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The Impact of Industrial Emissions on Outdoor Air Pollution in Different U.S. Cities from 1980 to 2024

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Abstract: During the last century, because of the rapid development of industry, the emissions of many pollutants increased rapidly, raising outdoor air pollution levels in cities worldwide. Using the U.S. Environmental Protection Agency recording, I analyzed air quality trends in five U.S. cities and concluded that pollution levels generally decreased from 1980 to 2024 in all the cities. However, different pollutants decreased by different degrees in each city. Urban planning and the growth and decline of industry appear to play essential roles in changing ambient air pollution levels. This study examines the relationship between policies related to industry and ambient levels of air pollution. I find that different state policies have had different impacts on pollution levels. In particular, policies and pollution levels in Riverside, California, and Pittsburgh, Pennsylvania, are examined in depth.

1. Introduction

Since the Industrial Revolution, rapid growth in coal combustion in factories spread from the United Kingdom to mainland Europe to North America. Rapid urbanization increased sulfur dioxide (SO_2), nitrogen dioxide (NO_2), and other chemical emissions, increasing air pollution. The daily use of coal for heating and cooking also increased dramatically with the increasing population in cities. Aside from coal combustion, the large population of horses for transportation released ammonia (NH_3) emissions into the air. For example, 100,000 horses in New York City produced 1,000 tonnes of manure daily in the late 19th century [1]. The poor sewage system led to further ammonia emissions. Moreover, people began to drive vehicles at the beginning of the twentieth century, increasing emissions of air pollutant gases and particles [2].

An example of a major air pollution event is the Great London Smog event of 1952. This episode was caused by the emissions of sulfur gases and particles from coal burning combined with a low-lying temperature inversion, air stagnation, and fog in the city of London, England. In the end, this smog event resulted in the premature mortalities of approximately 12,000 people. This event gained the attention of policymakers, as did several other air pollution events in the U.S., including one in 1948 in Donora, Pennsylvania [3]. Ultimately, in 1963, the U.S. passed its original Clean Air Act, which marked the beginning of the fight against widespread air pollution. Nevertheless, air quality continued to degrade as ozone concentrations increased in regions with lots of sunlight, damaging human health and the environment [4].

Current estimates are that, worldwide, outdoor concentrations of particulate matter smaller than 2.5 micrometers in diameter ($PM_{2.5}$) alone are responsible for 4.2 million premature deaths and 100 million disability-adjusted life-years per year. Therefore, reducing outdoor air pollution is crucial for human health. Even though emissions of most primary pollutants have declined in Europe and North America, NO_x (NO plus NO_2) and ammonia emissions continue to rise in those continents. Ammonia is a leading source of particulate matter. Therefore, some appropriate solutions for controlling air pollution emissions became essential. In the rest of this report, I provide a literature review and then summarize my methodology, results, a discussion, and conclusions about air pollution trends in several U.S. cities [5].

1.1. Background Information about Air Pollution

Air pollution is the buildup in the air of different gases and particles from either chemical, physical, or biological sources. Air pollution can affect either outdoor or indoor air. Indoor air pollution usually refers to the air pollution inside of a building, and it is closely related to the health of building occupants [6]. Sources of indoor air pollution include fuel combustion for heating and cooking, tobacco smoke, the release of chemicals from building materials and products containing chemicals, and the infiltration of outdoor pollution into a building. Outdoor air pollution is air pollution outside of buildings that occurs at all altitudes from ground levels to several kilometers above the Earth's surface. Outdoor air has a significant function: it provides an essential gas (oxygen) for animals to survive and another gas (ozone), which resides in the ozone layer high above the surface, that protects the Earth's surface from harmful ultraviolet radiation. Ozone near the surface, forms from the emissions of oxides of nitrogen (NO_x) and organic gases in the presence of ultraviolet light. However, while it is the same ozone as higher up, it is harmful because it damages the lungs of people and other living animals. Therefore, outdoor air pollutants can severely affect the quality of life and human survivability [7].

From a regulatory perspective, under the U.S. Clean Air Act Amendments of 1970 (CAAA70), outdoor air pollutants are classified into three main categories: criteria air pollutants, air toxics, and other pollutants. Stratospheric ozone loss is an additional concern that is treated under the Clean Air Act Amendments [8]. Criteria air pollutants are pollutants deemed harmful for people to breathe in high concentrations, so their outdoor levels are regulated under CAAA70. Sulfur dioxide, nitrogen dioxide, ozone, lead, some particular matter, and carbon monoxide are the six main criteria pollutants today. The U.S. Environmental Protection Agency (EPA) regulates them by setting permissible outdoor levels (primary standards) for them that will not harm human health. The EPA also sets secondary standards, which are levels above which these pollutants will damage the environment (agriculture and forests) and human welfare (e.g., visibility and works of art). The criteria pollutants are required to be periodically reviewed by the EPA to reflect the appropriate level of outdoor air pollution to minimize damage to human health. Some main criteria pollutants have been studied extensively, so that the impacts of different ambient concentrations on human health are well known [9].

Air toxics are chemicals that cause various reproductive illnesses birth defects or cancer or other harmful impacts. Currently, 193 chemicals are regulated by the EPA as air toxics [10].

Stratospheric ozone issues refer to the release of long-lived compounds containing chlorine and bromine, emitted since the 1930s, that damage, over a 50 -to 100-year time frame, the stratospheric ozone layer, which resides 8 to 20 kilometers above the Earth's surface. The ozone layer protects the surface of the Earth from the sun's harmful ultraviolet radiation. The EPA regulates the emissions of harmful chemicals damaging the ozone layer. A decrease in the thickness of the ozone layer can increase the incidence of skin cancer, cataracts, and other illnesses in humans. Moreover, it also damages the productivity of marine phytoplankton and the health of animals around the Earth [11].

1.2. Purpose of the Study

Outdoor air pollution affects not only people's health, but it also increases the deposition of acids to forests and lakes, through acid rain, acid fog, or acid dry deposition. Air pollution can affect human health when people breathe vehicle exhaust, road dust, or industrial emissions. Air pollution can also cause various pollution-related diseases, such as respiratory disease, asthma, certain cancers, pneumonia, emphysema, and chronic obstructive pulmonary disease (COPD), for example [12]. According to the State of the Air report, 131.2 million people, or about 39% of people in America, still lived in places with unhealthful levels of ozone or particulate matter pollution in 2024. Compared with 2023, 11.7 million more people breathed unhealthy air in 2024. Overall, air pollution is closely related to climate change because most of the same sources that emit air pollutants emit greenhouse gases, which are gases that increase global warming [13].

The purpose of this study is to understand air pollution trends better so as to be able to find better solutions to the problem. Here, I hypothesize that different levels of industrial production and different geographies can affect the severity of outdoor air pollution. I aim to report measurements of and analyze the relationship between different factors and the levels of several contaminants. Some factors, such as location, population, and industries, are hypothesized to have a significant impact on outdoor air pollution levels [14].

2. Method

In this study, I select five U.S. cities with distinctly different characteristics: Houston, Atlanta, Pittsburgh, Riverside, and New York City. Each city has a unique trait. For example, Pittsburgh historically experienced emissions from the burning of coal for steel and other industries. Burning coal produces large amounts of air pollutant gases and particles that deteriorate outdoor air quality. New York City is the most populated city in the U.S., which means New York City has the densest traffic among U.S. cities. The emissions from cars, trucks, buses, and other vehicles can also generate large amounts of pollution. Riverside, California, has the disadvantage of its geography because it is located to the west of San Bernardino Mountains, which blocks the movement of air pollutants from the Los Angeles Basin to the eastern side of California. In addition, on most days of the year, a high-pressure system sits over the Los Angeles Basin. Under such a system air descends and compresses on top of air below it. This descending air prevents polluted air from rising and flowing, with the daily sea breeze, above and over the San Bernardino Mountains, causing pollution to be trapped under an inversion layer in Riverside. Atlanta, Georgia, is close to large forests that emit biogenic hydrocarbon gases. These gases combine with NO_x from the city to produce ozone in Atlanta. Houston, Texas, is exposed to heavy ultraviolet radiation from the sun. Its high emissions of NO_x and organic gases from combustion sources, particularly the oil and gas industry, are cooked up by the sun to produce lots of ozone in photochemical smog in the city, levels of which rival those of Riverside [15].

My outdoor air quality data come mainly from the U.S. Environment Protection Agency (EPA). The EPA usually uses ambient air sensors and stationary source emission monitors to detect air quality. When particulate matter ($PM_{2.5}$ and PM_{10}), which includes particles with aerodynamic diameters below 2.5 microns and below 10 microns, respectively, and pollutant gases (NO_2, SO_2, O_3, CO) flow through a detector, the ambient air sensor can indicate its presence through optical, electrical thermal and other methods. Then, it can establish measurement quality performance with a set of parameters (precision, bias and minimum detection levels, etc.) and set a value for each parameter demonstrating the quality level sought [16]. During the process of detecting pollutants in the air, the EPA uses two primary measurement methods: Federal Reference Methods (FRMs) are methods of sampling and analyzing the ambient air for an air pollutant. Federal Equivalent Methods (FEMs) are methods of measuring the concentration of an air pollutant in the ambient air that has been designated as an equivalent method). FRMs can be classified as either manual reference methods or automated reference methods. Manual reference methods are required for some specific pollutants (SO_2, Pb, PM_{10}, $PM_{2.5}$ and $PM_{10-2.5}$). For those pollutants, the FRM specifies the complete analytical procedure in detail. Because the functional aspect of a commercial sampler may differ from that of other manufacturers, EPA will send multiple samplers with different aspects of the FRM, which can be a candidate manual method for FRM designation [17].

The automated reference methods have measurement principles and calibration procedures (as opposed to specifying a unique manual procedure). Automated reference methods are used to monitor CO, O_3, and NO_2. The measurement principle of automated reference methods can allow a significant variation in the design and operation of the analyzer. Therefore, if any analyzer meets the requirement in the measurement principles with a specified calibration procedure, those analyzers can be considered as candidate methods. So, the EPA designates multiple FRMs for pollutants. FEMs also can be classified as manual equivalent methods and automated equivalent methods. Manual equivalent methods and automated equivalent methods must meet the requirements of seven steps set out by the EPA: Determination of comparability, selection of test sites, test atmosphere, sampling collection, operation, calibration and submission). Other than that, all types of automated FEMs also need to meet the same requirement as automated FRMs: measurement principle with correct test atmosphere and calibration procedures [18].

After collecting the data on pollutants in different sites for the years 1980 to 2023, I plotted the one-year data every tenth year from 1980 to 2023 (I used 2023 instead of 2020 because of the proximity of 2023 to today). Then, I calculated the average, over all days of each tenth year from 1980 to 2010 plus 2023. Next, I draw conclusions from the graphs.

3. Results

The statistical data and graphs show the levels of the different pollutants in the five cities. For the pollutant $PM_{2.5}$, Riverside, in California had significantly higher levels than the other four cities in the year 2000. The other four cities have an average close to each other of around 15 ug/m^3. However, Riverside has a concentration of around 30 ug/m^3, about 15 ug/m^3 more than in the other cities. At the same time, all five cities decreased to about the same level in 2023, about 10 ug/m^3. Therefore, all five cities have an effective strategy for decreasing $PM_{2.5}$.

For ozone, Riverside in California maintained a high level of about 0.055 ppm for 20 years (1980-2000), different from the other four cities. Houston, Pittsburgh, and New York all had around 0.035 ppm during the same period. New York City experienced a dramatic decrease in ozone levels from 1990 to 2000. However, Atlanta increased only about 0.01 ppm, from 0.045 to 0.055 ppm, from 1990 to 2000 [Figure 1].

For NO_2, all five cities found an effective way to reduce the emission. All five cities dropped from an average of 50 to 60 ppb in 1980 to a 20 to 30 ppb level in 2023. New York City rebounded twice, once in 1990 and once in 2010. Atlanta, Houston and Pittsburgh initial amounts of NO_2 close to each other, about 60 ppb. In addition, New York City had the lowest level in 1980, but the highest in 2023.

For CO, Pittsburgh had the highest CO levels in 1980, 4.21 ppm. Atlanta and Houston were at the second level, with around 2.7 ppm of CO. New York City and Riverside had the lowest level, about 1.5 ppb. All five cities experienced significant decreases in CO levels from 1980 to 2023, especially Pittsburgh, which reduced CO from 4.21 to 0.32 ppm [Figure 2].

For SO_2, Pittsburgh had the highest SO_2 in 1980, 136.6 ppm. The other four cities had less than 50 ppb of SO_2 in 1980. Riverside, in California, had the lowest level, about 10.99 ppb of SO_2. Pittsburgh reduced its SO_2 quickly from 1980 to 2000, to about 120 ppb of SO_2 [Figure 3].

In sum, California had higher NO_2 levels before 1990 than did any other city examined. Pollutant levels in Pennsylvania dropped dramatically from 1980 to 2024, corresponding to a decrease in industrial output [Figure 4]. Thus, there appears to be a relationship between the presence of factories and outdoor pollution levels [Figure 5].

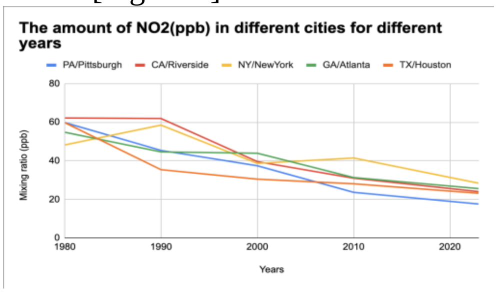

Figure 1: Ambient NO_2 mixing ratios (ppb) in each of the five cities examined, from 1980 to 2024. (United States Environmental Protection Agency).

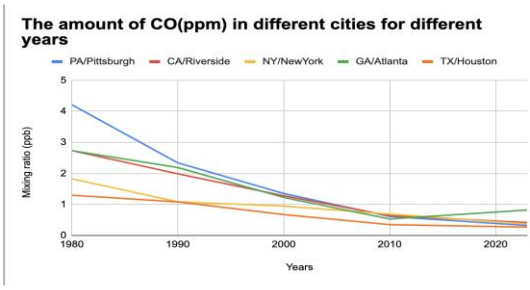

Figure 2: Ambient CO mixing ratios (ppm) in each of the five cities examined, from 1980 to 2024. (United States Environmental Protection Agency).

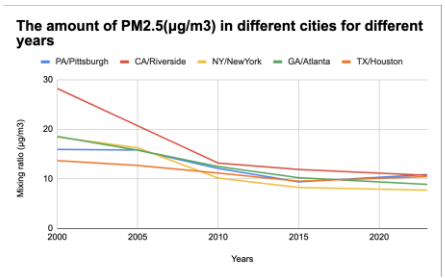

Figure 3: Ambient $PM_{2.5}$ concentration ($\mu g/m^3$) in each of the five cities examined, from 1980 to 2024. (United States Environmental Protection Agency).

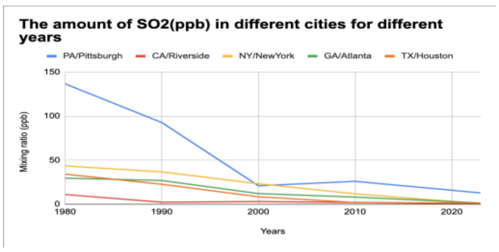

Figure 4: Ambient SO_2 mixing ratio (ppb) in each of the five cities examined, from 1980 to 2024. (United States Environmental Protection Agency).

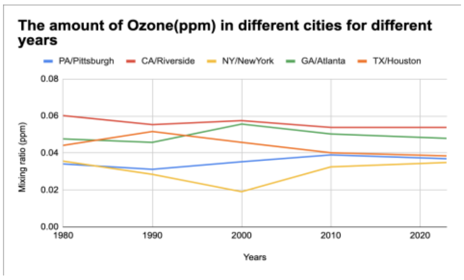

Figure 5: Ambient O_3 mixing ratio (ppm) in each of the five cities examined, from 1980 to 2024. (United States Environmental Protection Agency).

4. Limitations and Uncertainties

In my study, I only selected one year of data every tenth year. The resulting time series shows the general trend of different pollutant levels in cities. Therefore, I omitted the small change between years of data. Such omitted data may provide important information on how the timing of different policies changes air pollution. Therefore, for future work, one can collect all the yearly data and analyze it, showing more precise data each year [19]. Moreover, even though the EPA named the data "daily data" for all pollutants, some data were omitted, likely due to an instrument being down, which makes the data less reliable. In order to improve the results, one may go to the local government to search for more complete data.

Secondly, there are many other reasons aside from those mentioned for the decrease in air pollution. For example, the NO_2 and $PM_{2.5,}$ amounts were high in Riverside because such pollutants were trapped under an inversion there in addition to being emitted in abundance. Moreover, the population of New York City may play a more important role in air pollution than factories. To understand the cause of air pollution declines more thoroughly, more research is needed.

Among different types of pollutants, I only choose five major pollutants selectively, depending on their importance and downward trend. Other pollutants may have different trends under the same policy. Therefore, the policies discussed may have affected only certain pollutants [20].

Lastly, I could not find data from before 1980, limiting my ability to analyze the effect of different policies. The Clean Air Act was enacted in 1963, which is an important act for preventing air pollution; however, I did not have data to measure the effectiveness of this act from its beginning.

5. Discussion/Conclusions

The data show that each city reduces each gas mixing ratio or particle concentration to a different degree. I hypothesize that this is because of the policies and geography of each city or state that the city resides in. Among those cities, Riverside and Pittsburgh show the greatest reduction in pollution levels: Pittsburgh had the greatest reduction in both CO and SO_2; Riverside had the largest decrease in NO_2 and $PM_{2.5}$. Pollution levels in Riverside, in fact, decreased to the same levels of pollution as in cleaner cities by 2023, for all pollutants aside from ozone.

Pittsburgh experienced the greatest reduction in air pollution among the five cities because of the phase-out of its coal and steel industries. Pittsburgh is strategically located in Western Pennsylvania, at the intersection of the Allegheny and Monongahela Rivers. People began building boats as a business in the early 1800s. Iron and glass became increasingly essential for the local economy as did steel production in years thereafter. The iron and steelmaking industry became an iconic industry in Pittsburgh, which required coal as a fuel to produce. Coal burning caused a horrendous amount of air pollution emissions, including of CO, SO_2, and $PM_{2.5}$ in particular. At the turn of the

20th century, more than 10 million tons of coke were produced annually in the Connellsville area.

Even though policymakers brought a lawsuit alleging that beehive coke plants should be liable for damages, courts did not issue injunctions, apparently because of the high social value of coking. Moreover, state courts also rejected the tough city ordinances addressing air quality between 1895 and 1907 by reasoning that such ordinances exceeded the city's delegated powers. Because of the worsening air quality, the citizens of Pennsylvania cities began anti-smoke movements, appealing to the state government to help reduce emissions in the city. *The Economic Cost of the Smoke Nuisance* by O'Connor in 1913 is a landmark book illustrating people's awareness to the smoke's damage: it describes the smoke research in the book, an evaluation of smoke's effects on vegetation, materials, daylight, laundry, and other washing that connected air pollution to people's life and business. However, air pollution still worsened. In 1940, about 81% of Pittsburgh residents used coal for home heating and cooking. Ironically, the first air pollution disaster recorded in the U.S. occurred amid these smoke abatement efforts in Donora, PA, in October 1948. This town of 13,000 people was located 30 km from Pittsburgh. Because of the unusual meteorology, the normal dispersion of pollutants was prevented, and heavy fog prevented the solar heat from breaking up the inversion. Twenty people died, and nearly 6000 fell ill due to the week-long buildup of toxic air pollution in the river valley surrounding Donora. This disaster provoked a strong public reaction to the anti-smoke movement. Communities began to enforce smoke abatement regulations outside of Pittsburgh city limits in May 1949.

During the next several years, considerable progress was made in reducing emissions. Some companies replaced old, worn-out equipment with modern facilities designed for less smoky operations. At the same time, the Civic Club, in February 1945, collaborated with some 80 organizations to form the United Smoke Council (USC) to implement the usage of a cleaner (in terms of air pollution form of energy: natural gas. Between 1945 and 1950: more than half of Pittsburgh's households switched from coal to natural gas. Government workers can follow the same steps to create a council to enact laws to use cleaner energy to replace coal or other resources that can cause large amounts of air pollution. Moreover, the poor management of air pollution may cause a strong public reaction when a disaster happens. Even though coal and other less environmentally favorable sources of energy involving combustion may bring large benefits, they cause damage to society because of their environmental damage.

Another result of the buildup of air pollution in Pittsburgh was the Pennsylvania Air Pollution Control Act (APCA) of January 8, 1960. The APCA established a framework for air pollution control activities in Pennsylvania. This act is consistent with the 1990 Amendment to the U.S. Clean Air Acts that required the Department of Environmental Protection (DEP) to implement a series of prescriptive programs: establishing emission fees, revising the pre-construction review requirements for new or modified primary stationary sources, and establishing the Small Business Compliance Assistance Program for changing industry structure. In 1960, the APCA significantly expanded air pollution control measures, pollution emission standards, and air quality standards. Following the APCA, the Federal Clean Air Act (CAA) of 1963 was passed by the federal government. The 1970 amendment to the CAA set a deadline for states to inform the federal government how they planned to reduce their ambient pollution level through the submission of state implementation plans.

Subsequently, the Coal and Gas Resource Coordination Act was enacted on December 18, 1984, to prevent the overuse of coal and natural gas. It also determined the active coal mines that could be used going forward. The Clear Skies Act of 2003 also helped Pittsburgh and even the whole of Pennsylvania to improve air quality further. Under this act, Pennsylvania was to use a proven, market-based, flexible approach with incentives for innovation rather than relying solely on the energy industry for improvements. The Clear Skies Act resulted in Pennsylvania reducing emissions of SO_2 by 81%, and NO_x by 68% by 2020. The Pennsylvania benefit from the act is a total of $9.3 billion through its reduction in health care and hospitalization costs.

NO_2 and $PM_{2.5}$ were the pollutants of major concern in Southern California. Air pollution in the Los Angeles Basin is linked to the car industry and human health, in particular. In Los Angeles, a 1% reduction in total suspended particulates resulted in a 0.35% decline in the infant mortality rate at the county level. The Los Angeles Air Pollution Control District and, subsequently, the South Coast Air Quality Management District (SCAQMD), have regulated air pollution in the Los Angeles Basin (which includes Riverside). The SCAQMD has focused on reducing vehicle emissions mainly. California's pioneering efforts to reduce air pollutants date back to 1943. The first recognized episodes of what is known as 'photochemical smog' occurred in Los Angeles. On August 30, 1967, California's elected leaders united to unify statewide efforts to address severe air pollution. Governor Ronald Reagan approved the Mulford-Carrell Air Resources Act to create the California Air Resources Board (CARB) CARB mandated a series of plans and tasks for districts within California to meet the emissions requirements. At the same time, in 1967, the U.S. Air Quality Act recognized California's earlier efforts and authorized the state to set its own separate and stricter-than-federal vehicle emissions regulations to address the extraordinary circumstances of population, climate, and topography that generated the worst air in the nation.

Gradually, CARB regulated vehicle pollutant emissions: CO in 1966, NO_x in 1971, and particulate matter from diesel-fueled vehicles in 1982. Correspondingly, the California Environmental Quality Act (CEQA) was passed to reduced further emissions. In the 2000s, CARB became responsible for monitoring and reducing greenhouse gas emissions by the passing of Assembly Bill 32. The achievement of lowering air pollution strongly encourages the Zero Emission Vehicle (ZEV) industry, and further emission reductions will be driven by the Governor's Executive Order with a goal of 100 percent Zero Emission Vehicle sales of new passenger cars and trucks by 2035. From California's history of reducing air pollution, one can see that concentrating on several aspects of air pollution is essential for reducing air pollution.

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