EXPOSURE AND ECOLOGICAL IMPACTS OF CHEMICAL POLLUTION ON BIODIVERSITY

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***Abstract*— Despite its growing magnitude, chemical pollution has generally been overlooked, especially in developing countries. This has caused this immense global problem the desired intervention and attention from international and national agencies and individuals. This review explores the ecological impacts of chemical pollution on biodiversity. Chemical pollution affects every aspect of biodiversity – affecting all land, air, and water biospheres. A lot still needs to be done to combat chemical pollution worldwide and ensure environmental equality.**

Keywords—Hydrogen; Energy; Developing country; Cost; Renewable

I. INTRODUCTION

In recent years, there has been tremendous progress in science and technology, leading to improved economic, environmental, and social development. Energy is rated a foremost raw material in modern civilization. Thus, the degree of an individual's, family's, and/or community's standard of living or industrialization is measured in terms of energy consumption [12]At present, energy is obtained from fossil fuel (natural gas, coal, petroleum produce) combustion, a minute proportion from nuclear and hydropower and a trace proportion from renewable energy sources (e.g. solar, hydro, tidal wave, wind etc) [12]. However, excessive energy use, most especially from the combustion of fossil fuels, comes with hazardous effects, such as air and water pollution, environmental degradation, and economic difficulties from an increase in energy prices and tensions in access and distribution of energy resources, on the environment, society and economy, leading to negative impart on the world population, including humans, animals and plants. Aside the negative effects on health and environment, there is an increasingly steady depletion of the limited fossil fuel reserves in the world, thus the need for an alternative main energy source(s) and technologies.

For sustainable and secure energy for humans globally, it has become imperative to develop energy systems with little or no negative impact on the environment and society, thus developing green energy systems. "Green" is used in relation to the production of products and processes that cause a reduction in the use and/or release of harmful substances for a safer environment and human health [8]. Thus, green energy systems include several vital elements that affect energy use, such as green alternative and renewable energy sources, energy carriers and energy conversion technologies [12].

A number of studies have presented green hydrogen energy as a reliable alternative to fossil fuel combustion. It has also been identified as the most promising alternate energy

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technology in relation to environmental sustainability, energy security and economic development

A. The E-factor

The E-factor is usually used for comparing the ratio of the mass of waste generated (kg) to the mass of produce (kg). It considers the total amount of waste (including unrecycled solvents and other reagents used and products without further use) generated in a process [8]. In most chemical industries, an E-factor around 0.1 is generally considered good; however, this varies from industry to industry (Table 1) [16].

Table 1: E-factors in the Industry [16]

Industry	Product (tonnes)	E-factor
Oil refining	10^6 - 10^8	<0.1
Bulk chemicals (salt)	$10^4 – 10^6$	<1-5
Fine chemicals	10^2 - 10^4	5-50
Pharmaceuticals	$10 – 10^3$	25-100

B. Pollution

Pollution, which is usually referred to as an unwanted waste of human origin that is released to the environment – atmosphere, water and land, is a threat not only to human health (responsible for every one in every six deaths globally) but also to the planet. Pollution is currently a considerable issue that endangers global health, degrades the Earth's ecosystems, undermines the economic security of nations, and is responsible for an enormous global burden of disease, disability, and premature death [10]. Pollution includes contamination of air (usually by fine particulate matter; ozone; oxides of sulphur and nitrogen); freshwater and ocean pollution (usually by mercury, nitrogen, phosphorus, plastic, and petroleum waste) and land poisoning (usually by lead, mercury, pesticides, industrial chemicals, electronic waste, and radioactive waste) [6] Ambient air pollution, hazardous chemical pollution and soil pollution, collectively regarded as modern pollution, resulting mainly from industrialization and urbanization (that is, forms of pollution produced by industry, energy/electricity generation, petroleum-powered vehicles, construction, mining, mineral processing and mechanized agriculture- massive applications of pesticides and herbicides), are the leading cause of pollution [10] [11] [6]

Pollution is outrageously expensive, amounting from productivity losses, healthcare costs, and costs resulting from damages to ecosystems. However, pollution's costs are largely invisible because they are generally unseen as caused by pollution. The productivity losses and hospital bills of pollution-related diseases are hidden in labour statistics and hospital budgets. This has resulted in the underestimation of the outrageous loss that should be appropriated to pollution, with the consequence of economically based arguments against pollution control [10]. In 2015, the Lancet Commission on Pollution and Health estimated that economic losses from pollution were 6.2% of the global economic output (about US $4,600,000,000,000) and resulted in 16% global death [10].

Cities, the residence of 55% of the global population account for 85% of global economic activity with concentrated energy consumption, construction activity, industry, and traffic, severely affected by pollution [10]. Pollution is closely interwoven with both climate change and biodiversity loss [6]

C. Air Pollution

Air pollution is a major health crisis associated with increased morbidity and mortality [19]. It has been established that air pollution is the cause of 11% of deaths worldwide (over 6·5 million deaths each year and increasing); however, it affects residents of developing nations, most especially the most vulnerable, such as children, children, the elderly and people with chronic diseases (Fuller et al. 2022; Tong 2019; UNEP 2022). Individuals susceptible to the most significant risks of air pollution are those exposed to high fine particulate matter concentrations [19].

A major source of chemical pollution in air is fossil fuels burnt in utilities, industries and motor vehicles. Sulphur dioxide is produced when coal is burnt. It is an ingredient to acid rain and can cause lung damage to people who breathe large amounts of it. Motor vehicles such as cars, trucks and airplanes- produce nitrogen oxides as a byproduct, which also causes acid rain and lung damage to people. Other chemicals that cause air pollution include ozone, carbon monoxide and lead. Air pollution in the form of carbon dioxide and methane raises the earth's temperature, thereby not only to climate change but exacerbating it (Friedman 2021).

Exposure to outdoor fine particulate matter ($PM_{2.5}$) is the fifth leading cause of death globally [19]. In 2019, it was estimated that only 1% of the global population was living in areas that adhered to the WHO's 2021 air quality guideline (annual mean levels of $PM_{2.5}$ of 5 $\mu g/m^3$) [20]. However, in 2022, 9.9% countries (out of 131 countries included in the estimation) have attained the required WHO guideline for annual $PM_{2.5}$ concentrations [7]. In 2019, China and India had the highest percentage of countries with the highest number of deaths resulting from fine particle pollution, with $PM_{2.5}$ of 32 $\mu g/m^3$ and 83 $\mu g/m^3$ resulting in 100 deaths and 70 deaths per 100,000 people, respectively. In Nigeria, $PM_{2.5}$ for each person's annual mean exposure was 70 $\mu g/m^3$, and 32 deaths per 100,000 people as attributed to fine particle pollution [20]. Air pollution is the greatest environmental factor leading to global health threats and accounts for over six million deaths every year [7]. Fine particle air pollution is the primary contributory factor of death as a result of chronic obstructive pulmonary disease (22%). It has also been implicated in stroke (17%), lower respiratory disorders (15%), neonatal disorders (7%), type II diabetes (12%) and ischemic heart disease (14%) [20] as shown in Figure 1.

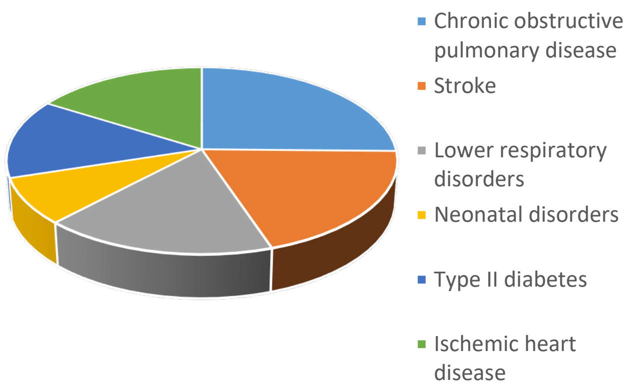

Figure 1: Percentage of death from various diseases attributed to fine particle outdoor pollution

Major sources of fine particle pollutants result from human activities such as fossil fuels burning, transportation, waste burning, chemicals and agriculture (source of methane and ammonia) [20].

An increase in hydrogen concentration in the atmosphere would lead to cooling of the stratosphere, destruction of the stratosphere, increment in noctilucent clouds, and changes in tropospheric chemistry and atmospheric and biospheric interactions. The increment of hydrogen concentration may also affect microorganisms in soil and water with hazardous effects [12].

D. *Chemical Pollution*

Climate change and biosphere degradation are the severe environmental problems being faced by humans globally. The primary causative factor of these problems is caused as a result of chemical pollution, which keeps growing globally (3.5% yearly and is expected to have doubled by 2020) [6]. Chemicals have been detected everywhere on the planet, from the upper atmosphere to the deepest oceans, to remote regions not habited by life, in soil, water, air, and the human food chain [14]. There is evidence that chemical pollution causes both direct and indirect impacts on the ecosystem, leading to instability of populations and community shifts in the wild, thus impairing ecosystem services [13]. Hazardous chemicals can also lead to the extinction of species, and these impacts may be increasingly exacerbated as the resilience of species is reduced because of additional stressors such as global warming [13].

Since 1950, over 140,000 chemicals and pesticides have been produced, with about 5000 produced in large quantities. These are now widely distributed in the environment and responsible for human exposure worldwide [10]. For instance, in a 24-hour period in July 2012, more than 700 new chemicals were entered into the American Chemical Society database, corresponding to a discovery rate of more than 30 new chemicals per hour [2]. Even though a few of these chemicals passed through a series of safety or toxicity assessments in a few high-income countries in the past decade, more than half of these chemicals and pesticides have undergone insufficient safety assessment, and these have repeatedly been the causative factors of disease, death, and environmental degradation [10]. These chemicals have been recognized to be toxic in small doses, combined with other pollutants, or as breakdown products after release into the biosphere and geosphere [14]. They include chemicals and pesticides such as lead, asbestos, dichlorodiphenyltrichloroethane (DDT), chlorofluorocarbons, polychlorinated biphenyls (PCBs), and other emerging chemicals in the past two to three decades such as pharmaceutical wastes, novel insecticides, chemical herbicides, developmental neurotoxicants, endocrine disruptors, and nanomaterials [10]. These new chemicals are of utmost concern because of the increasing movement of chemical production (about 70%) to low-income and middle-income countries where public health and environmental protections are often scant. Another concern is the conglomerate of many contaminated hot-spots, such as communities polluted by toxic chemicals, radionuclides, and heavy metals released into air, water, and soil by active and abandoned factories, smelters, mines, and hazardous waste sites (Landrigan Philip et al. 2018; Landrigan et al. 2018).

The use of stoichiometric amounts of chemicals (such as metals and metal hydrides as reducing agents, e.g., $NaBH_4$, Mg, Zn and Na; chromium (VI) compounds and permanganate as oxidants; mineral and Lewis acids e.g., H_2SO_4, BF_3, $AlCl_3$ and bases such as NaOH as stoichiometric reagents) in industries is a major source of chemical pollution.

Many synthetic pesticides, solvents, refrigerants, chemical feedstocks, intermediates, and unintentional byproducts that are, by design or coincidence, resistant to natural degradation processes. Many of these substances have environmental half-lives measured in years, decades, or centuries ([18]). For instance, chloroform perchloroethylene and chlorodifluoroethane have a half-life of 1850 years, 990×10^6 years, and 13.2 years, respectively. Most of these chemicals, such as trichlorobenzenes, atrazine, carbon tetrachloride, perchloroethylene and monochlorostyrene bioaccumulate in the fatty tissues of living organisms, progressing geometrically as they move up the food chain ([18]).

Chemical pollutants (Figure 2) grouped into organic and inorganic chemicals have contributed majorly to ozone depletion, climate change, and degradation of the biosphere. In the United States, the chemical industry produces about 70% of the hazardous waste generated [8]. Lead and other chemicals are responsible for more than 1·8 million deaths worldwide yearly [6] Incidentally, CO_2 is a major contributor to global climate change in addition to other greenhouse gases like methane and N_2O. The introduction of CO_2 to the natural environment in amounts that cannot be absorbed from the use of fossil products has resulted in serious climate change [16] – failing one of the requirements for sustainable technology. Chlorofluorocarbons (CFCs) and other halogen compounds are the major chemicals causing ozone depletion.

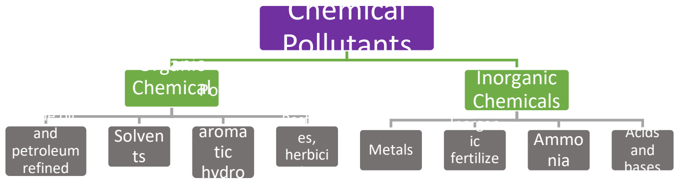

Figure 2: Causes of Chemical Pollution

Chemical pollution is a global emergency concerning the health of all the different ecosystem components, i.e., the environment, animals, and humans [4]. The release, distribution and exposure of hazardous chemical pollutants and their mixtures are often sporadic, thereby increasing chronic exposure of humans to them. There is compelling evidence of their global migration in the form of airborne particles, gases and aerosols, water-borne suspended particles, and dissolved pollutants. Chemicals are also distributed by vectors such as contaminated humans and animals, wildlife and people, waste materials (such as plastics), and nano- and micro-scale synthetic particles (e.g. micro-plastics) [14].

Chemicals also affect all links in the food chain, from the smallest (plankton) to the largest (whale). Chemicals, because of their potential to exert long-standing adverse effects on ecosystems, have their own planetary boundary and also affect other boundaries such as the generation of air pollutants, climate change etc. [9].

Biodiversity

Biodiversity is all the different kinds of life found in an environment, that is, the variety of animals, plants, fungi, and even microorganisms like bacteria that make up our natural world. Each of these species and organisms work together in ecosystems, like an intricate web, to maintain balance and support life.

Biodiversity loss refers to decreased biodiversity within a species, an ecosystem, a given geographic area, or Earth as a whole. This loss in the variety of life can lead to a breakdown in the functioning of the ecosystem where the decline has happened due to a decrease in the niche as a species number is reduced [15]. Biodiversity loss consequently has a great role in the proper functioning of the ecosystem and structure, such as green hydrogen energy production.

Biodiversity is critical for maintaining ecosystem health. The close connection between biodiversity and basic ecosystem services (e.g. primary production and nutrient recycling) as well as final ecosystem services (e.g. provision of quality water and food) [2] is central to the sustainable development goals (SDGs).

Impacts on biodiversity are particularly critical as they have tremendous direct or indirect effects on most if not all, ecosystem services – but are almost impossible to mitigate as soon as they occur on a larger scale [2]. Declining biodiversity lowers an ecosystem's productivity (the amount of food energy that is converted into biomass), including green hydrogen energy generation and reduces the quality of the ecosystem's services (which often include maintaining the soil, purifying water that runs through it, and supplying food and shade, etc.) [15].

Biodiversity loss may occur naturally, for example, due to seasonal changes, natural ecological disturbances – volcanic eruptions, wildfire etc., or human-driven. Human driven biodiversity loss occurs as a result of human activities, such as construction, mining, energy production etc., which are more severe and long-lasting. Five important drivers of biodiversity loss include habitat degradation, invasive alien species, overexploitation, pollution and climate change [15].

Ecological Impacts of Chemical Pollution

Hazardous chemicals may act as a factor that limits the chance of achieving or maintaining good ecological status [1]. Industrial chemicals, including known carcinogens and their residues, have been found in humans' and animals' blood and tissues, mammalian milk, aquatic biota, plants and foodstuffs [14]. Chemical pollution inflicts disastrous losses on wildlife, ecosystems and their services, such as pollination or clean water, on which humans depend for existence [14].

The impacts of chemical pollution on the ecosystem may be direct or indirect. Direct impacts include lethal effects (mortality), which are sublethal effects which involve a decrease of specific capacities of individuals (reproduction, nutrition, respiration, etc), whereas indirect impacts results from the effects that direct impact may cause on ecosystem structure and productivity (eg. green energy production)

1. Terrestrial Ecosystems

Extensive forests are the dwelling of most of the terrestrial species worldwide in terms of diversity in the tropics. These ecosystems face the challenges of deforestation and overexploitation of natural resources, which are involved in tropical biodiversity loss, climate change, and invasive species introduction. Agriculture and mining complicate this picture by representing the main drivers of chemical pollution of water and soil with the release of ubiquitous environmental chemical pollutants such as organochlorine compounds (OCs) and heavy metals [4]. In these areas, the adverse effects of climate change may also increase the impacts of anthropogenic pressures, such as chemical pollution on the ecosystem [4].

Developmental neurotoxicity, reproductive toxicity, and immunotoxicity are the most worrisome and inadequately charted consequences of chemical pollution in humans. Developmental neurotoxicity is caused from exposure to over 200 chemicals, even at low doses at developmental stages of life, commonly used nowadays such as lead, arsenic, methylmercury, organic solvents, organochlorine and organophosphate pesticides. Low doses exposure to pesticides, halogenated flame-retardants, dioxins, environmental chemicals of pharmaceutical origin and toxic metals have been implicated in fertility and pregnancy problems. Exposure to these chemicals at prenatal and early stages of life is linked to an increased incidence of reproductive diseases such as breast cancer, cervical cancer, endometriosis, testicular cancer and uterine cancers. Chemicals that have been identified as toxic to the immune system include perfluoroalkyl acids, and cadmium [6]

A degradation product of octocrylene, i.e., benzophenone, leads to liver morbidity and homeostatic distress in mammals [13].

II. Soil Ecosystems

Mining, agriculture and waste disposal have caused substantial chemical soil pollution. The presence of heavy metals like cadmium, fluoride, manganese, mercury and lead can affect soil quality and reduce the number of microorganisms such as bacteria and fungi that support soil fertility, making land unsuitable for agriculture and any local vegetation to survive [3]; Friedman 2021). Crops grown in contaminated soil also contain residue chemicals and thus become unfit for human and animal consumption.

Aside from over-felling and over-grazing, chemical pollution is one of the causative factors of soil erosion. The chemicals cause erosion by destroying the natural vegetation cover of soil.

III. Aquatic Ecosystems

In addition to nitrate- and phosphate-containing pesticides and fertilizers, fluoride, manganese, cadmium, barium, etc, are water chemical pollutants contaminating surface and groundwater. These chemicals are carried into water bodies in various ways, including aerial spraying of chemicals on cultivated areas, movement in drainage, surface runoff, and blowing of surface dust by effluents of chemicals manufacturing plants.

The aquatic ecosystem is polluted via drainage and irrigation of the field's water overflow of water, careless handling of chemicals by labourer's spillage runoff erosion (Singh et al. 2019). The ocean suffers from a high level of plastic and other chemical pollution, leading to 'dead zones' – where the oxygen level in the water cannot support life. High or prolonged exposure to harmful chemicals has also impacted marine biodiversity [3]).

Aquatic plants supply as much as 80% of the dissolved oxygen essential for aquatic life in ponds, rivers and lakes. Spraying of chemical pesticides in agricultural fields, entering the waterways via runoff can also result in low oxygen levels and the suffocation of aquatic organisms as well as significantly reducing aquatic flora and fauna productivity (Singh et al. 2019).

More than 90 per cent of aquatic ecosystems contain several pesticides. Samples collected from major rivers with mixed agricultural and urban land use influences carry a high percentage of pesticides responsible for aquatic life degradation (Singh et al. 2019).

Nitrates in drinking water are chemical hazards. Certain bacteria in the intestinal canal can convert them into nitrites, which destroy the oxygen carrying capacity of haemoglobin in red blood corpuscles after reaching the blood. Infants whose food is made up with such water have been found to suffer greatly and even die of asphyxia. Fluoride in water causes fluorosis in men. It also creates stomach ailments and mental disorders, while manganese salts generate eye blindness in human beings. Fluoride and manganese salts also affect the growth and development of plants and make them more susceptible to chemical attacks.

Industrial emissions can also cause water pollution. An example is mercury in wastewater from the paper industry. The mercury reacts with bacteria in the water and changes to methyl mercury, which enters into fish such as swordfish and can pose a danger to people who eat it.

Flame retardants are widely detected in soils and in aquatic systems where exposures can cause behavioural, neurological and physiological effects in organisms inhabiting such environments.

IV. Air Ecosystem

Air pollution is a major health crisis, causing cause of 11% of deaths worldwide (over 6·5 million deaths each year and increasing) [19]. Air pollution affects residents of developing nations, especially the most vulnerable, such as children, people above 55 years and people with chronic diseases ([6]; UNEP 2022').

A major source of chemical pollution in the air is fossil fuels burnt in utilities, industries and motor vehicles. Sulphur dioxide is produced when coal is burnt. It is an ingredient in acid rain and can cause lung damage to people who breathe large amounts of it. Motor vehicles such as cars, trucks and airplanes produce nitrogen oxides as a byproduct, which also causes acid rain and lung damage to people. Other chemicals that cause air pollution include ozone, carbon monoxide and lead.

V. Conclusion

Pollution, climate change and biodiversity loss are the primary environmental problems of this age. A solution to combat one will also positively affect the other two since they are all interwoven. Also, One Health and Eco-Health use approaches that believe that the environment, humans, and other animals can affect each other, so protecting ecosystems means protecting ourselves. Therefore, there is a need for a balance in the production and release of harmful chemicals by industrials and human activities to create a safe environment that is harmless to all living organisms, including humans.

Much work has been done to combat chemical pollution globally; however, there is still a long way to achieve environmental equality. Even though it is quite impossible to eliminate chemical waste generation in practice, various ways can be devised to convert the waste into a useful path (such as recycling), leading to pollution prevention. As in high-income and some middle-income countries, new laws and regulations about pollution and its health effects can be enacted in developing countries, which may be based on the polluter-pays principle. Standards should be set at levels that prevent disease and establish principles that promote chemical safety, like a ban on toxic pollutants such as lead, asbestos, and DDT. Also, chemicals can be designed in a way that is effective with little or no toxicity for a safer environment.

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