Effects of Air Pollution and Increased Carbon Emissions on Humans and Animals

I. Introduction

Air pollution and its impacts on human health, animal habitats, and the balance of nature have been concerns for over at least 50 years. As studies continue to emerge, it is evident that the effects of carbon emissions on our environment are more observable than ever.

Urban air consists of gaseous compounds including ozone (O_3), carbon monoxide (CO), sulfur oxide (SO_4) and nitrogen oxide (NO_3). Particles less than 2.5 μm in aerodynamic diameter can lodge deep in the respiratory tract and cause inflammation in the lungs as well as impede cellular function throughout the body. (2)

There have been numerous studies on how air pollution affects animals as well. Fluorine is a common chemical present in the air and widely distributed in soils, water and animal feeds. Research shows that fluorine acts as a protoplasmic poison, by interfering with normal calcification in animals leading to fluorosis, a condition that results in the hardening of bones.

A detailed investigation conducted following the air incident at Donora, Pennsylvania in 1948 unveiled that animals near the affected area were reported to have become ill and that some died during the week of the intense smog. (3)

The effects of air pollution and increased carbon emissions in the 21st century may be substantial, though statistics show that long-term effects are less predictable and foreseeable.

II. Disruption of the Carbon Cycle

The carbon cycle is nature's way of reusing carbon atoms. Humans release carbon dioxide and water to the atmosphere through respiration, in which oxygen (O_2) is taken in and combined with glucose (sugar) to create energy (ATP). The carbon dioxide (CO_2) in the atmosphere goes through stages of photosynthesis to be converted back into oxygen (O_2).

Increased greenhouse gas emissions significantly disrupt the balance between carbon sources. Fossil fuel combustion, deforestation, cement production, gas-powered vehicles and more all contribute to the overwhelming of natural carbon sinks. Higher carbon dioxide (CO_2) concentrations trap more heat in the atmosphere, causing global warming. Ocean acidification is another effect of higher greenhouse gas levels, as oceans absorb about 30% of emitted carbon dioxide (CO_2), which reacts with water to form carbonic acid. Acidification renders marine organisms like corals, shellfish and plankton unable to build calcium carbonate shells or skeletons, causing disruption of marine food webs and ecosystems.

Elevated CO_2 levels may cause forests, tundra and ocean ecosystems to reach tipping points, turning them from carbon sinks to carbon sources. This conversion results in an ecosystem collapse, causing species extinction and loss of biodiversity. Warmer temperatures and pest infestations can kill large areas of boreal forests, releasing stored carbon and causing a positive feedback loop.

There have been examples in history where global warming ultimately led to thermal stratification, increased evaporation and anoxic events. During the times the Cenomanian-Turonian Boundary Event (Ocean Anoxic Event 2) took place, approximately 94 million

years ago, the oceans were critically depleted of oxygen (O_2) and the carbon dioxide (CO_2) presence in the atmosphere was extreme. (5) This combination of events has caused widespread marine extinctions, black shale formations, increased greenhouse gas levels, hydrogen sulfide (H_2S) toxicity and disruptions of biogeochemical cycles. (5)

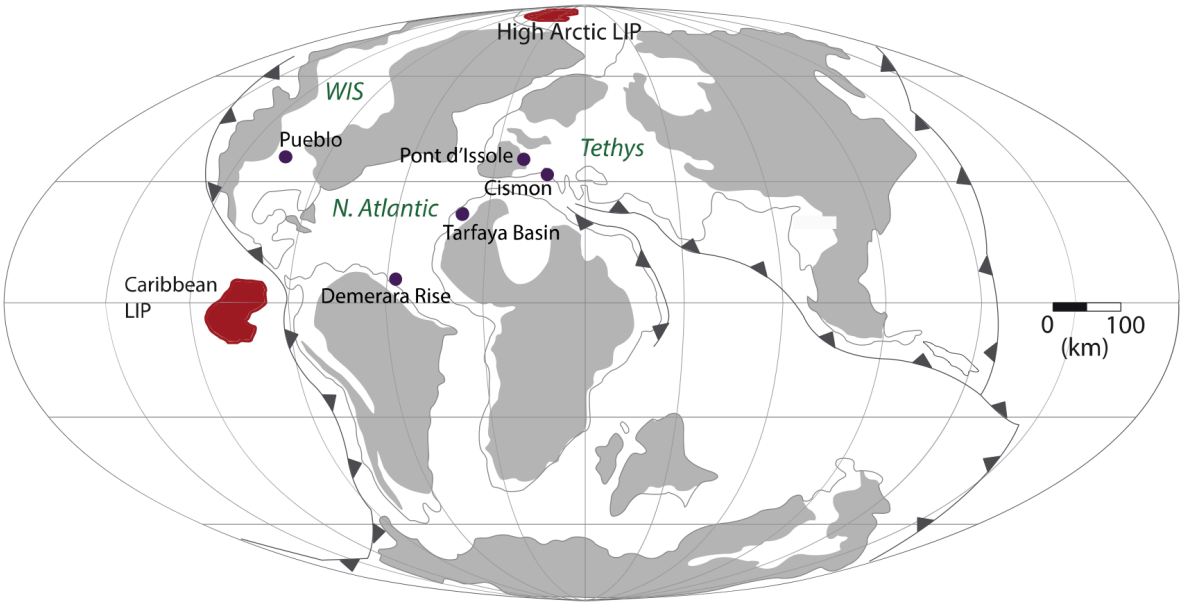

Fig. 1 Paleo-geography of study sites during OAE-2 (5)

The imbalance between carbon sources and sinks has been noted to contribute to a higher incidence of heat-related illnesses in humans. Rising temperatures increase the risk of heat exhaustion, heatstroke and cardiovascular stress. It has also been observed that higher CO_2 levels encourage the growth of allergenic plants (e.g., ragweed), worsening respiratory issues such as asthma. Warmer climates also ease the spread of vector-borne diseases like malaria, dengue and Lyme disease to new regions.

III. Air Pollution

Air pollution derives from a variety of sources, of which the combustion of fossil-fuel products is the principal source. (7) Air pollutants can be classified by their source, chemical composition, size, and mode of release into indoor or outdoor environments. (7) Pollutants directly emitted into the atmosphere are known as primary pollutants, whereas pollutants that form as as result of chemical reactions with other pollutants or atmospheric gases are known as secondary pollutants. (7) This distinction is important from the perspective of abatement. (7)

Incremental doses of pollutants have been noted to sequentially induce protective and injurious cellular responses. (7) Epidemiological, human and animal model studies have demonstrated that diesel exhaust particulates (DEPs) increase airway inflammation and can exacerbate and initiate asthma and allergy. (7) Diesel combustion results in production of DEPs, nitrogen oxides, and precursors of ozone, which are harmful to the lungs. (7)

Numerous *in vitro* and animal studies have investigated the inflammatory effects of ozone on the respiratory tract. (7) Controlled ozone-exposure studies in healthy human volunteers have consistently demonstrated a decrease in forced vital capacity associated

with chest discomfort on inspiration and increased nonspecific airway hyperresponsiveness. (7)

Particulate matter (PM), ozone, nitrogen oxides (NO_x) and volatile organic compounds (VOCs), can generate reactive oxygen species (ROS) when they enter the body. (7) ROS include free radicals like superoxide anion ($O_2^{\bullet-}$) and hydroxyl radicals ($OH^{\bullet}$), which are highly reactive molecules capable of damaging biological macromolecules such as lipids, proteins and DNA. (7) ROS can lead to lipid peroxidation, damaging cell membranes and resulting in the formation of toxic byproducts (e.g., aldehydes) that can further damage cells and tissues. ROS can modify proteins, leading to changes in their structure and function, impairing enzymatic activity and affecting cell signaling pathways. (7) ROS can induce DNA strand breaks, base modifications and cross linking, which may result in mutations, genomic instability, and carcinogenesis. (7)

Pollutants can activate inflammatory pathways, leading to the release of pro-inflammatory cytokines (e.g, TNF-α, IL-6), chemokines (e.g., IL-8) and inflammatory mediators like prostaglandins. Nuclear Factor-kappa B (NF-κB) pathway is activated in response to pollutants and leads to the transcription of genes involved in inflammation, immune response and cell survival. Chronic activation of NF-κB is implicated in many inflammatory diseases, including asthma, COPD and cardiovascular diseases. The activation of immune cells like macrophages, neutrophils and T-cells results in the release of cytokines and chemokines, further promoting inflammation and tissue injury.

Air pollution has been observed to influence epigenetic mechanisms, including DNA methylation, histone modifications and non-coding RNA expression. These changes can result in altered gene expression, contributing to diseases such as asthma, cardiovascular disease and cancer.

Air pollutants like PM2.5 and NO_x can trigger the activation of endothelial cells that line blood vessels, resulting in vascular inflammation, oxidative stress and increased vascular permeability.

IV. Effects on Mental Health

Few studies have examined the adverse effects of air pollution on mental health. Tzivian (2015) summarized the existing research on the effects of air and noise pollution on mental health in adults and extracted a total of fifteen and eight articles on the long-term effects of air pollution and environmental noise, respectively; they surmised that a relationship between air pollution and mental health exists. (Zhiming Yang et al 2021 Environ. Res. Lett.) (1)

A study comparing the Center for Epidemiologic Studies Depression (CES-D) scale score of individuals exposed to less and more air pollution has been done by a group of researchers using the micro data collected from China Famil
y Panel Studies (CFPS) 2010 and 2014. This study suggests that an increase in the concentration of particulates with a diameter of less than 2.5 μm leads to an increased incidence of mental illness. (1)

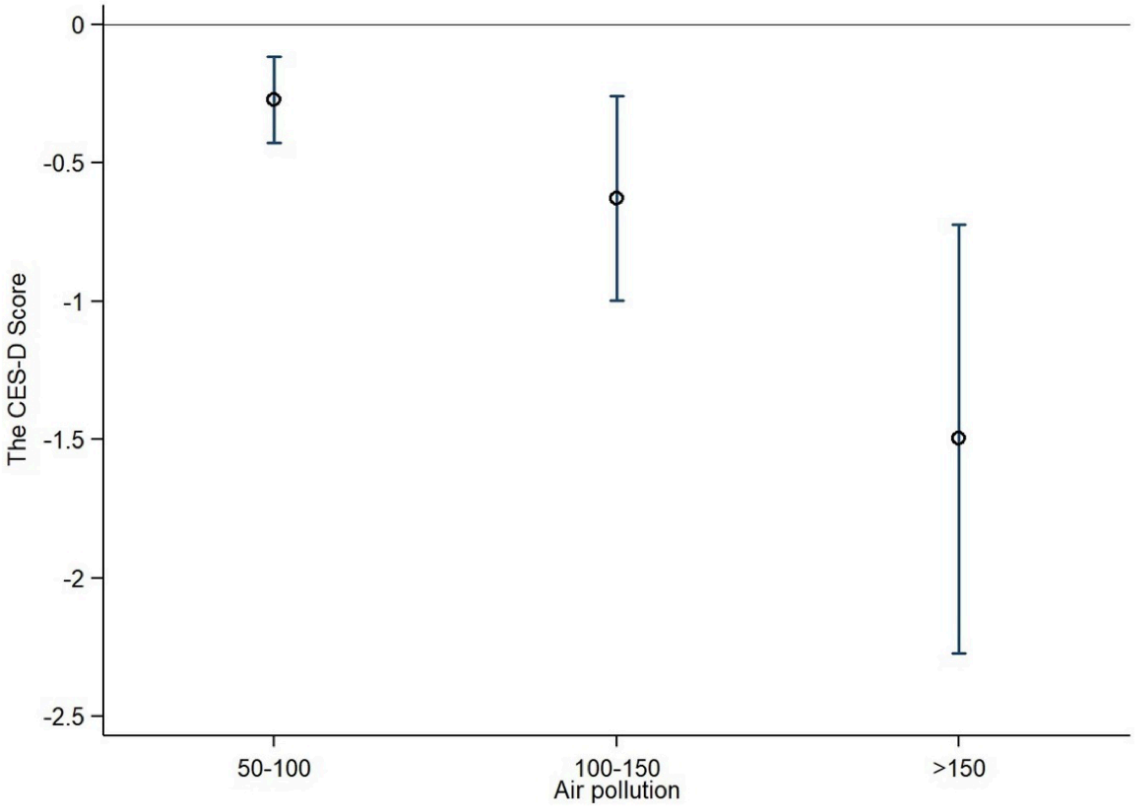

Fig. 2 The potential impact of different levels of air pollution on mental health, according to China's ambient air quality standards (1)

V. Acid Rains

Acid rains are caused by the emissions of sulfur dioxide (SO_2) and nitrogen oxides (NO_x) through the combustion of fossil fuels, which react with the water molecules in the atmosphere (oxidation) to produce H_2SO_4 and HNO_3 acids respectively (Schwartz, 1989). (8) The procedures of formation of these two acids are as follows:

Formation of sulfuric acid (H_2SO_4):
Sulfur in coal burns in oxygen to form sulfur dioxide. Typically, less than 5% of the sulfur is dissolved into SO_2;

$$S\ (from\ coal) + O_2(g) \rightarrow SO_2(g).$$

This SO_2 reacts with O_2 in the atmosphere to form sulfur trioxide (SO_3);

$$SO_2(g) + O_2(g) \rightarrow SO_3(g).$$

This SO_3 reacts with H_2O in the atmosphere to form H_2SO_4;

$$SO_3(g) + H_2O(l) \rightarrow H_2SO_4(aq).$$

Formation of nitric acid (HNO_3):
Nitric oxide (NO) can react with oxygen (O_2) to form nitrogen dioxide (NO_2), which can be broken down again by sunlight ($h\upsilon$) to produce NO and an oxygen radical (O^{2-});

$$2NO(g) + O_2(g) \rightarrow 2NO_2(g),$$
$$NO_2(g) + h\upsilon \rightarrow NO(g) + O^{2-}.$$

This O^{2-} reacts with O_2 to create ozone (O_3);

$$O^{2-} + O_2(g) \rightarrow O_3(g).$$

In the presence of ozone, NO forms more NO_2;

$$NO(g) + O_3(g) \rightarrow NO_2(g) + O_2(g).$$

The O^{2-} reacts with H_2O to produce hydroxyl radical (OH^-);

$$O^{2-} + H_2O(l) \rightarrow 2OH^-.$$

This OH^- reacts with NO to produce nitrous acid (HNO_2), and reacts with NO_2 to produce nitric acid (HNO_3);

$$NO(g) + OH^- \rightarrow HNO_2(aq),$$
$$NO_2(g) + OH^- \rightarrow HNO_3(aq).$$

Acid rains affect humans and animals directly and indirectly. Sulfur dioxide and nitrogen oxide emissions from acid rains cause eye, nose, throat irritations and lung disorders such as dry coughs, asthma, headaches and bronchitis. Toxic metals absorbed by the water, crops or animals that humans consume cause severe nerve damage, lung disorders (asthma and bronchitis), brain damage, kidney problems, cancer, Alzheimer's disease and may even lead to death.

Fish are also gravely affected by acid rains, presenting altered blood chemistry and retarded egg development. Some lakes in Sweden have become so acidic that they are no longer able to support fish life (EPA, 2004). At pH 6, freshwater shrimp cannot live. At pH levels lower than 5, most fish eggs do not hatch. At pH levels lower than or equal to 4.5, no fish can live. Snails, crayfish and certain other invertebrates are very sensitive to acid and may rapidly disappear if acidity increases. (13)

VI. Agricultural Effects

Relatively little attention has been paid in recent years to impacts of air pollution on agricultural crops in urban areas in the modern world. However, in the last 50 years of the twentieth century there were many filtration studies conducted in British cities at the time when high SO_2 levels prevailed. Bleasdale (1973), in his pioneering study in Manchester in the early 1950s, showed dramatic growth improvements ingresses in filtered air compared with ambient air in a series of chamber experiments, which were attributed to SO_2. (10)

A study of Usher (1984), who investigated impacts of ambient London air pollution on a range of vegetable and ornamental species grown in London allotments and gardens. (10) The main part of this work involved growing the plants in chambers ventilated with ambient or filtered air, together with concomitant measurement of SO_2 and NO_2 concentrations at each site. (10) Fig. 3 shows an example of Usher's results for cabbage (*Brassica oleracea*) grown at the Royal Botanic Gardens, Kew, in a southwest London suburb and in Hackney, which is an inner suburb of northeast London.

Site	Mean pollutant concentrations (ppb)		Duration (days)	Effect on dry weight in ambient cf. filtered air
	SO_2	NO_2		
Kew Gardens	15	~16	122	n.s. living leaves –33% stems n.s. roots
	14	19	192	n.s. living leaves +17% stems n.s. roots
Hackney	14	19	169	–15% living leaves n.s. stems –34% roots

Note: n.s., not significantly different.

Fig. 3 The effects of ambient air pollution on *Brassica oleracea* at Kew Gardens and Hackney, London (Usher 1984) (10)

This demonstration of ambient urban air producing positive and negative impacts on growth was later confirmed in the research of Honour (2004) and Honour *et al.* (2009) with diesel exhausts. While the SO_2 levels are somewhat high for the developed world cities at the present time, the NO_2 concentrations are highly realistic. (10)

While there must be concerns for impacts of air pollution on urban ecosystems, gardens and allotments in developed countries, the problem is infinitely more serious in the developing world. (10) Urban agriculture plays a paramount role in nutrition of the very poor. Reduced yields inevitably lead to higher prices, while effects on nutritional value will also have serious consequences. It has already been noted that crop yield was massively reduced and pest attacks greatly increased in Chongqing (Zheng *et al.* 1996). (10)

VII. Disruption of Livelihoods

Communities, particularly those in urban areas with high pollution levels, may experience reduced quality of life, limiting outdoor activities, reducing tourism and decreasing property values. The impact of pollution is often more pronounced in low-income areas. (11)

Coral bleaching, deforestation and loss of biodiversity caused by climate change and pollution reduce the appeal of eco-tourism destinations, impacting local economies reliant on tourism earnings. Poor air quality and heatwaves pose a serious health risk for tourists as well, leading to reduced footfall in tourist-dependent regions. (11)

Rising sea levels, desertification and extreme weather events linked to increased carbon emissions can make certain areas uninhabitable, forcing people to migrate. For instance, island nations and coastal regions are at high risk. Displacement due to environmental degradation can lead to overcrowding in urban areas, straining infrastructure, services and job markets. (11) Just one year ago, many Ethiopian pastoralists were forced to go job hunting after being affected by a severe drought, worsened by climate change. (12) It has been reported that an Ethiopian from Kebribeya district, a region of semiarid plains, lost nearly all of their livestock to a devastating drought that struck the Horn of Africa. (12)

Indigenous communities, particularly those dependent on forest or coastal resources, are often uprooted from their ancestral lands due to pollution or resource depletion, threatening their cultural identity and economic stability. (11)

High levels of air pollution increase the incidence of respiratory and cardiovascular diseases among workers, leading to absenteeism and reduced labor productivity. Extreme weather events and heatwaves can overwhelm energy infrastructure, leading to blackouts that disrupt industries and services reliant on stable energy supply. Industries are often forced to invest in pollution control measures or transition to cleaner technologies, which can impose high initial costs, particularly for smaller enterprises. (11)

Increased incidence of air-pollution-related illnesses like asthma, COPD and cardiovascular diseases places a financial strain on individuals, communities and governments. For low-income families, this can mean a choice between healthcare and other essentials. Chronic health problems caused by air pollution reduce life expectancy and workforce participation, particularly in vulnerable populations, contributing to long-term economic losses. (11)

Environmental degradation, extreme weather events and pollution-related infrastructure failures can interrupt supply chains, affecting global trade and manufacturing. Pollution of air, water and soil reduces the availability of natural resources, driving up costs for industries and consumers. For instance, water scarcity due to climate change impacts agriculture, energy production and urban water supplies. (11)

VIII. Disruption of the Wildlife

Air pollution poses significant threats to the preservation of wildlife. It has been observed that ground-level ozone and particulate matter can block sunlight, affecting plant growth and the photosynthetic activity that many species rely on for food and shelter.

Airborne pollutants such as PM2.5, PM10 and carbon monoxide is known to irritate or damage the respiratory systems of animals, decreasing survival rates, especially in species with sensitive lungs like birds. Long-term exposure to air pollution weakens immune systems, making animals more susceptible to diseases and infections.

Pollutants eventually settle into ecosystems, where they accumulate in plants and small organisms leading to the toxification of the food chain, harming predators like birds of prey, large fish and mammals.

Altered weather patterns and temperatures caused by pollution-related climate change have been noted to confuse migratory species like birds, disrupting their migration routes and timing. This occurrence can ultimately lead to significant ecological consequences, causing birds that arrive at the breeding grounds too early or too late to miss the peak availability of critical resources such as insects, seeds or nectar. This greatly reduces their chances of successful reproduction. Migratory birds also play key roles in pollination and seed dispersal. Timing shifts can disrupt these processes, affecting ecosystem health.

Environmental pollution fundamentally affects reproductive abilities in animals by altering the production or signaling efficacy of sex hormones. A variety of chemical pollutants, for instance, can interact with steroid hormone receptors directly or indirectly, altering levels of blood sex steroids and disrupting sexual development. Such chemicals are collectively referred to as endocrine-disrupting chemicals (EDCs). For example,

ethinyloestradiol, an oestrogen commonly used in contraceptive pills, can enter the environment via urine (Johnson & Williams 2004) and has been shown to induce physiological feminization in wild fish through its interaction with oestrogen receptors (Jobling *et al.* 1998, Lange *et al.* 2009). (13) Various other chemical pollutants that mimic endogenous steroids are also known to interact directly with oestrogen receptors (e.g. bisphenol) and androgen receptors (e.g. the livestock growth promoter trenbolone), with downstream consequences for reproductive physiology. (13)

Such changes in sex hormone levels can have repercussions for the development of reproductive anatomy and morphology in organisms. For example, in Lake Apopka, Florida, exposure of American alligators (*Alligator mississippiensis*) to a mixture of chemicals - including a spill of dicofol and DDT, agricultural runoff such as pesticides, and sewage treatment outflow - resulted in females exhibiting abnormal ovarian morphology and unusually prominent polyovular follicles, while males developed poorly organized testes and small phalli (Guilette *et al.* 1994, 1995, 1996). (13) Furthermore, developmental exposure of amphibians to the widespread herbicide atrazine has been shown to induce reproductive malformations due to feminization of males. (13) This includes the anomalous development of multiple gonads (Hayes *et al.* 2002*a*), altered testicular anatomy (Tavera-Mendoza *et al.* 2002, Hayes *et al.* 2003), development of ovotestes and testicular oocytes (Hayes *et al.* 2006, 2010, Murphy *et al.* 2006) and hermaphroditism (Hayes *et al.* 2002*a,b*) (13)

IX. Conclusion

It is evident that consequences of irresponsible actions which humans indulge in without a care about the environment are bound to get more and more discernible under current circumstances.

In consideration of the fact that a notable lot of the environmental problems of today's world arise from air pollution, it would only be rational to assume that the underlying solution is to minimize the release of pollutant gases into the atmosphere. The damages of air pollution must never be understated for many reasons.

The carbon cycle is visibly disrupted due to the extreme amount of carbon gases in the atmosphere compared to oxygen, this is also referred to as global warming as carbon gases let more heat to trap inside of the atmosphere.

Air pollution stands to be a toxic threat to mainly respiratory health in humans and animals, as well as other vital organs. Long-term effects are still to be monitored for an exact viewpoint on its importance, though it has been shown that air pollution decreases lifetime expectancy and increases occurrence of mental health diseases in humans.

It is important to know that the Earth is not ours, it is for many species to share. It is important to live by that principle as the damages we do to our environment affects some other species like freshwater fish worse than they do us.

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