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Photochemical Smog: Shocking Effects and Remedy

E.G. Kazerooni

Canadian Scientific Researchers, Richmond Hill, ON, Canada, L4C1R9

Abstract

A distinct kind of air pollution, photochemical smog was initially identified in Los Angeles in the 1940s. A brown haze is produced above cities by a combination of pollutants called photochemical smog, which is created when nitrogen oxides and volatile organic compounds (VOCs) react with sunlight. Carbon oxides, nitrogen oxides, sulfur dioxide, suspended particulate matter, ozone, and volatile organic compounds are the main air pollutants that cause photochemical smog. In many places, this kind of air pollution is a major issue that harms children, the elderly, and those with heart and lung diseases. Ozone and PAN are the primary agents of harm. Rubber, plastics, paints, dyes, metals, stone, concrete, clothes, and other materials can all deteriorate more quickly in the presence of smog. Although ozone formation has a non-linear reliance on precursor emissions, photochemical ozone concentrations can be reduced by lowering NOx and hydrocarbon and other VOC emissions. The combination of sunlight, fog, and air contaminants produces smog. By producing reactive oxygen species, air pollution can cause oxidative stress in people. Unexpected health hazards could arise if these mutualistic micro biota are disturbed, particularly for infants and young children. Photochemical Smog generation could be reduced by using sophisticated techniques to remove sulfur and nitrogen in fossil fuels. The study promotes proactive, possible remedies to protect air quality and advance a sustainable, healthy future.

Keywords: photochemical smog, shocking effects and remedies

Full length article **Corresponding Author*, e-mail: elhamghasemi@gmail.com

1. Introduction

High amounts of chemicals released into the atmosphere by human activity or natural phenomena are referred to as air pollution. Primary air pollutants are released into the atmosphere directly, and secondary air pollutants are created when primary pollutants react with elements that are typically present in the atmosphere (Table 1). Urban air was dominated by main pollutants during the 20th century, but secondary contaminants are now important. Acid deposition from coal burning and motor vehicle exhaust, industrial smog from burning coal, and photochemical smog from industrial and motor vehicle emissions are the three main issues with outdoor air pollution [1]. A special kind of air pollution called photochemical smog is brought on by the interaction of sunlight with pollutants such as nitrogen dioxide and hydrocarbons. It is particularly prevalent in urban areas with plenty of motor vehicles and sunny, warm, dry weather [2]. In cities with heavy traffic and industrial activity, brownish haze, photochemical smog is generated by NO_2 and other pollutants, is widespread.

2. Causes of Photochemical Smog

A condition known as photochemical fog is brought on by a photon's energy, or wavelength, being absorbed by an atom, molecule, free radical, or ion. It can happen anywhere there are significant and ongoing emissions of major air pollutants. The persistence and intensity of photochemical smog are significantly influenced by location and climate. Topography, which shifts air masses both horizontally and vertically, and temperature inversion, which traps pollutants close to the earth's surface, are two factors that affect its creation. Carbon oxides, nitrogen oxides and nitric acid, sulfur dioxide and sulfuric acid, particulates, ozone, and volatile organic compounds are the main air pollutants that cause photochemical smog (Figure 1). Hydrocarbons and nitrogen oxides involved in these processes, which are irrigated by sunshine. These processes, which involve nitrogen oxides and hydrocarbons released from cars, are watered by sunshine. Photochemical smog, which is more prevalent in cities with sunny, warm, dry weather and a high concentration of motor vehicles, is thought to be an issue of modern industrialization [3].

3. How smog is formed

Under the sun, smoke and fog combine to generate a bothersome mixture of gasses and airborne particles known as smog. It has a direct connection to the land's terrain and weather. Warmer air on the ground rises to the upper atmosphere under normal circumstances, and the air temperature drops by roughly 6.4°C every kilometer as height increases [4]. Temperature inversion, on other hand, occurs when the temperature gradient is reversed, making the air above warmer than the air below. This can occur in a variety of ways, including when warm air passes over cold ground or when a warm, less dense air mass passes over a cold, dense air mass. An atmospheric inversion layer nearer the ground acts as a cap to stop air up flow that spreads and dilutes the contaminants, and troposphere itself may be colder than air temperature above it. Because of their geographic location, cities including Los Angeles, London, Taipei, Beijing, Tehran, and Mexico City are vulnerable to smog buildup [5].

4. Sources of Pollutants

The discharge of pollutants from stationary sources, including power plants, industrial boilers, paper mills, smelters, refinery processing facilities, chemical processing plants, and petroleum storage tanks, is a complicated problem that contributes to air pollution. Motor cars, ships, wood stoves, and farmers' controlled burning of agricultural waste are examples of nonpoint sources of air pollution [6]. Carbon monoxide (CO), lead (Pb), nitrogen oxides (NOx), ozone (O_3), sulfur dioxide (SO_2), and particulate matter (PMs) are the six main air pollutants for which the U.S. Environmental Protection Agency (EPA) has set national air quality standards since 1972 [7]. Both direct emissions and atmospheric gas aggregates are responsible for the generation of PMs. The majority of contaminants with tiny particles agglomerate due to intricate interactions. O_3 is created when sunlight and volatile organic compounds (VOCs) interact in a complex way to collect majority of the fine particle contaminants. Benzene, chloroform, acetaldehyde, dioxin, polycyclic organic matter, chromium, lead, nickel, and mercury compounds are among the air pollutants.

That can have detrimental effects on environment and human health, including cancer, birth defects, and ecological and environmental issues [8-9]. Trees, plants, automobiles, and industrial pollutants all produce volatile organic compounds (VOCs), which combine with nitrogen oxides to create ground-level ozone, a major component of smog. The human body's cardiorespiratory system is impacted by nitrogen oxides (NOx), which are created when carbonaceous fuels like coal, gasoline, and diesel burn. Diesel fuels from automobiles and coal-burning power plants produce sulfur dioxide (SO_2), which poses serious health concerns to asthmatics and young children. PMs are a complicated mixture of liquids and minuscule particles that enter the air and have a major negative impact on heart and lungs (Figure 2). Due to indoor Smokey coal pollutants that contain high quantities of polycyclic aromatic hydrocarbons, Xuanewi City in China had a lung cancer risk that was about five times higher than national average [10-11].

- ***Biogenic Sources***

Nitrogen oxides are naturally occurring substances like terpenes, which are hydrocarbons in oils that give them their burning properties, and are created by lightning, bushfires, and soil microbes [12].

- ***Anthropogenic Sources***

The main source of nitrogen oxides is the burning of fossil fuels in power plants and automobiles [13]. Incomplete combustion, solvent evaporation, and burning plant matter are other sources of volatile organic compounds (VOCs) [14].

5. Factor affecting Smog Formation

Numerous substances, such as nitrogen oxides, hydrocarbons, and UV radiation, combine to create photochemical smog. Because they are produced by burning fossil fuels, industrialization and transportation are associated with high amounts of these pollutants. Smog levels are also influenced by the time of day; early morning traffic increases nitrogen oxide emissions, while evening traffic decreases, raising concentrations of hazardous compounds and nitrogen dioxide. Smog generation also influenced by the meteorological elements such as temperature inversions, precipitation, and winds. Because of strong temperature inversions & decreased air flow, topography, especially in valleys, makes areas more vulnerable to smog. All things considered, these elements play a part in the development of smog Table 2 [15].

5.1. Nitrogen Oxide (NOx) Formation

Lightning naturally produces nitrogen oxides (NOx) when air nitrogen combines with oxygen to produce nitrogen dioxide and nitrogen monoxide. In natural world, soil microorganisms create nitrous oxide, which oxidized by atomic oxygen and ozone. Anthropogenic sources of NOx include high-temperature burning, which produces nitric oxide at 1600 K when nitrogen and oxygen combine. The proportion of mobile & stationary NOx sources is equal [16].

5.2. Ozone (O_3) Formation

By absorbing UV light, atmospheric oxygen is converted into ozone, a pale blue gas found in the stratosphere. Its essential screening effect is aided by its continuous creation and destruction. In the lower atmosphere, ozone can also be created by chemical interactions involving the nitrogen, hydrogen, and chlorine, electric sparks, lightning, and reactions between the nitrogen oxides and hydrocarbons [17].

5.3. Hydrocarbon Formation

When nitrogen oxides and hydrocarbons combine in the presence of sunshine or electric sparks from automobile engines or electrical equipment, hydrocarbons are created. They have elements of hydrogen and carbon. Car exhaust contains unburned hydrocarbons, and organic solvents and volatile solvents from unattended gasoline can be harmful to one's health if they are in the air [18].

5.4. Particulate Formation

Ash from burning fuel and carbon-based compounds like aldehydes, ketones, and hydrocarbons are among the particles that make up smoke. Soot is mostly produced in factories, incineration facilities, and diesel automobiles when fossil fuels are not completely burned [19].

5.5. Peroxyacetyl Nitrates (PAN)Formation

The main component of particulates produced by incomplete combustion of fossil fuels like coal and oil is soot, or carbon. These microscopic particles contribute to smoke emissions and are created in industries, incinerators, and diesel automobiles [20].

5.6. Impact of Location and Weather on Photochemical Smog Formation

- ***Topography***

A city's topography has a big influence on how photochemical smog forms; valley cities have more problems than wide plain cities because of the restricted airflow [21].

- ***Meteorology***

The sun's energy causes the air nearest the Earth's surface to be generally warmer than the air at higher altitudes. This unstable state aids in the upward movement of contaminants, dispersing and diluting them. However, cities may endure protracted episodes of photochemical haze during a temperature inversion [22]. This happens when the cooler layer of air close to the ground surface is trapped by warmer air, which prevents contaminants from dispersing. Advection, in which warmer air is brought in, and radiation inversion, in which the ground cools the air layer next to it, are the two main processes that allow for inversions [23].

6. Shocking Impacts of Photochemical Smog

6.1. Impact of Photochemical Smog on Health

Many populations, including children, the elderly, people with heart and lung disorders, and others, are at serious risk for health problems due to smog, which includes ground-level ozone, sulfur dioxide, nitrogen dioxide, and carbon monoxide. It dries out protective membranes, impairs the body's capacity to fight infections, and can cause inflammation, shortness of breath, and irritation of the nose and throat, all of which increase vulnerability to disease. Hospitalizations and respiratory fatalities can result from high ozone levels, and high death rates have been noted in regions with high ambient pollution levels. Numerous illnesses, including those of the heart, lungs, skin, eyes, reproductive system, neurological system, inflammatory response, and cancer, are associated with exposure to smog. Because of their distinct surface characteristics, nanoparticles may have unanticipated harmful biological effects, including the production of reactive oxygen species (ROS), apoptosis, and cancer by oxidative means. Apolipoprotein E and PM2.5 in the air may interact to hasten the onset of Alzheimer's disease and cause brain aging. One common element linking the harmful effects of pollution is oxidative stress, with heavy metal-induced neurotoxicity primarily targeting the electron transport chain [7].

6.1.1. Impact on Human Wellbeing

Volatile organic compounds (VOCs), sulfur dioxide, and nitrogen dioxide are dangerous chemicals that can irritate the respiratory system and eyes, damage the lungs, and affect lung function. One type of ozone can cause severe health issues, especially in youngsters, and irritate the eyes, nose, and throat. Smog can limit lung development, raise the risk of asthma, and decrease the diversity of certain freshwater species as it rises [24]. Because of its poisonous and irritating qualities, peroxyacetyl nitrates (PAN), a highly oxidized, unstable organic nitrogen molecule, can also be detrimental to both humans and plants. One of most phototoxic compounds known is PAN, which can cause obvious damage to leaves, as well as leaf loss, reduced growth, and even death. PAN's typical damage is a glaze, which is followed by bronzing of the bottom leaf surface. PAN can result in yield losses of up to 50% in cotton, citrus fruits, grapes, potatoes, and tobacco [25].

6.2. Environmental consequences

6.2.1. Impacts on Vegetation Components

Trees, delicate crops, and other vegetation are all harmed by ozone and PAN, two of the main drivers of vegetation destruction. Ozone at ground level can harm leaves, lower growth, productivity, and reproduction, and make plants more susceptible to disease, insects, and plant mortality. Crops can be seriously harmed by high ozone levels. Global climate change is expected to result from the heightened greenhouse effect, which is facilitated by ozone [26].

6.2.2. Materials-related effects

Smog damages metals, stone, concrete, clothes, rubber, and plastics, and it speeds up the decay of paints, dyes, rubber, and plastics. Each year, contaminants such as nitric acid, sulfur dioxide, sulfuric acid, and ozone inflict $10 billion in damages [27].

6.2.3. Affected Areas

A consequence of urban or industrial pollution, smog can arise in a variety of climates, especially during warmer, sunnier times. It can persist over heavily populated towns or metropolitan regions, possibly reaching lethal levels, and is especially common in geologic basins encircled by hills or mountains. Vertical circulation is inhibited by temperature of the higher air.

6.2.4. Smog induced oxidative stress

Food undergoes oxidation during respiration, which combines electrons with molecular oxygen to create water. In aerobically developing cells, the HabereWeiss and Fenton reactions continuously produce reactive by-products, including hydrogen peroxide, superoxide anion radicals, and hydroxyl radicals [28]. By altering DNA, proteins, and lipids through covalent interactions, these free radicals can harm cells oxidatively. More reactive aldehydes, lipid radicals, and other reactive chemicals are created by the chain reaction known as lipid peroxidation. One polyunsaturated fatty acid that is particularly vulnerable to lipid peroxidation and has a major impact on inflammation is arachidonic acid [29].

7. Remedies for Photochemical Smog Formation

Photochemical ozone concentrations can be reduced by reducing hydrocarbon and other VOC emissions and NOx. However, ozone production is dependent on precursor emissions. Models predict ozone concentrations but face challenges due to variability in source and sink terms, air sample transport, and chemistry formulation. Assessing the impact of a mixture of anthropogenic VOCs and ozone produced by biogenic hydrocarbons is crucial [30].

7.1. Regulations

7.1.1. Standards for Emissions

Controlling NO_x and VOC emissions from a variety of sources, such as automobiles and industry, is the aim [31].

7.1.2. Air Quality Standards

The main goal of the air quality standards is to establish and implement regulations for ozone and other important pollutants [32].

7.2. Technical solutions

7.2.1. Catalytic Converter

Through catalytic conversion of exhaust gases, the method seeks to lower vehicle emissions. In this case, an alumina substrate with a layer of precious metal functions as a three-way catalyst.

All three gases have conversion efficiencies close to 90%, but only when the air-to-fuel ratio is strictly regulated. In the exhaust flow, an O_2 sensor is frequently included [33].

7.2.2. Biodiesel & Diesel

Particle emissions are increased by diesel-powered vehicles, while unburned hydrocarbon and CO emissions are far lower, and NOx emissions are slightly worse than those of gas-powered vehicles with effective catalytic converters [34]. Biofuels are being investigated as a possible way to lower harmful pollutants from urban transportation and greenhouse gas emissions [35].

7.2.3. Energy and Hydrogen

Electric and H-powered cars produce less water and emit less pollutants, making the road cleaner. However, emissions from the production of energy or H_2 must be taken into account in pollution audits [36].

7.2.4. Industrial controls

To reduce emissions from industrial processes, industrial controls must use scrubbers, filters, and other technology [8].

7.3. Behavioral Modifications

7.3.1. Modifications to Lifestyle

Reductions in legal speed limit Using public transit more often helps lower photochemical smog and hydrocarbon emissions while conserving fuel and lowering NOx emissions [37].

7.3.2. PAHs, or polycyclic aromatic hydrocarbons

The atmosphere is filled with PAHs, which are produced by incomplete combustion in power plants, automobiles, homes, and intentional biomass. The principal sources are anthropogenic because of their effects on human health, even if natural sources like forest fires and volcanoes also add to the burden [38].

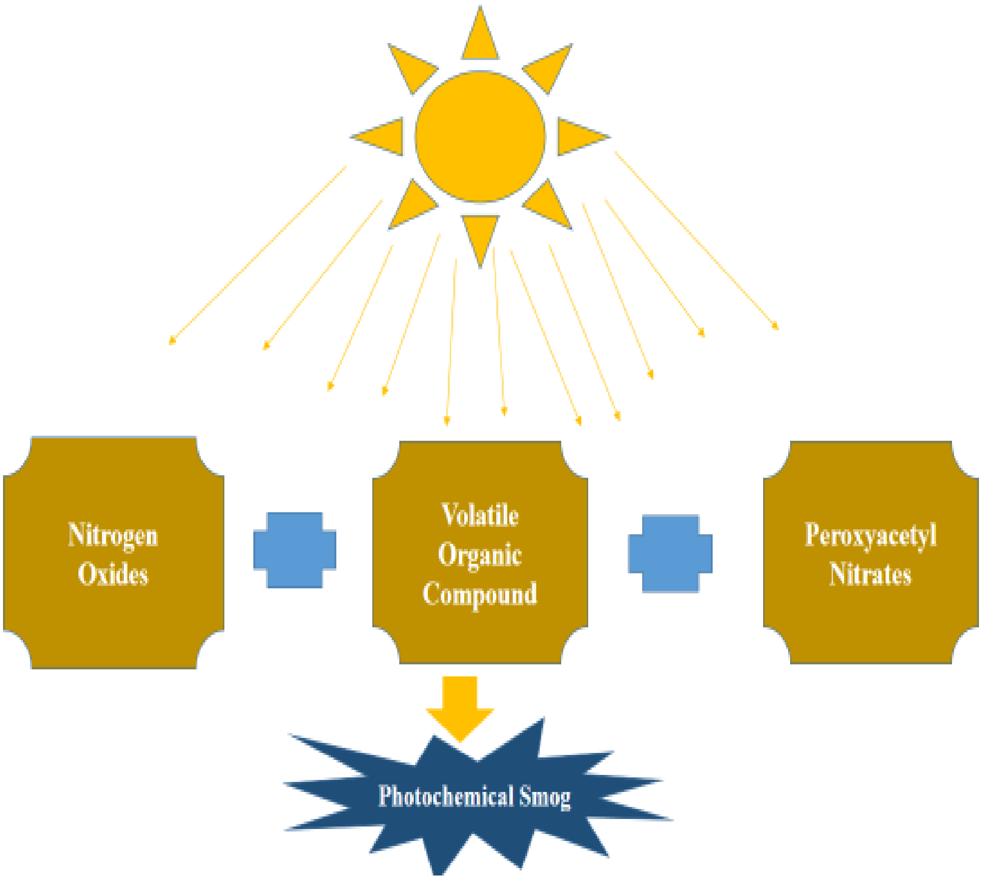

Figure 1: Causes of Photochemical Smog

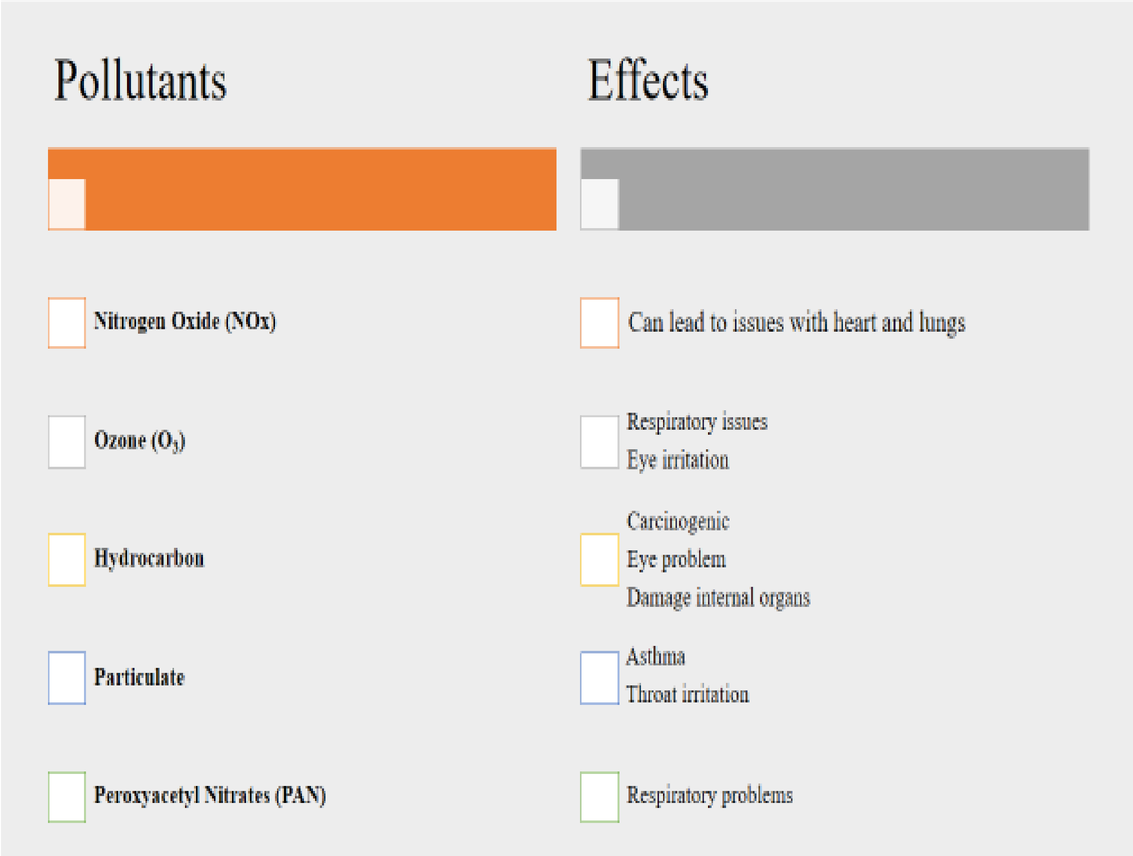

Figure 2: Photochemical smog pollutants and their effects

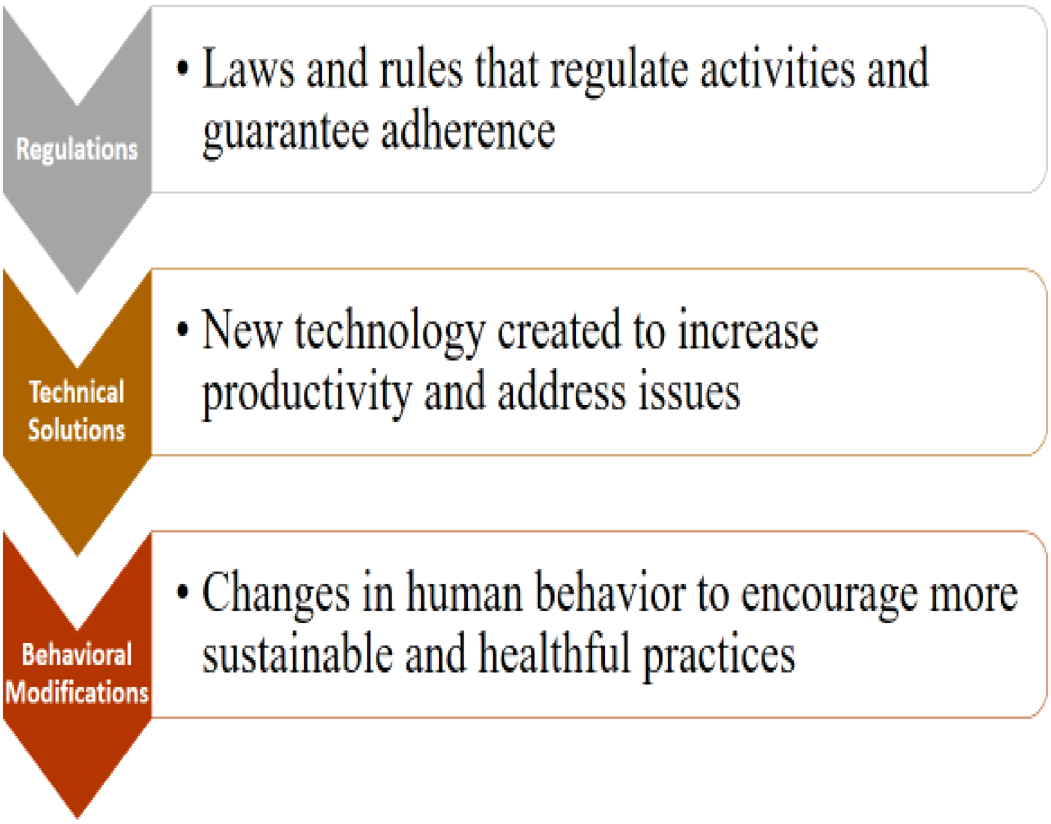

Figure 3: Remedies for Photochemical Smog Formation

Table 1: Pollutants in photochemical smog

Primary Pollutants	Secondary Pollutants
• An air pollutant that is released straight from the source is called a primary pollutant.	• A secondary pollutant is created when other pollutants (primary pollutants) react in the atmosphere rather than being released directly.
• Examples are CO, NO_2, SO_2, and particulate matter	• Examples are ozone and secondary organic aerosol
• It is possible to try to manage or lower their levels to acceptable levels.	• Secondary pollutants are more difficult to manage because of their distinct synthesizing and poorly understood production.

Table 2: Chemical reactions involved in formation of photochemical smog

N_2+O_2	2NO
2NO+ O_2	$2NO_2$
NO_2+Sunlight	NO+O
O+O_2	O_3
O_3+NO	NO_2+O_2
NO_2+R	PAN
NO+RO_X	NO_2+Other products

7.4. The WHO's Global Air Quality Standards

Guidelines for major air pollutants, such as particle matter (PM), ozone (O_3), nitrogen dioxide (NO_2), and sulfur dioxide (SO_2), are provided by the WHO Worldwide Air Quality Regulations. Subjective recommended practices for dark carbon/essential carbon, ultrafine particles, and particles from sand and residue storms are included in these guidelines, which are applicable both indoors and outdoors. The amount of PM2.5, a particulate matter created by burning gasoline in cars, power plants, and wildfires, has decreased from 10 g/m3 in 2005 to 5 g/m3 in 2021. Guidelines for PM10 annual average emissions have also been revised by the WHO, going from 20 g/m3 in 2005 to 45 g/m3 in 2021. During peak season, ozone layer, a pollutant and greenhouse gas, has been set at 60 g/m3. The annual level of nitrogen dioxide has been lowered from 40 to 10 g/m3, with a new benchmark of 25 g/m3 per 24 hours. Guidelines for sulfur dioxide remain at 500 g/m3 each 10-minute interval, however limits have raised from 20 g/m3 to 40 g/m3 in a 24-hour period. The regulations have been updated to include carbon monoxide levels [39].

8. Future Perspectives

For millions of years, microorganisms and humans have coevolved, and throughout that time, the microbes have evolved defense mechanisms to keep their alliances with us and with each other intact. Chronic pollution exposure, however, upsets the delicate balance of microbial populations in the human body, especially in infants and young children. Since the majority of the data that is currently accessible describes species diversity, richness, and evenness based on sequence homologies, our knowledge of the human-associated micro biota is still in its infancy. The internal mechanisms of the human and human-associated micro biota are less understood, and metagenomics data do not offer useful insight into metabolic pathways of these microorganisms. To learn more about the effects of smog-induced micro biota changes on human health, functional genomics and culturomics are being investigated. According to ecological principles, the environment, animals, and plants are all interconnected. According to ecological principles, the environment, animals, and plants are all interconnected, and changes in the environment have the potential to upset bio community and cause ecosystem to collapse. Fecal transplants demonstrate that a collapsed microbial community can be restored, and other activities like exercise, nutrition, and lifestyle modifications may modify the micro biota of the epithelium to mitigate or prevent negative impacts of pollution-induced micro biota alterations.

The best way to prevent smog generation is to reduce the combustion of fossil fuels, however this objective is unlikely to be achieved in nations with lower economic standing. Rock, ash, and sulfur can all be eliminated from coal using physical and chemical cleaning techniques. An excellent substitute for sulfur removal in petroleum products is bio desulfurization in fossil fuels. Even though pollution levels in major cities and regions have decreased, smog is increasing in once-pristine places like Cape Cod and the Great Smokies. This illustrates the need for regional solutions because pollution can spread across long distances. For instance, ozone and acid rain are causing 30 plant species in the Great Smoky Mountains National Park to become extinct or to suffer damage. The creation of an alternative to perchloroethylene, a solvent used in dry cleaning that emits vapor into the atmosphere, is one possible remedy. The more polluted the air, the greater the need for the hydroxyl radical, which purifies the atmosphere. NOx-catalytic converters in automobiles and factories, the enforcement of environmental protection laws, and the decrease of primary pollutants may all be beneficial.

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