B, Yüksel B, Ustaoğlu F. Potentially hazardous elements in sediments and Ceratophyllum demersum: an ecotoxicological risk assessment in Miliç Wetland, Samsun, Türkiye. Environ Sci Pollut Res. 2022;30(10):26397–416. https://doi.org/10.1007/s11356-022-23937-2.
10. Tijani MN, Onodera S. Quality assessment of stream water and bed sediments: a case study of urbanization impacts in a developing country", presented at the self-sustaining solutions for streams, Wetlands, and Watersheds, 12–15, September 2004. Am Soc Agric Biol Eng. 2004. https://doi.org/10.13031/201317380.
11. Sedky MM, Fawzy SM, Baki NAE, Eishi NHE, Bohy AEMME. Systemic sclerosis: an ultrasonographic study of skin and subcutaneous tissue in relation to clinical findings. Skin Res Technol. 2012. https://doi.org/10.1111/j.1600-0846.2012.00612.x.
12. Akoto O, Bruce TN, Darko G. Chemical and biological characteristics of streams in the Owabi watershed. Environ Monit Assess. 2009;161(1–4):413–22. https://doi.org/10.1007/s10661-009-0757-4.
13. Bai J, et al. Contamination characteristics of heavy metals in wetland soils along a tidal ditch of the Yellow River Estuary, China. Stoch Environ Res Risk Assess. 2011;25(5):671–6. https://doi.org/10.1007/s00477-011-0475-7.
14. Yuksel B, Arica E. Assessment of toxic, essential, and other metal levels by ICP-MS in Lake Eymir and Mogan in Ankara, Turkey: an environmental application. At Spectrosc. 2018;39(5):179–84. https://doi.org/10.46770/as.2018.05.001.
15. El-Nemr MA, El-Desuki M, El-Bassiony AM, Fawzy ZF. Response of growth and yield of cucumber plants (*Cucumis sativus* L.) to different foliar applications of humic acid and bio-stimulators. Aust J Basic Appl Sci. 2012;6(3):630–7.
16. Karbassi AR, Monavari SM, Nabi Bidhendi GhR, Nouri J, Nematpour K. Metal pollution assessment of sediment and water in the Shur River. Environ Monit Assess. 2007;147(1–3):107–16. https://doi.org/10.1007/s10661-007-0102-8.
17. Muller CH. Allelopathy as a factor in ecological process. Vegetatio. 1969;18(1–6):348–57. https://doi.org/10.1007/bf00332847.
18. Omran MGH, Mahdavi M. Global-best harmony search. Appl Math Comput. 2008;198(2):643–56. https://doi.org/10.1016/j.amc.2007.09.004.
19. Faroque S, South N. Water pollution and environmental injustices in Bangladesh. J Crime Justice Soc Democr Int. 2021. https://doi.org/10.5204/ijcjsd.2006.
20. St Naydenova A, Veli ZM, Hudai S, Hristova E, Gonsalvesh-Musakova L. Atmospheric levels, distribution, sources correlation with meteorological parameters and other pollutants and health risk of PAHs bound in PM2 5 and PM10 in Burgas, Bulgaria—a case study. J Environ Sci Health Part. 2022. https://doi.org/10.1080/10934529.2022.2060669.
21. Ma Y, et al. Differences in bacterial community composition, structure and function between sediments in waterways and non-navigable channels in a plain river network area. Environ Sci Pollut Res. 2023;30(16):45910–23. https://doi.org/10.1007/s11356-023-25535-2.
22. Frogner P, Reynir Gíslason S, Óskarsson N. Fertilizing potential of volcanic ash in ocean surface water. Geology. 2001;29(6):487.
23. Khan A, Khan S, Khan MA, Qamar Z, Waqas M. The uptake and bioaccumulation of heavy metals by food plants, their effects on plants nutrients, and associated health risk: a review. Environ Sci Pollut Res. 2015;22(18):13772–99. https://doi.org/10.1007/s11356-015-4881-0.

24. Larsen TA, Hoffmann S, Lüthi C, Truffer B, Maurer M. Emerging solutions to the water challenges of an urbanizing world. Science. 2016;352(6288):928–33. https://doi.org/10.1126/science.aad8641.
25. Chowdhury S, Mazumder MAJ, Al-Attas O, Husain T. Heavy metals in drinking water: Occurrences, implications, and future needs in developing countries. Sci Total Environ. 2016;569–570:476–88. https://doi.org/10.1016/j.scitotenv.2016.06.166.
26. Ulutaş K. Assessment of the pollution level, microscopic structure, and health risk of heavy metals in surface dusts in a sports field. Pamukkale Univ J Eng Sci. 2023;29(5):529–36. https://doi.org/10.5505/pajes.2022.50880.
27. Bhattacharya A, Routh J, Jacks G, Bhattacharya P, Mörth M. Environmental assessment of abandoned mine tailings in Adak, Västerbotten district (northern Sweden). Appl Geochem. 2006;21(10):1760–80. https://doi.org/10.1016/j.apgeochem.2006.06.011.
28. Moreno T, Oldroyd A, McDonald I, Gibbons W. Preferential fractionation of trace metals-metalloids into PM10 resuspended from contaminated gold mine tailings at rodalquilar, Spain. Water Air Soil Pollut. 2006;179(1–4):93–105. https://doi.org/10.1007/s11270-006-9216-9.
29. Sun Y, Xie Z, Li J, Xu J, Chen Z, Naidu R. Assessment of toxicity of heavy metal contaminated soils by the toxicity characteristic leaching procedure. Environ Geochem Health. 2006;28(1–2):73–8. https://doi.org/10.1007/s10653-005-9014-0.
30. Lottermoser BG, Cleverley JS. Controls on the genesis of a high-fluoride thermal spring: innot hot springs, north Queensland *. Aust J Earth Sci. 2007;54(4):597–607. https://doi.org/10.1080/08120090701188988.
31. Martínez-Sánchez MJ, et al. Assessment of the mobility of metals in a mining-impacted coastal area (Spain, Western Mediterranean). J Geochem Explor. 2008;96(2–3):171–82. https://doi.org/10.1016/j.gexplo.2007.04.006.
32. Tian W, et al. Microplastic materials in the environment: Problem and strategical solutions. Prog Mater Sci. 2023;132: 101035. https://doi.org/10.1016/j.pmatsci.2022.101035.
33. Dakheel Almaliki AJ, Bashir MJK, Llamas Borrajo JF. Appraisal of groundwater contamination from surface spills of fluids associated with hydraulic fracturing operations. Sci Total Environ. 2022;815: 152949. https://doi.org/10.1016/j.scitotenv.2022.152949.
34. Oti WO. Bioaccumulation factors and pollution indices of heavy metals in selected fruits and vegetables from a derelict mine and their associated health implications. J Environ Sustain Int. 2015. https://doi.org/10.24102/ijes.v4i1.548.
35. Fagbote E, Olanipekun E. Speciation of heavy metals in sediment of Agbabu Bitumen deposit area. J Appl Sci Environ Manag Nigeria. 2011. https://doi.org/10.4314/jasem.v14i4.63255.
36. Chen W, et al. Cancer statistics in China, 2015. CA Cancer J Clin. 2016;66(2):115–32. https://doi.org/10.3322/caac.21338.
37. Pejman A, Nabi Bidhendi G, Ardestani M, Saeedi M, Baghvand A. A new index for assessing heavy metals contamination in sediments: a case study. Ecol Indic. 2015;58:365–73. https://doi.org/10.1016/j.ecolind.2015.06.012.
38. Mazurek R, et al. Assessment of heavy metals contamination in surface layers of Roztocze National Park forest soils (SE Poland) by indices of pollution. Chemosphere. 2017;168:839–50. https://doi.org/10.1016/j.chemosphere.2016.10.126.
39. Shu Y, Zhai S. Study on soil heavy metals contamination of a lead refinery. Chin J Geochem. 2014;33(4):393–7. https://doi.org/10.1007/s11631-014-0703-1.
40. Sołek-Podwika K, Ciarkowska K, Kaleta D. Assessment of the risk of pollution by sulfur compounds and heavy metals in soils located in the proximity of a disused for 20 years sulfur mine (SE Poland). J Environ Manage. 2016;180:450–8. https://doi.org/10.1016/j.jenvman.2016.05.074.
41. D. Tang, B. Qin, and T. Liu. Document Modeling with Gated Recurrent Neural Network for Sentiment Classification," presented at the Proceedings of the 2015 Conference on Empirical Methods in Natural Language Processing, Association for Computational Linguistics. 2015. https://doi.org/10.18653/v1/d15-1167.
42. Bechambi O, Sayadi S, Najjar W. Photocatalytic degradation of bisphenol a in the presence of C-doped ZnO: effect of operational parameters and photodegradation mechanism. J Ind Eng Chem. 2015;32:201–10. https://doi.org/10.1016/j.jiec.2015.08.017.
43. Gao X, Chen C-TA. Heavy metal pollution status in surface sediments of the coastal Bohai Bay. Water Res. 2012;46(6):1901–11. https://doi.org/10.1016/j.watres.2012.01.007.
44. Ogunkunle CO, Fatoba PO. Contamination and spatial distribution of heavy metals in topsoil surrounding a mega cement factory. Atmospheric Pollut Res. 2014;5(2):270–82. https://doi.org/10.5094/apr.2014.033.
45. Ben Mohamed E, Souissi MN, Baccar A, Bouri A. CEO's personal characteristics, ownership and investment cash flow sensitivity: evidence from NYSE panel data firms. J Econ Finance Adm Sci. 2014;19(37):98–103. https://doi.org/10.1016/j.jefas.2014.10.002.
46. Liu Z, et al. Ozonation of trace organic compounds in different municipal and industrial wastewaters: kinetic-based prediction of removal efficiency and ozone dose requirements. Chem Eng J. 2020;387: 123405. https://doi.org/10.1016/j.cej.2019.123405.
47. Ripin SNM, Hasan S, Kamal M. Environmental geochemical mapping on distribution of metal contamination in Topsoils Perlis Malaysia. J Med Bioeng. 2014. https://doi.org/10.1720/jomb.3.4.277-281.
48. H. E. Hawkes and J. S. Webb. 1965. Geochemistry in mineral exploration. Harper Row.
49. Zhou X, Wang Q, Jiang G, Liu P, Yuan Z. A novel conditioning process for enhancing dewaterability of waste activated sludge by combination of zero-valent iron and persulfate. Bioresour Technol. 2015;185:416–20. https://doi.org/10.1016/j.biortech.2015.02.088.
50. Kierczak J, Pędziwiatr A, Waroszewski J, Modelska M. Mobility of Ni, Cr and Co in serpentine soils derived on various ultrabasic bedrocks under temperate climate. Geoderma. 2016;268:78–91. https://doi.org/10.1016/j.geoderma.2016.01.025.
51. Kelepertzis E. Accumulation of heavy metals in agricultural soils of Mediterranean: Insights from Argolida basin, Peloponnese, Greece. Geoderma. 2014;221–222:82–90. https://doi.org/10.1016/j.geoderma.2014.01.007.
52. Al-Anbari S, Khalina A, Alnuaimi A, Normariah A, Yahya A. Risk assessment of safety and health (RASH) for building construction. Process Saf Environ Prot. 2015;94:149–58. https://doi.org/10.1016/j.psep.2015.01.009.
53. Begum S, Yuhana NY, Md Saleh N, Kamarudin NHN, Sulong AB. Review of chitosan composite as a heavy metal adsorbent: material preparation and properties. Carbohydr Polym. 2021;259:117613. https://doi.org/10.1016/j.carbpol.2021.117613.
54. Baran B, Mert Ozupek N, Yerli Tetik N, Acar E, Bekcioglu O, Baskin Y. Difference between left-sided and right-sided colorectal cancer: a focused review of literature. Gastroenterol Res. 2018;11(4):264–73. https://doi.org/10.14740/gr1062w.
55. Kowalska J, Mazurek R, Gąsiorek M, Setlak M, Zaleski T, Waroszewski J. Soil pollution indices conditioned by medieval metallurgical activity—a case study from Krakow (Poland). Environ Pollut. 2016;218:1023–36. https://doi.org/10.1016/j.envpol.2016.08.053.
56. Obiora SC, Chukwu A, Davies TC. Heavy metals and health risk assessment of arable soils and food crops around Pb–Zn mining localities in Enyigba, southeastern Nigeria. J Afr Earth Sci. 2016;116:182–9. https://doi.org/10.1016/j.jafrearsci.2015.12.025.

57. Wu W, Wu Z, Yu T, Jiang C, Kim W-S. Recent progress on magnetic iron oxide nanoparticles: synthesis, surface functional strategies and biomedical applications. Sci Technol Adv Mater. 2015;16(2):023501–023501. https://doi.org/10.1088/1468-6996/16/2/023501.
58. Caeiro S, et al. Assessing heavy metal contamination in Sado Estuary sediment: an index analysis approach. Ecol Indic. 2005;5(2):151–69. https://doi.org/10.1016/j.ecolind.2005.02.001.
59. Reimann C, Garrett RG. Geochemical background—concept and reality. Sci Total Environ. 2005;350(1–3):12–27. https://doi.org/10.1016/j.scitotenv.2005.01.047.
60. Adamu CI, Nganje TN. Heavy metal contamination of surface soil in relationship to land use patterns: a case study of Benue State, Nigeria. Mater Sci Appl. 2010;01(03):127–34. https://doi.org/10.4236/msa.2010.13021.
61. Karim Z, Qureshi BA, Mumtaz M. Geochemical baseline determination and pollution assessment of heavy metals in urban soils of Karachi, Pakistan. Ecol Indic. 2015;48:358–64. https://doi.org/10.1016/j.ecolind.2014.08.032.
62. Matschullat J, Ottenstein R, Reimann C. Geochemical background—can we calculate it? Environ Geol. 2000;39(9):990–1000. https://doi.org/10.1007/s002549900084.
63. Peter E, Adeniyi G. Spatial relationships of urban land use, soils and heavy metal concentrations in Lagos Mainland Area. J Appl Sci Environ Manag. 2011. https://doi.org/10.4314/jasem.v15i2.68533.
64. Ulutaş K. Risk assessment and spatial distribution of heavy metal in street dusts in the densely industrialized area. Environ Monit Assess. 2022. https://doi.org/10.1007/s10661-022-09762-7.
65. Li J, Song L, Chen H, Wu J, Teng Y. Source apportionment of potential ecological risk posed by trace metals in the sediment of the Le'an River, China. J. Soils Sediments. 2020;20:2460–70.
66. Khalilova H, Mammadov V. Assessing the Anthropogenic impact on heavy metal pollution of soils and sediments in Urban Areas of Azerbaijan's Oil Industrial Region. Pol J Environ Stud. 2016;25(1):159–66. https://doi.org/10.15244/pjoes/60723.
67. Bern CR, Walton-Day K, Naftz DL. Improved enrichment factor calculations through principal component analysis: examples from soils near breccia pipe uranium mines, Arizona, USA. Environ Pollut. 2019;248:90–100. https://doi.org/10.1016/j.envpol.2019.01.122.
68. Al-Taani AA, et al. Contamination assessment of heavy metals in agricultural soil, in the Liwa Area (UAE). Toxics. 2021;9(3):53. https://doi.org/10.3390/toxics9030053.
69. Monjardin CEF, Senoro DB, Magbanlac JJM, de Jesus KLM, Tabelin CB, Natal PM. Geo-accumulation index of manganese in soils due to flooding in Boac and Mogpog Rivers, Marinduque, Philippines with Mining Disaster Exposure. Appl Sci. 2022;12(7):3527. https://doi.org/10.3390/app12073527.
70. Nasir MJ, Wahab A, Ayaz T, Khan S, Khan AZ, Lei M. Assessment of heavy metal pollution using contamination factor, pollution load index, and geoaccumulation index in Kalpani River sediments Arab. J Geosci Pakistan. 2023. https://doi.org/10.1007/s12517-023-11231-5.
71. Senoro DB, et al. quantitative assessment and spatial analysis of metals and metalloids in soil using the geo-accumulation index in the capital Town of Romblon Province, Philippines. Toxics. 2022;10(11):633. https://doi.org/10.3390/toxics10110633.
72. Hassan J, et al. Optimizing textile dyeing wastewater for tomato irrigation through physiochemical, plant nutrient uses and pollution load index of irrigated soil. Sci Rep. 2022;12(1):10088–10088. https://doi.org/10.1038/s41598-022-11558-1.
73. Gąsiorek M, Kowalska J, Mazurek R, Pająk M. Comprehensive assessment of heavy metal pollution in topsoil of historical urban park on an example of the Planty Park in Krakow (Poland). Chemosphere. 2017;179:148–58. https://doi.org/10.1016/j.chemosphere.2017.03.106.
74. Gong ZL, Li YX, He GN, Li J, Yang Y. Nanostructured Li[sub 2]FeSiO[sub 4] electrode material synthesized through hydrothermal-assisted sol-gel process. Electrochem Solid-State Lett. 2008;11(5):A60. https://doi.org/10.1149/1.2844287.
75. Kouamé AN, Masson R, Robert D, Keller N, Keller V. β-SiC foams as a promising structured photocatalytic support for water and air detoxification. Catal Today. 2013;209:13–20. https://doi.org/10.1016/j.cattod.2012.12.008.
76. Rodrguez JMC, et al. Highlights on practical applications of agents and multi-agent systems: international workshops of PAAMS 2013, Salamanca, Spain, May 22–24, 2013 in Computer and Information Science. Berlin: Springer Publishing Company; 2013.
77. Pan H, et al. Reversible aqueous zinc/manganese oxide energy storage from conversion reactions. Nat Energy. 2016;1(5):1–7.
78. Su M, et al. Association between perceived urban built environment attributes and leisure-time physical activity among adults in Hangzhou, China. Prev Med. 2014;66:60–4.
79. Duodu GO, Goonetilleke A, Ayoko GA. Comparison of pollution indices for the assessment of heavy metal in Brisbane River sediment. Environ Pollut. 2016;219:1077–91. https://doi.org/10.1016/j.envpol.2016.09.008.
80. Hakanson L. An ecological risk index for aquatic pollution control.a sedimentological approach. Water Res. 1980;14(8):975–1001. https://doi.org/10.1016/0043-1354(80)90143-8.
81. Chaker A, El-Fadl K, Chamas L, Hatjian B. A review of strategic environmental assessment in 12 selected countries. Environ Impact Assess Rev. 2006;26(1):15–56. https://doi.org/10.1016/j.eiar.2004.09.010.
82. Milner HV, Kubota K. Why the move to free trade democracy and trade policy in the developing Countries. Int Organ. 2005. https://doi.org/10.1017/s002081830505006x.
83. DeJesus E, et al. Simplification of antiretroviral therapy to a single-tablet regimen consisting of efavirenz, emtricitabine, and tenofovir disoproxil fumarate versus unmodified antiretroviral therapy in virologically suppressed HIV-1-infected patients. JAIDS J Acquir Immune Defic Syndr. 2009;51(2):163–74. https://doi.org/10.1097/qai.0b013e3181a572cf.
84. Grec A, Dumescu F, Maior C. assessment of the environmental impacts generated by rubber processing activity. Environ Eng Manag J. 2009;8(6):1533–40. https://doi.org/10.30638/eemj.2009.222.
85. Popa ME, et al. Impact of a future H 2 transportation on atmospheric pollution in Europe. Atmos Environ. 2015;113:208–22. https://doi.org/10.1016/j.atmosenv.2015.03.022.
86. Zaharia C, Murarasu I. Environmental impact assessment induced by an industrial unit of basic chemical organic compounds synthesis using the alternative method of global pollution index. Environ Eng Manag J. 2009;8(1):107–12. https://doi.org/10.30638/eemj.2009.015.
87. Azeh Engwa G, Udoka Ferdinand P, Nweke Nwalo F, Unachukwu MN. Mechanism and health effects of heavy metal toxicity in humans world—new tricks old dog poisoning Mod. London: IntechOpen; 2019. https://doi.org/10.5772/intechopen.82511.
88. Valko M, Morris H, Cronin M. Metals, toxicity and oxidative stress. Curr Med Chem. 2005;12(10):1161–208. https://doi.org/10.2174/0929867053764635.

89. Orellana CI, Orellana LM. Predictores de síntomas emocionales durante la cuarentena domiciliar por pandemia de COVID-19 en El Salvador. Actualidades en Psicología. 2020;34(128):103–20.
90. World Health Organization, WHO report on the global tobacco epidemic, 2021: addressing new and emerging products. World Health Organization, 2021.
91. Liu P, Teng M, Han C. How does environmental knowledge translate into pro-environmental behaviors?: The mediating role of environmental attitudes and behavioral intentions. Sci Total Environ. 2020;728:138126.
92. Yao W, Zhang X, Gong Q. The effect of exposure to the natural environment on stress reduction: A meta-analysis. Urban forestry & urban greening. 2021;57:126932.
93. Nair DN, Padmavathy S. Impact of endophytic microorganisms on plants, environment and humans. The Sci. World J. 2014.
94. Patel NA, Khan MD, Shahane S, Rai D, Chauhan D, Kant C, Chaudhary VK. Emerging pollutants in aquatic environment: source, effect, and challenges in biomonitoring and bioremediation-a review. Pollution. 2020;6(1):99–113.
95. Qian H, Jin Y, Leprieur F, Wang X, Deng T. Geographic patterns and environmental correlates of taxonomic and phylogenetic beta diversity for large-scale angiosperm assemblages in China. Ecography. 2020;43(11):1706–16.
96. Verma RK, Pandey A, Verma S, Mishra SK. A Review of Environmental Flow Assessment Studies in India with Implementation Enabling Factors and Constraints. Ecohydrol Hydrobiol. 2023.
97. Thomas P, Baldwin C, Bissett B, Boden I, Gosselink R, Granger CL, Hodgson C, Jones AY, Kho ME, Moses R, Ntoumenopoulos G. Physiotherapy management for COVID-19 in the acute hospital setting: recommendations to guide clinical practice. Pneumon. 2020;33(1).
98. Arulprakasajothi M, Chandrasekhar U, Yuvarajan D, Teja MB. An analysis of the implications of air pollutants in Chennai. Int J Ambient Energy. 2020;41(2):209–13.
99. Mazumdar I, Goswami K. Chronic exposure to lead: a cause of oxidative stress and altered liver function in plastic industry workers in Kolkata, India. Indian J Clin Biochem. 2014;29:89–92.
100. Bhardwaj AK, Garg A, Ram S, Gajpal Y, Zheng C. Research trends in green product for environment: A bibliometric perspective. Int J Environ Res Public Health. 2020;17(22):8469.
101. Rajput N, Lakhani A. Measurements of polycyclic aromatic hydrocarbons at an industrial site in India. Environ Monit Assess. 2009;150:273–84
102. Sankar KM, Booba B, Boopathi S. Smart Agriculture Irrigation Monitoring System Using Internet of Things. InContemporary Developments in Agricultural Cyber-Physical Systems 2023 (pp. 105–121). IGI Global.
103. Bishayee B, Chatterjee RP, Ruj B, Chakrabortty S, Nayak J. Strategic management of nitrate pollution from contaminated water using viable adsorbents: an economic assessment-based review with possible policy suggestions. J Environ Manage. 2022;303:114081. https://doi.org/10.1016/j.jenvman.2021.114081.
104. Nazeer M, Tabassum U, Alam S. Environmental Pollution and sustainable development in developing Countries. Pak Dev Rev. 2016;55:589–604. https://doi.org/10.1541/v55i4i-iipp.589-604.
105. Foxon T, Kemp R. Innovation impacts of environmental policies. Int Handb Environ Technol Manag. 2007. https://doi.org/10.4337/9781847203052.00016.

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