



Toxic pollution and its consequences for human health and ecosystem stability

Yatendra Pratap Singh¹, Dilip Kumar Burnwal²

¹ Department of Environmental Studies, Ramanujan College, University of Delhi, New Delhi, India

² Department of Food Technology and Home Science, Vivekananda College, University of Delhi, New Delhi, India

Corresponding Author: Yatendra Pratap Singh

Abstract

Environmental toxicants refer to the unfriendly chemical, physical/biological substances that are discharged to the atmosphere, water, and soil both naturally and through human actions. Blistering industrialization, urbanization, and intensive farming have contributed greatly to the increase in the amount of these poisonous elements in the environment. The purpose of this review is to analyse the significant sources of environmental toxicants and determine their effects on the ecosystem and human health. The major ones are industrial releases, agricultural chemicals, heavy metals, air pollutants, plastics, and the emerging substances like endocrine-disrupting compounds. The environmental health effects of exposure to these toxicants have been associated with acute and chronic health issues, such as respiratory illnesses, neurological and cancer, reproductive, and developmental defects. Ecosystems, too, are heavily impacted, which leads to loss of biodiversity, damage to habitats, bioaccumulation, and food chains. The results underscore the fact that ecological toxicants are a great risk to the ecological balance and human well-being on the globe. In this way, proper regulation, pollution control, and sustainability are of high priority to reduce the toxic exposure and prevent the threat to young and upcoming generations.

Keywords: Environmental toxicants, toxic pollution, ecosystem stability

Introduction

Environmental toxicology represents a field of science that studies the adverse impact of chemical, physical, and biological entities on the environment and living organisms. It incorporates the concepts of toxicology, ecology, chemistry, and public health to comprehend the interaction between pollutants and the ecosystems and human populations. The field not only aims at identifying toxic substances but also assessing their origins, exposure routes, actions, and their effects in the long run. With the ever-changing human activities, which change natural systems, environmental toxicology has become crucial in determining risks related to environmental contamination. Environmental toxicants are those substances found in the environment that can create unpleasant biological effects on humans, animals, plants, or an entire ecosystem (Landrigan *et al.*, 2018) [13]. These toxicants can be natural sources like volcanic gases or naturally occurring metals, though most of them are a result of anthropogenic activities. Generally, commonly used environmental toxicants are heavy metals (e.g., lead, mercury, cadmium, arsenic), pesticides, industrial chemicals, particulate matter, plastics, petroleum products, and persistent organic pollutants (Carson, 1962) [4]. Pharmaceuticals, nanomaterials, and endocrine-disrupting chemicals are also on the upsurge on the list of emerging contaminants because of their ubiquitousness and long-lasting impact even at low levels. It is imperative to study the toxic exposure as environmental toxicants may get into the body by inhalation, ingestion, or dermal contact and accumulate over an extended period. Exposure to acute levels may cause instant health outcomes that include poisoning or respiratory problems, whereas long-term exposure may cause serious conditions such as cancer, neurological disorders, heart diseases, reproductive issues, and developmental abnormalities (WHO, 2021). Children,

pregnant women, the elderly, and workers who are occupationally exposed are at a high risk as they are vulnerable populations. In addition to the health of humans, toxic exposure also disrupts ecological balance through the endangering of species, decreasing biodiversity, polluting food chains, and also compromising life in ecosystems that provide essential services. Over the past decades, the magnitude of pollution in the world has been on a meteoric increase owing to the high rate of industrialisation, urbanisation, population increase, rise in energy use, and intensive agricultural activities (UNEP, 2019). Car and industrial emissions, water pollution caused by the release of unprocessed waste into the water, soil erosion caused by chemical fertilizers and pesticides, as well as plastic debris accumulating, are now of great concern in terms of environmental pollution in all parts of the world. Climate change also contributes to the redistribution and toxicity of pollutants due to the changes in the environment and frequency of unfavorable occurrences. The weak regulatory systems, poor waste management systems, and high population density are some of the challenges that face developing countries, especially to a severe extent. Since such and such environmental toxicants are a complex and diverse problem and widespread, it is necessary to have an overall review to derive a synthesis of evidence of their origin, routes, and effects (Jaishankar *et al.*, 2014) [11]. A review such as this can be used to discover gaps in research and policy formulation and facilitate effective mitigation efforts. This analysis is aimed at making contributions to the further analysis of such environmental toxicity and the necessity of an immediate global approach. It looks at the key contributors of toxic substances generated due to industrial processes, farming practices, urbanization, and contemporary consumerism products. The paper reveals that these toxicants find their way to the environmental media-

air, water, and land- and consequently to the biological systems via different exposure routes. Special consideration: The health effects of toxic exposure, such as respiratory diseases, neurological diseases, cancer, reproductive losses, and ecological effects of toxic exposures, such as loss of biodiversity, habitat loss, and ecological food chain disruption, are considered. In this paper, I will be trying to provide a holistic perspective of the scope of environmental toxicity and the multifaceted nature of this issue by generalising on the available scientific literature. It illustrates the need for having the right regulatory authorities, pollution control strategies, and sustainable and efficient development approaches to reduce the pollution of the environment and save both the present and future generations from poisonous risks.

Research Objective

1. To identify and classify the major types and sources of environmental toxicants present in air, water, and soil.
2. To examine the pathways through which environmental toxicants enter biological systems and spread through ecosystems.
3. To assess the short-term and long-term impacts of toxic exposure on human health, including physical, neurological, and reproductive effects.
4. To evaluate the effects of environmental toxicants on ecosystems, biodiversity, and ecological balance.
5. To highlight the importance of regulatory measures, risk management strategies, and sustainable practices for reducing environmental pollution and toxic exposure.

Sources and Types of Environmental Toxicants

The major sources of environmental toxicants are natural and anthropogenic, with a great number of sources, and they are spread by human activity in numerous ways into the air, water, and soil. The chemicals are also persistent in the environment, accumulate in life and can cause some negative effects in the biological systems (Gore *et al.*, 2015) [7]. Industrial pollutants, agricultural chemicals, air pollutants, water contaminants, as well as new pollutants associated with new technologies and consumer products, are examples of major categories of environmental toxicants.

Industrial Pollutants

One of the greatest contributors to environmental pollution is industrial activity. Discharge of toxic substances into the environment is done in large amounts through factories, power plants, smelters, and manufacturing units. Virulent metals like lead, mercury, cadmium, and arsenic are especially harmful because they are toxic and persistent and can bioaccumulate in living tissues. Exposure to lead may result in neurological impairment, particularly in children, whereas mercury results in neurological system and kidney dysfunctions. Cadmium erodes the bones and kidneys, and arsenic is also a known carcinogen, which is impacting the skin, lungs, and bladder cancers (Alloway, 2013; Jaishankar *et al.*, 2014; Tchounwou *et al.*, 2012) [3, 11, 22]. Besides the heavy metals, industries produce chemical waste that includes solvents, acids, dyes, and synthetic compounds that pollute soil and water bodies. The mining activities also contribute to the escalation of pollution because they cause the release of harmful metals and acidic drainage into the ecosystems adjacent to the mining activities, in most cases,

resulting in environmental degradation in the long term (Younger, Banwart, & Hedin, 2002) [32].

Agricultural Chemicals

Competent industrial agriculture is based on the use of chemical inputs in order to enhance the yield of crops, yet the chemicals may have severe environmental effects. Pests and insects are contained by the use of pesticides, which, however, are harmful to the non-target organisms such as other insects, birds, aquatic organisms, and even human beings. The herbicides used to kill the unwanted plants may remain in the soil and water and have negative effects on the plant diversity and the stability of ecosystems (Carson, 1962 [4]; Aktar, Sengupta, & Chowdhury, 2009) [1]. The chemical fertilizers (fertilizers containing nitrogen, phosphorus, and potassium) enhance soil fertility, with the prolonged application of these chemicals resulting in mountains of diseases that drain into water bodies, leading to eutrophication and algal growth. Agricultural chemicals have been linked with long-term neurological disorders, endocrine disorders, and specific cancers, especially in farmers and the rural segment of the population (Smith & Schindler, 2009) [21].

Air Pollutants

One of the most crucial environmental health issues is air pollution, particularly in cities and industrial areas. The particulate matter (PM_{2.5} and PM₁₀) is made of minute particles suspended in the air that may enter the respiratory system. Trucks and other motor vehicles, industries, building and construction, as well as burning biomass, are the sources of these particles. Respiratory disorder, cardiovascular disease, and early death are some of the exposures to particulate matter. Nitrogen oxides, which are primarily generated during the combustion of fossil fuels, add to the formation of smog and irritation of the respiratory system. Sulfur dioxide, which is emitted by coal-burning power stations and the industry, may lead to acid rains and worsen asthma and bronchitis (WHO, 2021; Pope & Dockery, 2006) [20]. The ozone, which is produced in the ground through the reaction of pollutants under sunlight, damages the lung tissue, reduces crop yield, and affects natural vegetation.

Water Pollutants

Contaminants to water bodies are posed by both point and non-point sources of contamination. Toxic chemicals, heavy metals, and thermal pollution are also usually introduced by the industrial discharge in rivers, lakes, and oceans, rendering water harmful to the aquatic life as well as for consumption. Pharmacological residues, such as antibiotics and hormones, are released into the water body as a result of improper disposal and the effluent of the wastewater, which adds to the antimicrobial resistance and endocrine imbalance in fish (Kümmerer, 2009). One area of concern has been microplastics, or small plastic particles that are formed after breaking down larger plastic wastes or coming into existence in the manufacture of microbeads. Aquatic life consumes these particles, which build up on food webs and, later, can impact the human body by eating fish and drinking contaminated seawater.

Emerging Contaminants

The contemporary technological exploits have also introduced a different category of environmental poisons,

and their long-term impacts are still unsurpassed. Popular nanomaterials used in electronics, medicine and consumer goods contain properties that are exclusive and can easily lead to cellular sickness, as well as are damaging to the ecology through dumping into the environment. They interfere with the hormonal system, and the toxins such as bisphenol A (BPA) and phthalates are linked to reproductive anomalies, developmental disorders, and metabolic diseases (Thompson *et al.*, 2004; Galloway *et al.*, 2017) [6, 23]. Persistent organic pollutants (POPs), PCBs and dioxins are particularly recalcitrant substances not easily degraded in the environment, nor do they exhibit fading properties, nor are they stored in the body fats of animals (Gore *et al.*, 2015) [7]. As they are hard to deal with since they are persistent and poisonous, these new contaminants have become significant challenges in environmental management and the protection of the health of the population. All of these sources of environmental toxicants combine to explain that modern pollution is intricate and interdependent, as well as showing the urgency of adequate monitoring, control, and sustainability (Nel *et al.*, 2006) [18].

Environmental Distribution and Pathways

The environmental toxicants exist, are released, and when they do, they are not found in concentrated forms but rather are dispersed in the environmental spheres through natural processes. They are primarily carried through the air, water and soil whereby pollutants move locally, regionally and internationally. There are possibilities of air pollutants travelling long distances, by wind patterns, and finally, they reach the land or water surface by dry or wet pollution (UNEP, 2019). Another important source of transport is water that contains rivers, lakes, and oceans full of dissolved chemicals, heavy metals, and microplastics. Soil is a sink and the secondary pollutant, as it harbors toxic substances which can subsequently be transferred into the groundwater, crops, or the atmosphere as the secondary source of pollutants. Bioaccumulation is a process whereby toxic substances are accumulated in an organism over a period of time, especially in cases where the rate of intake surpasses the rate of elimination. Most of the environmental toxicants (particularly, heavy metals and persistent organic pollutants) accumulate in fats and body organs, leading to chronic health hazards (Tchounwou *et al.*, 2012) [22]. Biomagnification is when the successive stages of the food chain have a higher concentration of the same substances. Top species in the food web, such as humans, tend to have the greatest toxic load. Ecosystems also transfer pollutants through the food chains. The polluted soil can contaminate the plants, which in turn are eaten by herbivores and passed to carnivores at the trophic levels. There is a particular susceptibility to aquatic systems because the toxins that are taken up by planktons may ultimately find their way to fish, birds, and mammals (Galloway *et al.*, 2017) [6]. Also, certain pollutants are transported long distances, being able to cross their borders as well as impact ecosystems that are far away from their point of emission. Constant contaminants may travel by the wind and oceanic currents, and accordingly, environmental pollution is a transboundary problem where international collaboration is necessary.

Impact on Human Health

Human health is greatly affected by environmental toxicants. The exposure can be done in three forms, which

include inhalation of polluted air, consumption of food and water contaminated by harmful substances, or direct contact with the harmful substances. The health effects also differ with the kind of toxicant, level, exposure time, and individual susceptibility. These are effects that can be short-term and immediate or take years to manifest through repeated exposure, which is chronic (World Health Organization [WHO], 2021) [29].

Acute Toxic Effects

The acute toxic effects are those that are experienced in the short term upon exposure to high doses of toxic materials. Among the most direct impacts would be poisoning, most of the time due to the use of contaminated water, food, or simply being in contact with chemicals, such as pesticides or heavy metals, accidentally. The signs may be nausea, vomiting, dizziness, damage to the organs, and, in severe instances, death. Respiratory distress is another common acute effect, particularly due to the factors that are present in air pollution, like particulate matter, sulphur dioxide, nitrogen oxides, and toxic industrial gases. Patients can complain of breathlessness, coughing, chest tightness, and asthma exacerbations. Exacerbation of chronic lung diseases and acute respiratory infections is very common in highly polluted settings (United States Environmental Protection Agency [EPA], 2022) [2]. There is also skin and eye irritation, which is a consequence of having come in contact with chemical contaminants, industrial solvents, or even contaminated water. The reactions may be mild, such as redness and itching, or harsh, such as dermatitis reaction or even burns. Such exposures are more particularly hazardous to workers in chemical industries and agriculture.

Chronic Diseases

Chronic diseases are greatly linked to long-term exposure to environmental toxicants. One of the most severe consequences is cancer. Arsenic, benzene, asbestos, and some pesticide carcinogenic materials can change the DNA of the cells, causing them to multiply unregulated and create tumors. The chronic exposure, even at a lower dose, causes a considerable risk of cancer over time (International Agency for Research on Cancer [IARC], 2020) [10]. The environmental pollution caused by cardiovascular diseases includes air pollution with fine particulate substances (PM_{2.5}) as well. They may be introduced into the blood, leading to inflammation, oxidative stress, and damage to blood vessels. Therefore, typical people who are affected by long-term air pollution are at risk of having hypertension, heart attacks, and strokes. Neurological disorders are another issue of serious concern. Some of the heavy metals that can slow down brain development and cognitive abilities include lead and Mercury. When exposed to it chronically, memory loss, loss of concentration, change of behaviour, and an increased likelihood of developing neurodegenerative diseases such as Parkinson's and Alzheimer's diseases are possible. Neurotoxicity is also particularly susceptible to children (Landrigan *et al.*, 2018) [13].

Endocrine and Reproductive Effects

The environmental toxicants include some endocrine-disrupting chemicals (EDCs), which disturb the hormonal system of the body. The substances could duplicate or disrupt natural hormones, which distort the normal

physiological processes. This may result in some kind of hormonal imbalance, and this may affect growth, metabolism, immunity and reproductive health. Pesticides, industrial chemicals, and plastic additives, including phthalates and bisphenol compounds, have been linked to infertility and reproductive disorders. Toxic exposure in men may lower sperm quality and sperm count, whereas in women, toxic exposure may cause irregular menstrual patterns and pregnancy problems. Another severe outcome is developmental defects, especially when it is exposed during the pregnancy period. Toxicants may penetrate the placental barrier and impact fetal development, which results in low birth weight, abnormalities at conception, and poor cognitive development. Interventions in early life periods may last throughout life (Diamanti-Kandarakis *et al.*, 2009).

Vulnerable Populations

Some populations become more vulnerable to the toxic impacts of environmental toxicants. Children are particularly susceptible since they are still in the developmental phase of organ development and immune response, and in many instances, they are exposed to a higher level than their body weight. Even low toxic exposure can seriously affect the physical and cognitive development of individuals exposed to low levels of toxins. Expectant mothers are also exposed to greater threats, where toxicants may impact not only the health of the mother but also of the baby. When exposed during the crucial periods of pregnancy, there might be miscarriage, premature birth, or developmental disorders. The older population is more prone as well since they have compromised immunity and underlying medical conditions. Chronic exposure can aggravate the current respiratory or heart diseases. Occupational exposure groups, such as industrial workers, miners, farmers, and waste handlers, are more in touch with hazardous materials. Unless adequate protection is implemented, these people will be at higher risk of acute poisoning, along with chronic diseases and chronic ailments. In general, the consequences of environmental toxicants on human health provoke the necessity of effective preventive, monitoring, and control measures (World Health Organization [WHO], 2021)^[29].

Impact on Ecosystems and Biodiversity

Environmental pollution is a highly threatening factor to the environment because it interferes with the natural mechanisms, as well as changing the habitats and survival of species. These effects can be traced both in water and on land and are usually caused by the eventual ecological imbalance. The toxic materials may be deposited in the living organisms and manipulate reproduction and growth, and eventually lower the resilience and productivity of the ecosystem (United Nations Environment Programme [UNEP], 2019)^[25].

Effects on Aquatic Ecosystems

The aquatic ecological systems are the most susceptible since pollutants are deposited in the water bodies through industrial effluent, agricultural run-offs, sewage effluents, and atmospheric deposition. Among the most direct effects is fish poisoning by harmful chemicals, metallic substances, oil spills, or a lack of oxygen due to the pollution of nutrients. Short-term toxicity may result in mass deaths, and

long-term exposure will cause a loss of growth, reproduction, and immunity (World Health Organization [WHO], 2021)^[29]. The coral reefs, being one of the rich marine ecosystems, are very sensitive to pollutants like sediment, pesticides, petroleum products, and heavy metals. Exposure to toxins compromises the skeleton of the corals, disturbs symbiotic relationships with the algae, and contributes to the corals becoming diseased and bleached. The other important impact would be a reduction in diversity as species that are weak are killed or die, and other species that are more hardy will replace them. This transition alters the arrangement of communities, food resources and ecology of aquatic systems.

Effects on Terrestrial Ecosystems

On the land, environmental poisonous elements are the most significant ones, which cause degradation of soil quality and ecosystem processes. Causal factors leading to eventually reduced soil fertility, altered microbial populations, and a lack of nutrient cycling are accumulated contaminants, e.g., industrial waste, pesticides, and heavy metals, which cause soil degradation (Food and Agriculture Organisation [FAO], 2018)^[19]. The condition of polluted soils may also be incapable of supporting plant-life, lowering the rate of agricultural productivity and protected ecosystems. The toxicity effect of the plant comes about when the roots absorb the toxic soil or water components. Effects of toxicity would inhibit seed germination, decrease growth, cause leaf damage, and decrease the photosynthesis rate. Sensitive vegetation species may begin to vanish in the long term, altering the makeup of vegetation and the habitat structure. Wildlife suffers as a result of exposure to environmental toxicants. Animals can either eat or drink contaminated food or water, breathe in polluted air, or take up toxins by means of the skin. There are physiological stress, reproductive failure, developmental abnormality, weakened immune system, and high mortality. Top predators are also quite susceptible because of their high location in the food chain and their dependence on a variety of food (International Union for Conservation of Nature [IUCN], 2020)^[10].

Bioaccumulation in Wildlife

Bioaccumulation is important in increasing the ecological effects of toxic materials. Long-term pollutants like mercury, pesticides, and specific chemicals from industries end up accumulating in the tissues of organisms over time. Predators up the food chain, such as birds of prey, large fish, and carnivorous mammals, are at increased risk since they feed on contaminated prey at more than one trophic level. The result of these processes may be dire health conditions, decreased fertility rates, and the demise of a population. Food web disruption consists of introducing toxicants into the ecosystem, which influences predator-prey relationships and energy transfer, and affects one or more species in the ecosystem (United States Environmental Protection Agency [EPA], 2022)^[2]. Dispersal of important species may cause cascades in the ecosystem, and this may result in the breaking down of ecological networks and ecological functional diversity.

Ecosystem Imbalance

When there is a cumulative impact of the environmental toxicants, it may lead to an imbalance in the ecosystem.

Extinction, whether caused by direct death or a lower reproduction rate, reduces biodiversity and destabilizes the ecosystem. When the environments become uninhabitable due to pollution, there is a chance of habitat destruction as the species will have to migrate or die. Coral reefs, freshwater systems, wetlands, and forests are very vulnerable to contamination. Another major implication is the compromised ecosystem services. Some of the fundamental gains of healthy ecosystems include clean water, arable soil, climatic control, pollination, and the storage of carbon. By preventing normal ecological functions when toxicants interfere, such services would deteriorate, which would eventually impact human livelihood and sustainable growth (Millennium Ecosystem Assessment, 2005) [14]. Therefore, ensuring that the ecosystems are safeguarded against toxic pollutions is not only essential in preserving biodiversity, but also in preserving the natural systems upon which life on earth relies.

Risk Assessment and Monitoring

Essential elements of environmental toxicology should be risk assessment and monitoring, as this provides the necessary conditions to prevent toxicity through measuring the future risks of toxic substances, and to take the necessary actions to prevent risks to human health and the environment. These procedures entail the identification of toxic substances, the levels of exposure, the negative consequences, and the suitable levels (National Research Council, 2009) [15]. The harmful effects of chemicals on living organisms are determined through the use of toxicity testing methods. These tests might refer to laboratory tests on cell cultures, microorganisms, plants, and animals to test acute and chronic toxicity, carcinogenicity, mutagenicity, and reproductive impacts. The use of alternative techniques, such as *in vitro* testing, computational modeling, and analysis of biomarkers, is becoming increasingly used in modern approaches to cut down on animal testing and enhance the accuracy of the testing (Organisation for Economic Co-operation and Development [OECD], 2018) [19]. Environmental monitoring includes the systematic examination of the pollutants of air, water, soil, and biological materials. Examination of physical and chemical identifies levels of heavy metals, pesticides, and particulate materials, and so on. Biological monitoring applies indicator species and biomarkers to evaluate ecosystem health and pollutant exposure in living organisms (World Health Organization [WHO], 2021) [29].

Management and Mitigation Strategies

To prevent threats to human health, maintain the ecosystems, and support sustainable development, environmental toxicants need to be managed and mitigated. The problem of pollution can be resolved through a multi-level solution, involving a combination of technology, regulation, sustainable business, and involvement of the population in the process. Societies can considerably decrease the risks of environmental toxicity by decreasing the emission of harmful substances and reducing the exposure levels.

Pollution Control Measures

The period of pollution control is aimed at preventing or decreasing the emission of toxic substances at their origin. The emission control measures involve clean-up of the

processes in industries, the use of more efficient energy sources, and the use of filters, scrubbers, and catalytic converters to achieve a clean environment. A shift to cleaner energy sources also contributes to the reduction of harmful gas and particle emissions. Another important element is proper waste treatment. Treatment of industrial effluents, hazardous chemicals, and municipal waste before discharging into the air, water, and soil should be undertaken to ensure contamination of the air, water, and soil is avoided. Chemical neutralization, biological treatment, incineration, and secure landfill are some of the most common methods that are usually used to handle hazardous waste safely. Recycling and minimization of waste also reduce the amount of pollutants coming to the environment. Cleaner production places more focus on manufacturing processes that produce little to no waste and those that consume less toxic material. This strategy will encourage the efficiency of resources, lessening the effect on the environment, and in many instances, it may be economically beneficial due to the cut in material and energy expenditure (United Nations Environment Programme [UNEP], 2019) [25].

Policy and Regulations

Policy frameworks and regulatory mechanisms are important in ensuring that there is control of environmental pollution. The national environmental laws set the standards of emission, waste disposal, and environmental quality such that industries are sufficiently independent in their activities. Compliance is checked by the regulatory agencies, and the penalties aimed at violating regulations are enforced, and the agencies promote environmentally responsible practices. International conventions are also very significant, especially when it comes to cross-national pollutants. The global treaties and conventions cover issues like climate change, hazardous transport of waste, ozone depletion, and persistent organic pollution. International cooperation allows nations to exchange knowledge, technology, and resources to control environmental issues in a better manner (United Nations, 2015).

Sustainable Practices

The adoption of sustainable practices in various fields contributes to the long-term reduction of toxicants in the environment. Green chemistry is concerned with developing chemical products and processes that minimize or avoid toxic substances so that they impose less on the environment and human health. It promotes the utilization of more harmless raw materials, powerless reactions, and biodegradable items. There are cleaner alternatives to fossil fuels in the form of renewable resources like solar, wind, and hydro-power, which will greatly mitigate air pollution and greenhouse emissions. The development of renewable energy infrastructure is a step that helps in the safety of energy and the environment in general. Sustainable agriculture attempts to reduce the consumption of pesticides and chemical fertilisers, which are destructive, by promoting organic agriculture, integrated pest and crop rotation, as well as soil preservation techniques. These plans protect the quality of soil, water, and biodiversity, besides food security in the long run.

Public Awareness and Education

Environmental protection depends largely on education and public awareness. Educated populations tend to engage more in environmentally acceptable practices, embrace

regulation, and engage in conservation programs. Education programs, media campaigns, and community outreach can educate the people on the origins and effects of environmental toxicants. Local environmental management refers to the participation of the community in the management of the environment, as the citizens are involved in monitoring, waste management, planting of trees, and conservation works. Individual and household behavioral transformations, which include limiting plastic consumption, energy saving, segregating waste, and purchasing products that are environmentally friendly, can be used to reduce pollution altogether. In general, environmental toxicants have to be efficiently controlled and managed through the joint effort of governments, industries, scientists, and citizens. Through combining technological innovation, regulatory compliance, sustainable development, and social responsibility, environmental contamination can be reduced or even eliminated, hence protecting the current and future generations.

Future Challenges and Research Directions

Even though there is a massive improvement in protecting the environment, there are many issues that continue to be witnessed in mitigating the increasing load of environmental toxicants. Among the significant issues, it is possible to mention the emergence of new pollutants, such as microplastics, nanomaterials, pharmaceutical decay products, and recently produced industrial chemicals. The chemicals also appear more often in the environmental media and are most likely to be poorly characterised in terms of toxicity, which will make the risk assessment difficult. Their persistence, mobility, and the possibility to target the biological systems at low levels cause enormous mysteries to the environment and the health of individuals (United Nations Environment Programme [UNEP], 2019) [25]. Climate change is another problem that makes the circulation of environmental toxicity difficult. Increased temperatures, changing precipitation regimes, melting ice, and extreme weather conditions have potential impacts on the distribution, transformation, and bioavailability of the contaminants. To illustrate, an increase in temperature could increase the emission of harmful chemicals in the soils and sediments, whereas floods can cause contamination in larger regions. Ecosystems that have undergone stress due to climate change can also be more susceptible to toxic exposure and, hence, even worse effects on biodiversity and ecosystem stability (Intergovernmental Panel on Climate Change [IPCC], 2021) [8]. Advanced monitoring systems with a high degree of detection of pollutants are also in increased demand, which can detect the pollutants in a real-time environment. The conventional methods of monitoring could not capture low levels of contamination or multifaceted combinations of chemicals. Advanced surveillance, early warning systems, and environmental management can be done by emerging technologies like remote sensing, biosensors, artificial intelligence, and high-resolution analytical technologies. Constant surveillance is more especially relevant in fast urbanizing and industrializing areas. The approach used by future research should also be interdisciplinary, based on incorporating such fields as environmental science, toxicology, public health, ecology, economics, and social sciences. Interest from other disciplines is needed in understanding the complete effects

of toxicants, not just in scientific terms, but in policy terms, behavioral terms, as well as the socio-economic side. With this kind of combined research, there would be improved mitigation strategies and sustainable development planning (National Research Council, 2014) [17].

Conclusion

The review reveals the prevalence of environmental toxicants and their significant impact on both human health and the ecosystems. Predominant contributors are industrial effluents, farm chemicals, air pollution, and water pollution, and the upcoming materials as a result of contemporary technology. These toxicants are carried by the environmental routes, are deposited in the biological systems, and disrupt the ecological balance, bringing the loss of biodiversity, making the habitats worse, and causing the human populations to have a greater burden of diseases. The challenge of environmental toxicants is vital to maintaining environmental sustainability and the protection of the health of the people. The lack of potential to reduce pollution can put food security, water quality, and climate stability at risk, and the overall quality of life at risk. Pollution control technologies, effective regulatory frameworks, sustainable practices and population awareness make up the management of pollution. The need to collaborate internationally is thus urgent because the majority of the pollutants, which are exchanged across national boundaries, are transported through atmospheric and oceanic avenues. International agreements, transfer of technology and collaborative research can enhance the individual's ability to manage environmental hazards. It is necessary in the developing nations, particularly to assist the monitoring framework and the enforcement of the laws. The future policy must be placed on preventative practices, cleaner forms of production, utilisation of renewable forms of energy, and environmentally friendly processes of production. New contaminants, improved risk assessment approaches, and the development of new mitigating technologies require continuous research. Lastly, it is not only a human environmental requirement to protect the environment against toxic contamination, but it is a fundamental precept of extending and operating conditions of human beings.

References

1. Aktar W, Sengupta D, Chowdhury A. Impact of pesticides use in agriculture: Their benefits and hazards. *Interdisciplinary Toxicology*, 2009;2(1):1-12. <https://pubmed.ncbi.nlm.nih.gov/articles/PMC2984095/>
2. Agency for Toxic Substances and Disease Registry. Toxicological profile for hazardous substances. U.S. Department of Health and Human Services, 2022.
3. Alloway BJ. Heavy metals in soils: Trace metals and metalloids in soils and their bioavailability. 3rd ed. Springer, 2013. <https://link.springer.com/book/10.1007/978-94-007-4470-7>
4. Carson R. *Silent spring*. Houghton Mifflin, 1962.
5. Food and Agriculture Organization. Status of the world's soil resources. FAO, 2018.
6. Galloway TS, Cole M, Lewis C. Interactions of microplastic debris throughout the marine ecosystem. *Nature Ecology Evolution*, 2017;1:0116. <https://pubmed.ncbi.nlm.nih.gov/28812686/>

7. Gore AC, Chappell VA, Fenton SE, Flaws JA, Nadal A, Prins GS, *et al.* EDC-2: The Endocrine Society's second scientific statement on endocrine-disrupting chemicals. *Endocrine Reviews*,2015;36(6):E1-E150. <https://doi.org/10.1210/er.2015-1010>
8. Intergovernmental Panel on Climate Change. *Climate change 2021: The physical science basis*. Cambridge University Press, 2021.
9. Intergovernmental Panel on Climate Change. *Climate change 2022: Impacts, adaptation and vulnerability*. IPCC, 2022. <https://www.ipcc.ch/report/ar6/wg2/>
10. International Union for Conservation of Nature. *Global biodiversity outlook and conservation assessments*. IUCN, 2020.
11. Jaishankar M, Tseten T, Anbalagan N, Mathew BB, Beeregowda KN. Toxicity, mechanism and health effects of some heavy metals. *Interdisciplinary Toxicology*,2014;7(2):60-72. <https://pubmed.ncbi.nlm.nih.gov/26109881/>
12. Kümmerer K. The presence of pharmaceuticals in the environment. *Chemosphere*,2009;75(4):417-434. <https://pubmed.ncbi.nlm.nih.gov/19261375/>
13. Landrigan PJ, Fuller R, Acosta NJR, Adeyi O, Arnold R, Basu N, *et al.* The Lancet Commission on pollution and health. *The Lancet*,2018;391(10119):462-512. [https://doi.org/10.1016/S0140-6736\(17\)32345-0](https://doi.org/10.1016/S0140-6736(17)32345-0)
14. Millennium Ecosystem Assessment. *Ecosystems and human well-being: Synthesis*. Island Press, 2005.
15. National Research Council. *Science and decisions: Advancing risk assessment*. National Academies Press, 2009.
16. National Research Council. *Environmental health sciences decision making: Risk management, evidence, and ethics*. National Academies Press, 2013.
17. National Research Council. *Sustainability and interdisciplinary research in environmental health*. National Academies Press, 2014.
18. Nel A, Xia T, Mädler L, Li N. Toxic potential of materials at the nanolevel. *Science*,2006;311(5761):622-627. <https://pubmed.ncbi.nlm.nih.gov/16456071/>
19. Organisation for Economic Co-operation and Development. *Guidance document on toxicity testing and assessment*. OECD Publishing,2018.
20. Pope CA, Dockery DW. Health effects of fine particulate air pollution. *Journal of the Air Waste Management Association*,2006;56(6):709-742. <https://pubmed.ncbi.nlm.nih.gov/16805397/>
21. Smith VH, Schindler DW. Eutrophication science. *Trends in Ecology Evolution*,2009;24(4):201-207. <https://pubmed.ncbi.nlm.nih.gov/19246117/>
22. Tchounwou PB, Yedjou CG, Patlolla AK, Sutton DJ. Heavy metal toxicity and the environment. *EXS*,2012;101:133-164. <https://pubmed.ncbi.nlm.nih.gov/22945569/>
23. Thompson RC, *et al.* Lost at sea: Where is all the plastic? *Science*,2004;304(5672):838. <https://www.science.org/doi/10.1126/science.1094559>
24. United Nations. *Transforming our world: The 2030 agenda for sustainable development*. United Nations, 2015.
25. United Nations Environment Programme. *Global chemicals outlook II: From legacies to innovative solutions*. UNEP, 2019.
26. United Nations Environment Programme. *Global environment outlook – GEO-6: Healthy planet, healthy people*. UNEP, 2019.
27. United States Environmental Protection Agency. *Ecological risk assessment guidelines*. EPA, 2022.
28. World Health Organization. *Preventing disease through healthy environments: A global assessment of the burden of disease from environmental risks*. WHO, 2016.
29. World Health Organization. *WHO global air quality guidelines*. WHO, 2021.
30. World Health Organization. *Air pollution and child health: Prescribing clean air*. WHO, 2021.
31. World Health Organization. *Environmental health criteria and monitoring guidelines*. WHO, 2021.
32. Younger PL, Banwart SA, Hedin RS. *Mine water: Hydrology, pollution, remediation*. Springer, 2002.