A Comprehensive Systemic Review on Impacts of Air Pollution on Animals Health

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Abstract

The air pollution shows one of most impactful environmental threats on animal health of the 21 century, but non-human animals remain under characterized than human health effects. This review analyses the evidence on relation between impact of air pollutants and health issues across wildlife, domestic animals and captive populations. From recent research, epidemiological studies and mechanistic investigations, we examine the many effects of ozone, sulphur dioxide, particulate matter, heavy metals, and nitrogen oxides on vertebrate and invertebrate species. The evidence represents that human health impacts specially neurologic and respiratory disorders parallel associated with species-specific vulnerabilities with behaviour, anatomy and ecological niche. The cardiovascular and reproductive outcomes remain underrepresented in the veterinary literature compared to human studies. The haematological effects in urban wildlife, population-level declines in birds associated with ozone exposure and changing the behaviour of invertebrate by air pollutants. This review identifies the critical knowledge gaps, combined effects of pollutant mixtures, scarcity of research on cats and long term impacts on population of sub-lethal exposures, which helps to public health protection, wildlife conservation and veterinary guidance.

Keywords: respiratory disorder, wildlife, heavy metals, ozone.

Introduction

Air pollution is a major global health threat and the second leading risk factor for early death in humans, with about 7.9 million deaths occurs by the air pollution in 2023. The 2025 State of Global Air report confirms that the air pollution link to a broad range of human health outcomes, including cardiovascular disease, stroke, respiratory diseases such as asthma and chronic obstructive pulmonary disease (COPD), various types of cancers, neurologic disorders, adverse maternal and infant health outcomes (Adjei and Afriyie, 2025). These well-documented risks have prompted major policy interventions, including the US Clean Air Act's regulation of six criteria air pollutants: ozone, carbon monoxide (CO), nitrogen dioxide (NO_2), lead (Pb), coarse and fine particulate matter (PM_{10} and $PM_{2.5}$), and sulphur dioxide (SO_2) (Saxena and Sonwani, 2019).

The effects of air pollution on other than human are poorly characterized, due knowledge gap occurs to recognizing the ventilation rates, outdoor housing, and sustained contact with smoke and other pollutants in domestic animals.

The understanding to how air pollution affects animals is crucial for animal's welfare and conservation but also because animals are most important part of ecosystem to maintain its sustainability. This review synthesizes the published literature on associations between environmental air pollution and health outcomes across domestic animals, wildlife, and captive populations, describing effects on individual and population health, highlighting critical gaps, and outlining priorities for future research.

Major Air Pollutants

Gaseous Pollutants

- **Ozone (O_3)** is a secondary pollutants in troposphere when reacts with nitrogen oxides (NO_x) and volatile organic compounds (VOCs) in the presence of sunlight, which enters in plant leaves and reduces photosynthesis, growth and increasing vulnerability to pests and disease with a series of effects on herbivores and higher trophic levels. Ozone for animals acts as a potent oxidant causing respiratory inflammation and tissue damage.
- **Sulfur dioxide (SO_2),** primarily from industry and energy production, deposits as acid rain, altering the chemical composition of soils and water bodies, disrupting ecosystems, and contributing to biodiversity loss.

- **Ammonia (NH_3) and Nitrogen oxides (NO_x)** are originate from agricultural activities and combustion processes, respectively. These pollutants contribute to nitrogen deposition in terrestrial and aquatic ecosystems, leading to soil acidification, eutrophication, and altered plant community composition that affects habitat quality for animals (Kumar, *et al.,* 2020).

Particulate Matter

It is a generic term describing solid and liquid particles suspended in air, classified by aerodynamic diameter. PM_{10} (coarse particles ≤10 μm) primarily reaches the upper respiratory system, while $PM_{2.5}$ (fine particles ≤2.5 μm) penetrates deep into lung alveoli, and $PM_{0.1}$ (ultrafine particles) can translocate into the bloodstream and distribute throughout the body . The composition of PM varies by emission source like biomass combustion, industrial activities, mining, and vehicular traffic, includes nitrates, ammonium, elemental carbon, organic carbon, sulphates, and geological materials (Thangavel et. al., 2022).

Critically, PM functions as a "universal carrier" for multiple pollutants, particularly metals and metalloids. PM metal complexes contain a diversity of potentially toxic elements, including cadmium, chromium, arsenic, lead, mercury, aluminum, zinc, manganese, and nickel. The quantity and types of metals depend on emission sources, with industrial activities alone releasing an estimated 69,591 tons of metals annually into the atmosphere through fine PM, with Australia, Brazil, China, and India as major contributors (Ellwanger *et. al.,* 2025).

Heavy metals

These including cadmium, chromium, lead, and mercury, which travel long distances in the atmosphere, deposit into ecosystems, and subsequently bio-accumulate in organisms and bio-magnify through food chains. This property makes top predators particularly vulnerable to metal toxicity even when ambient concentrations are low.

Evidence in Domestic Animals

A recent scoping review identified 29 studies examining associations between ambient air pollution and health outcomes in domestic animals, with publications increasing in recent years, reflecting growing recognition of contribution of air pollution to animal health. Studies including cattle, sheep, goats, horses, and dogs, with reported outcomes spanning ophthalmologic, immunologic, cardiopulmonary, neurologic, metabolic, reproductive, behavioural, performance, production, and mortality.

Livestock Studies

Cattle, sheep, and goats comprised 41% of domestic animal studies. Research has examined effects on production parameters like milk, meat wools etc., reproductive success, and respiratory health.

Canine Studies

Calderón-Garcidueñas *et. al.,* 2001; reported that dogs are most affected species from air pollution and mainly impacts on respiratory and cardiac disorders. Canines chronically exposed to high pollution levels in Mexico City represented significant respiratory pathology, including epithelial damage, inflammation, and remodelling of airways.

Many research represented that the air pollutants shows neurological effects on dogs by DNA damage in nasal and brain tissues, which is related with evidence of chronic brain inflammation and neuro-degeneration.

Some other canine studies have also explored ophthalmologic, neoplastic, and behavioural disoders in less developed areas.

Equine Studies

Horses constituted about 28% of domestic animal studies, which focused primarily on respiratory outcomes, reflecting horse high ventilatory rates and frequent outdoor housing. Recurrent airway obstruction (heaves), a condition resembling human asthma, has been associated with exposure to airborne particulates and endotoxins from hay and bedding. However, ambient air pollution studies remain limited relative to indoor air quality research in stables (Couetil, *et. al.,* 2016).

Impacts on wildlife

The impact of air pollution on wildlife increases considerably behind domestic animal studies, despite the potential for population-level consequences. However, emerging studies are beginning to document physiological and ecological impacts across diverse taxa Vishwakarma, *et. al.,* 2026).

Urban bats: mammalian wildlife

A pioneering study of Egyptian fruit bats (*Rousettus aegyptiacus*) in Israel provides the first evidence of air pollution effects on wild mammal health. Researchers assessed $PM_{2.5}$ exposure and blood haemoglobin levels in 10 bat colonies across an urbanization gradient. They found a significant negative correlation between $PM_{2.5}$ exposure and haemoglobin concentrations: bats roosting and foraging in highly urbanized, polluted areas exhibited haemoglobin levels 25% lower than those in rural areas.

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This study is particularly significant because bats account for more than 20% of mammalian species (~1,500 species) and provide critical ecosystem services including pollination, seed dispersal, and insect control. Urbanization dramatically affects bat populations, reducing abundance and diversity while creating attractive habitats for synanthropic species. Air pollution may represent an underappreciated threat to urban bat conservation (Gal, *et. al.,* 2025).

Avian Populations and Ozone

Birds may be especially vulnerable to air pollution due to their high metabolic rates, efficient respiratory systems, and frequent exposure during migration and foraging. Recent epidemiological studies have reported significant declines in avian populations in Central Europe and the United States associated with air pollution, particularly ozone.

Ozone exposure causes oxidative stress in birds, adversely affecting health through multiple pathways. Laboratory experiments have documented respiratory tissue damage, reduced lung function, and increased susceptibility to respiratory infections. At the population level, ozone-related habitat degradation including reduced food availability and altered plant communities, may compound direct toxic effects (Richard, *et. al.,* 2021).

Lethal and sub-lethal effects on invertebrates

Terrestrial invertebrates, despite their important roles in pollination, decomposition, and food webs, have received minimal attention in air pollution research. A comprehensive literature review commissioned by Natural England examined lethal and sub-lethal impacts of six major pollutant groups like ammonia, nitrogen oxides, VOCs, ozone, PM, and heavy metals on invertebrates (Ryalls, *et. al.,* 2024).

The review highlighted substantial evidence gaps across all pollutant groups, particularly regarding direct physiological impacts and the combined effects of multiple pollutants. Most studies have focused on a limited number of model species (e.g., honeybees, *Drosophila*), leaving the vast majority of invertebrate taxa unstudied.

Effects on ecosystem

Air pollution impacts extend beyond direct toxicity to animals through ecosystem modification. The European Environment Agency reports that 73% of EU-27 ecosystems exceeded critical loads for eutrophication from nitrogen deposition in 2022. Excess nitrogen alters plant community composition, favouring insectivorous species at the expense of biodiversity. These vegetation changes cascade through food webs, affecting herbivore food availability, habitat structure, and predator-prey dynamics.

Ozone damages agricultural crops and forests, with estimated losses of €1.3 billion for wheat and €680 million for potatoes across Europe in 2022. In 2022, 62% of total forest area in 32 European countries exceeded critical ozone levels set to protect forests. Forest degradation reduces habitat quality for countless animal species, from canopy-dwelling insects to cavity-nesting birds (Wim de Vries, *et. al.,* 2024).

Heavy metal deposition from atmospheric sources contaminates soils and water bodies, with subsequent bioaccumulation through food chains. Top predators, including raptors, otters, and large carnivores, are at greatest risk from biomagnified metals. Aquatic ecosystems are particularly vulnerable: countries report that the main pollution pressure on surface waters (52%) is linked to diffuse sources such as atmospheric deposition.

Mechanisms of Toxicity

Endocrine Disruption

Several air pollutants, including certain metals and polycyclic aromatic hydrocarbons (PAHs) carried by PM, possess endocrine-disrupting properties. These compounds can interfere with hormone synthesis, receptor binding, and metabolism, potentially affecting reproduction, development, and stress responses. Reproductive effects remain understudied in animals despite their potential population-level significance.

Respiratory Deposition and Clearance

The respiratory system represents the primary route of entry for airborne pollutants. Particle deposition depends on size, with larger particles (PM_{10}) depositing in the upper airways and smaller particles ($PM_{2.5}$, $PM_{0.1}$) reaching alveoli. The lungs possess clearance mechanisms, including mucociliary transport and alveolar macrophages, but these become overwhelmed during chronic high-level exposure (Xing, *et. al.,* 2016).

Accumulation of PM in lung tissue, termed anthracosis in environmental exposure contexts and pneumoconiosis in occupational settings results in black pigmentation visible microscopically or macroscopically. This PM deposition triggers chronic inflammation, fibrosis, and impaired gas exchange. Importantly, deposited PM serves as a reservoir of toxic metals that slowly release into lung tissue and potentially translocate systemically.

Systemic Translocation and Metal Toxicity

Ultrafine particles ($PM_{0.1}$) and soluble metal components can cross the alveolar-capillary barrier and enter the bloodstream, distributing to distant organs including heart, liver, brain, and reproductive tissues. Once deposited, metals exert diverse toxic effects (Kwon, et. al., 2020):

Carcinogenicity: Arsenic, cadmium, chromium, and nickel are classified as human carcinogens.

Enzyme inhibition: Metals bind to sulfhydryl groups in enzymes, disrupting metabolic pathways.

Oxidative stress: Many metals (e.g., iron, copper, chromium) catalyse Fenton reactions, generating reactive oxygen species that damage lipids, proteins, and DNA.

Neurotoxicity: Lead, mercury, and manganese interfere with neurotransmitter synthesis and function.

Neuro-inflammation and Blood-Brain Barrier Disruption

The neurologic effects observed in dogs from polluted environments align with emerging understanding of how air pollution affects the central nervous system. Ultrafine particles and soluble pollutants may enter the brain via two routes: direct translocation along the olfactory nerve from the nasal cavity, or crossing the blood-brain barrier after systemic absorption. Once in the brain, pollutants trigger microglial activation, cytokine release, and neuro-inflammation processes implicated in neurodegenerative diseases (Costa, *et. al.,* 2020).

Clinical and Population Consequences

Wildlife Populations

For free-ranging species, isolating pollution effects from other environmental stressors remains challenging. However, evidence suggests multiple impacts:

- **Respiratory tissue damage:** Documented in mammals and birds from polluted areas.
- **Neurologic disorders:** Associated with heavy metal poisoning, affecting coordination, behaviour, and survival.
- **Reproductive failure:** Pollutants interfere with hormone production, disrupt mating cycles, and alter parental behaviour.
- **Reduced breeding success:** May result from direct toxicity or indirect effects on food availability.
- **Migration disruption:** Haze and reduced visibility can disorient migrating birds, causing navigation errors and landing in unsuitable habitats.
- The real concern for wildlife is long-term, cumulative effects that may not be immediately visible: population declines, altered genetic composition, and disrupted behavioural patterns that affect species persistence (Sokan-Adeaga, *et. al.,* 2023).

Companion Animals

Veterinarians in polluted regions report increasing presentations of animals with pollution-related conditions. During smog seasons, respiratory distress becomes the most common problem encountered, with animals developing throat irritation, coughing, wheezing, and if untreated, asthma. Street animals like dogs, cows, and buffaloes are worst-hit due to constant outdoor exposure without protection or shelter.

Long-term exposure triggers cardiovascular problems and genetic damage. Pollutants can alter DNA, leading to poor breeding outcomes and birth defects. The lifespan of stray animals is often shortened by several years compared to indoor animals.

Livestock

For livestock, air pollution impacts extend to economic consequences through reduced productivity. Ozone exposure decreases crop yields, affecting feed availability and cost. Direct health effects in animals may reduce weight gain, milk production, and reproductive success. The livestock sector's contribution to air pollution creates a feedback loop whereby animal agriculture degrades air quality, which in turn affects animal health and productivity (Shah, *et. al.,* 2025).

Knowledge Gaps and Future Research Directions

This review identifies substantial gaps in the current evidence base that limit our understanding of air pollution impacts on animal health and our ability to provide evidence-based guidance.

Outcome Measures

Cardiovascular and reproductive outcomes are notably underrepresented relative to human literature. Given that cardiovascular disease is a leading cause of pollution-related mortality in humans, understanding cardiac effects in animals is essential. Reproductive effects could have profound population consequences yet remain minimally studied.

Long-term, longitudinal studies tracking individual animals over time are lacking. Most research employs cross-sectional designs, limiting causal inference and ability to detect cumulative effects.

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Species Coverage

Cats remain entirely absent from the published literature on ambient air pollution effects, despite their popularity as companion animals and unique exposure patterns. Many cats spend time outdoors, yet their smaller size, grooming behaviours, and different respiratory physiology may alter pollution susceptibility compared to dogs.

Wildlife research has concentrated on a few accessible species (e.g., bats, birds), leaving most taxa unstudied. Invertebrate research, despite recent attention, covers only a tiny fraction of species and lacks standardized methodologies (Tan, *et. al.,* 2020).

Susceptibility Factors

Research has not adequately addressed factors that may modify susceptibility, including:

- Age (neonates, juveniles, aged animals)
- Breed or genetic background
- Pre-existing disease (respiratory, cardiac, metabolic)
- Nutritional status
- Concurrent environmental stressors (temperature, humidity, noise)

Exposure Assessment

Few studies have incorporated personal exposure monitoring or considered the complex mixtures of pollutants to which animals are exposed. Most rely on ambient monitoring station data, which may poorly represent individual animal exposure, particularly for animals with variable indoor/outdoor time or those that move across pollution gradients.

The combined effects of multiple pollutants remain virtually unstudied, despite realistic exposures involving complex mixtures rather than single agents.

Intervention and Mitigation

Evidence for effective interventions to protect animals from air pollution is extremely limited. No studies have evaluated the efficacy of air purifiers, masks, housing modifications, or pharmacological prophylaxis in veterinary patients. Guidance for pet owners and livestock producers relies on extrapolation from human recommendations rather than species-specific evidence.

Conclusions

Air pollution represents a significant and growing threat to animal health across domestic, wild, and captive populations. Evidence demonstrates parallels with human health impacts, particularly respiratory and neurologic effects, while also revealing species-specific vulnerabilities. Cardiovascular and reproductive outcomes remain understudied relative to their importance. Emerging research documents haematological effects in urban wildlife, population-level declines in birds associated with ozone exposure, and disruption of invertebrate behaviour by air pollutants.

Critical knowledge gaps include the absence of research on cats, limited studies on cardiovascular and reproductive outcomes, insufficient characterization of combined pollutant effects, and lack of evidence-based mitigation strategies. Advancing this field requires investment in longitudinal studies, personal exposure assessment, mechanistic investigations, and intervention trials.

Veterinarians, wildlife managers, and conservation biologists must recognize air pollution as an emerging risk factor for animal health. Integrating air quality considerations into clinical practice, habitat management, and species conservation planning is essential.

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