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Cover Page Footnote

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Carbon Dioxide and Particulate Matter Concentration on Hampton Roads Air Quality

By Gregory Hubbard

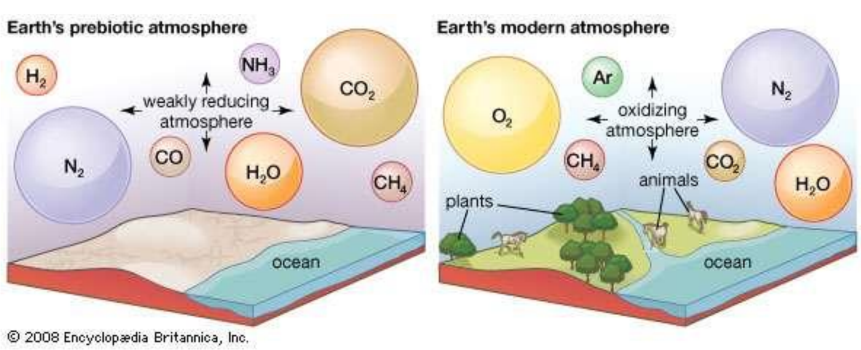
VSGC Student Research Conference

I. INTRODUCTION

In the grand scheme of atmospheric conditions, the pollution of anything beyond the natural amounts tolerated will have deleterious effects on the planet as a whole and on specific regions. This fundamental aspect of the Earth system has been observed many times over. An example of this can be seen in the direct relationship between excess CO_2 release and the subsequentially compounding of greenhouse gases in the atmosphere, which is causing temperature increases around the world. The effects of ambient particulate matter and CO_2 directly influence quality of life and pose health concerns not only for Norfolk residents but for everyone in every country.

On a broad scale, air pollution is the accumulation of substances artificially introduced into Earth's atmosphere. The source of pollutants can be classified as either natural or anthropogenic (man-made).

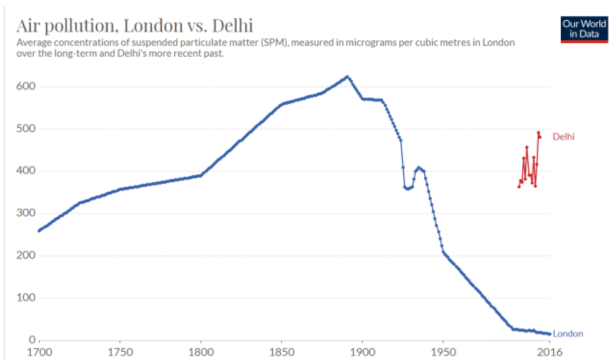
It is important to note that air quality has been naturally influenced since Earth's formation nearly 4600 million years ago (MacPhee, n.d.). Typically, natural sources of air pollution involve major natural events such as forest fires, volcanic activity, dust storms, and decomposition of organic compound. Before life, Earth's original atmosphere primarily consisted of carbon dioxide, methane, ammonia, noble gases, and water vapor (MacPhee, n.d.). The appearance of primordial life 2500 million years ago forever changed the composition of Earth's atmosphere through the mass biological production of oxygen. A generalized comparison of Earth's early and modern atmospheres is shown below (Hayes, 2020).



Through photosynthesis, unicellular organisms populated Earth's atmosphere by replacing abundant carbon dioxide with oxygen. With slight alterations, life on Earth evolved under these conditions.

Anthropogenic pollution intrinsically followed human evolution. From a technical perspective, the first anthropogenic footprint in air quality followed the dawn of civilization. In this sense, even the first ever man-made fire can be rooted as a source of anthropogenic pollution. Contemporary scientists now cite that large-scale agriculture spiked the first recordable increase of non-naturally occurring pollutants (Stromberg, 2013). This trend follows the growth of Roman and Han empires beginning in 100 B.C. Even though these "classical" emissions weren't large enough to alter the global climate as a whole, atmospheric pollutants increased enough to leave methane signatures in ice core analysis.

As civilizations grew, densely populated areas contributed the most towards global (and local) air pollution. This trend worsened at the onset of industrialization. To provide context for this industrialized spike, a historical analysis of London's air pollution can be referenced (Ritchie, 2017).



Historically, anthropogenic pollution trends a parabola-like characteristic over several hundred years. This characteristic function is commonly modeled as an Environmental Kuznets Curve or EKC (Ritchie, 2017). The purpose of this graphical description is to relate the historical quality of air against the historical stage of economic development. Generally, air pollution rapidly increases with the onset of industrialization, but then gradually declines as development progresses.

Looking at London's air pollution over time, the initial spike of air pollution occurred between 1800 and 1850. This spike unsurprisingly correlates with Britain's first industrial revolution. For over a decade, the concentration of particulate matter worsened, nearly doubling between 1800 and 1900. Even in the 1800s, people were not oblivious to the deleterious effects of contaminated air. Beginning in 1845, English legislators acknowledged the need for some form of regulation. By the early 1900s tighter industrial controls and availability of alternative fuel types lead to the plateau of pollutant concentration. To date, further initiatives continue to decrease the emission of industrial air pollutants. Measures taken involve the passing of English "Clean Air Acts" which target industries responsible for major particulate emissions (Changing Air Quality: Clean Air Acts: Great London Smog, n.d.).

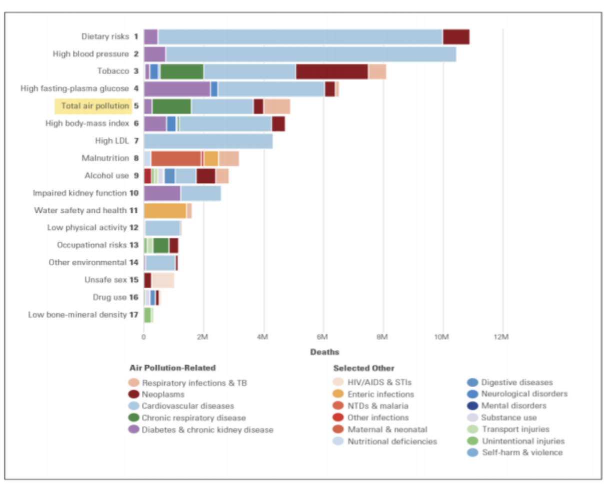
London is an excellent microcosm of how industrial emissions have evolved, but there are many other factors involving a "historical emission life cycle." Globally, the rate of industrializing nations is at an all time high, with each locality boosting a unique geographical profile. With such large-scale development, maintaining acceptable air quality has become a pressing global challenge (Ritchie). High traffic, as well as densely populated areas, are under particular danger of becoming "toxic" air zones.

The Hampton Roads community encompasses the combined metropolitan area surrounding the outlet between the Chesapeake Bay and the Atlantic Ocean. Hampton Roads is known for its large industrial character revolving around shipping and transportation.

<u>Health Factors</u>

Clean air is not only preferred but also needed for a healthy existence. There are five basic needs for human survival: air, water, food, shelter, and sleep. Poor air quality has been linked to increased hospitalizations, chronic illness, asthma, cancer, disabilities, and early deaths.

Annually, air pollution ranks as one of the top global risk factors for death. In 2017, air pollution alone contributed to nearly 5 million deaths globally. This statistic can be further broken down to the root of 10% of global deaths each year. Shown below is a ranking of risk factors verses number of deaths (State of Global Air 2019, 2019).



II. LOCAL IMPACT

The crown jewel of the region's economic engine is the Virginia Port Authority, governing four independent shipping terminals. Annually, the Port Authority oversees the movement of 2.70 million twenty-foot equivalent units or TEU (Port of Virginia Fast Facts, 2020). Nearby, the world's largest naval base - Naval Station Norfolk - operates as the home port of the US Navy's Atlantic Fleet. This massive facility serves as the home base for over 75 military vessels, including six aircraft carriers. In support of the massive naval and shipping operations, extensive industrial complexes are operated west of the water line.

Clearly, Hampton roads is a busy area – but how does this effect air quality? In a Sierra Club report, Hampton Roads ranked in the top 25 communities for the concentration of toxic air emissions. In the report, it is cited that the community is riddled with chronic air quality issues due to local industry, vehicle emissions, and coal piers (Dietrich, 2019). In these areas, emissions are linked to high concentrations of respiratory issues such as asthma. Compared to the national average, children in Newport News (a city within Hampton roads) are twice as likely to develop asthma (Dietrich, 2019).

As the industrial complex expands, the burden of air pollution moves away from the source facility and weights more heavily on the logistics behind it. Essentially, the main contributor of air pollutants over time is not the physical factory but the mass operation of moving product. The Port of Virginia relies not only on Hampton Roads maritime highway of ocean, bay and rivers, but also on a large network of interstate highways that connect the region to inland ports and shipping terminals. This is exactly why high volume shipping areas like Hampton Roads are challenged with environmental issues over time. While Hampton Roads has benefited from a stable and lucrative economy though the transport of naval product, the air quality has been adversely affected.

III. HIGHLIGHTED POLLUTANTS

A. Particulate Matter

As stated before, particulate matter is one of the most harmful forms of air pollution. Fine particles contain microscopic solids that reduce visibility and lead to serious health problems. The sources of particulate matter (PM) include construction sites, fires, automobiles, and industries. Particulate matter is classified as either PM 10 or PM 2.5. PM 10 denotes particulate matter with diameters 10 micrometers and smaller. On the other hand, PM 2.5

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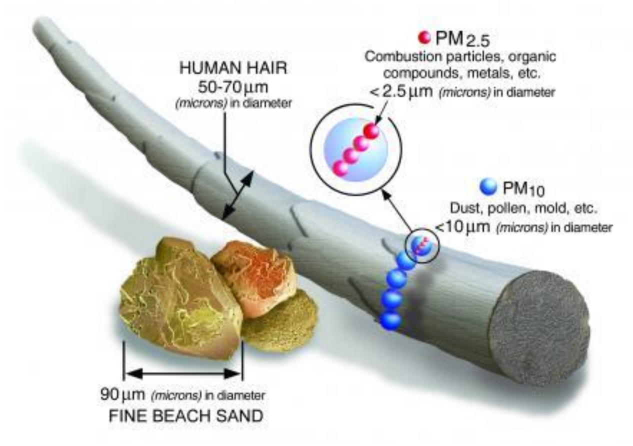
denotes particulate matter with diameters generally 2.5 micrometers or smaller. For a scale reference, this diagram was created by the EPA (Particulate Matter (PM) Basics, 2018).



Particulate Matter is most commonly expressed in micrograms per cubic meter of air(µg/m^3). This metric refers to the concentration of particulates in air. Currently, the EPA mandates that the health standard of PM 2.5 to be no greater than 35 µg/m^3 and

PM 10 to be no greater than 150 µg/m^3 (Particulate Matter (PM Standards), 2016).

Regardless of the level of particulate matter, there is no “safe” level of particulate matter. According to San Joaquin Valley air control center, the concertation levels of PM 2.5 against respective air quality levels can be explained as followed (Real-Time Air Advisory Network, 2020):

Air Quality	**PM 2.5 Concentration**
Good	1-12
Moderate	13-35
Unhealthy for Sensitive Groups	36-55
Unhealthy	56-75
Very Unhealthy	>75

B. CO_2

Carbon Dioxide is a known air pollutant. Modern studies reveal the health implications of CO_2. According to a 2017 study, the largest source of CO_2 pollutant is related to on-road transportation travel (Sources of CO2, 2018). Other major sources of CO_2 include electricity production, industrial emissions, and residential activities.

Although carbon dioxide has always been an important aspect of the respiration cycle, high concentrations over time lead to slowed brain function and illness. Carbon Dioxide is conventionally measured in units of parts per million or ppm. According to a 1994 study, the effects of increased concentrations of CO_2 can be summarized as (Rice, 2003):

Health Effect	**CO_2 Concentration**
Acceptable	1,000
Increase in Respiratory rate	10,000
Dizziness and Confusion	50,000
Visual Disturbances, vomiting, disorientation	100,000
Death	250,000

IV. DATA

A. NOAA Standard

The following particulate matter data was collected from National Oceanic and Atmospheric Administration (NOAA) air quality lot on Brambelton Ave between the coastline and Brambelton Ave in Norfolk. Since 1999, particulate matter data has been collected and averaged annually.

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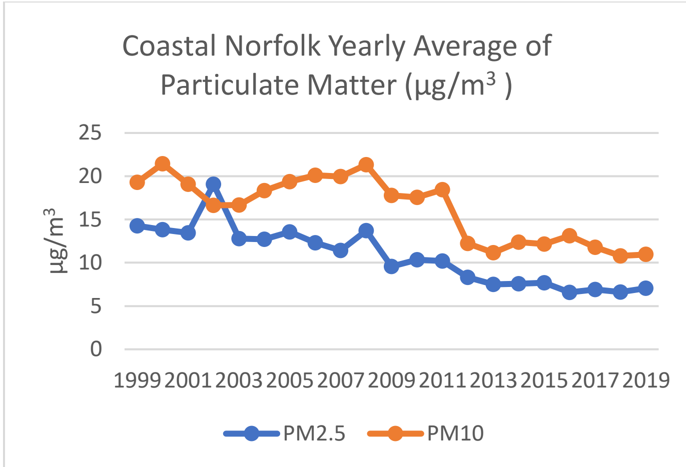


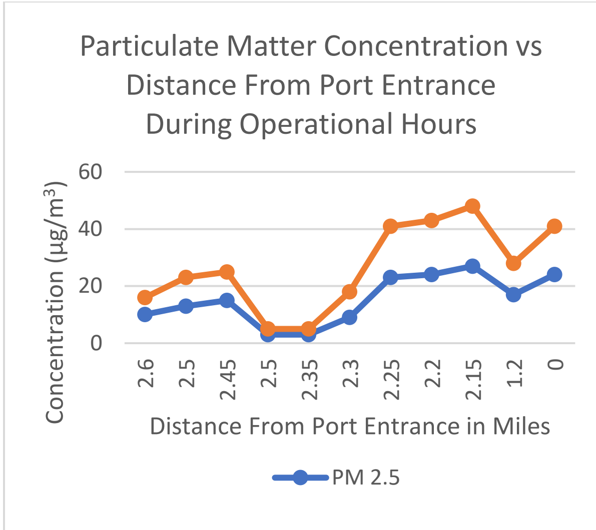
As shown, yearly average of particulate matter trends to decrease over the past 20 years for both PM 2.5 and PM 10.

<u>Independent Collection</u>

The locations of handheld readings were collected at the corresponding locations on Hampton Blvd in Norfolk. The enumerated distance from the port entrance in miles is shown below.

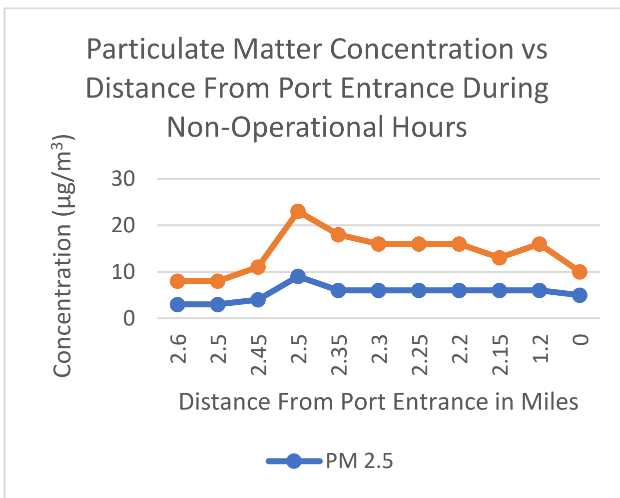
Location along Hampton Blvd	Distance in Miles
39th	2.6
40nd	2.5
41nd	2.45
43rd	2.5
45th	2.35
46th	2.3
47th	2.25
48th	2.2
49th	2.15
Lexan Ave	1.2
Virginia Port Authority entrance	0

Independently air quality data was collected on an operational Port of Virginia business day. All readings were collected using a *Yvelines Handheld Air Quality Monitor*.



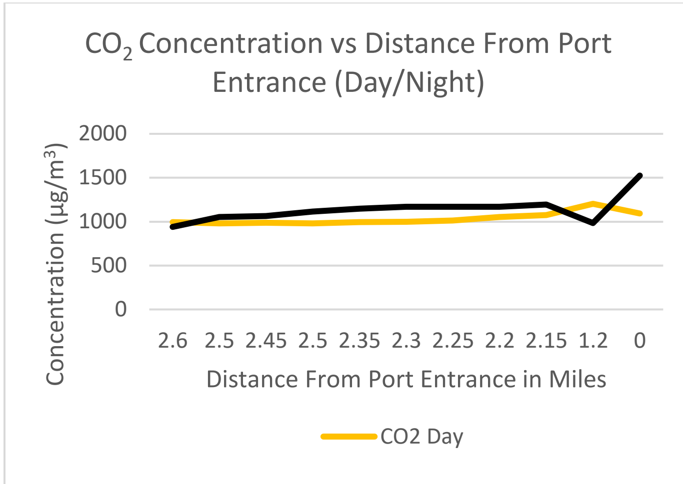
This graph displays a general decrease of both PM 2.5 and PM 10 as the distance from the port increases. There is an exception between 43rd and 46th Lexan Ave. These outliers will be explained in the discussion.

For further analysis, a secondary pool of data was conducted during non-operational hours. This data was collected under the same parameters as the operational information but at approximately 11pm.



During non-operational hours particulate matter seems to be relatively constant with a slight increase at 43rd street.

In addition, concentration of CO_2 against distance from the Norfolk Port of Virginia entrance was collected using a *Yvelines Handheld Air Quality Monitor*. A comparison between nighttime concentration (black) and daytime concentration (yellow) is shown against distance.



V. DISCUSSION

A. Independently Collected PM Data

Independently collected PM Data for operational hours tends to increase as the distance from the port entrance decreased. Therefore, the locations nearest to the port entrance are exposed to the highest concentrations of both PM 2.5 and PM 10. This is expected as the port itself hosts many operations, which may release particulate matter emissions. Notably, the Virginia Port Authority entrance is a high traffic location for transportation in and out of the port.

As noted before, this trend has outlying exceptions between 2.3 to 2.5 miles away from the port entrance and 1.2 miles away from the port. Respectively, these data pointes were collected between 43rd and 46th street and Lexan Ave in Norfolk, Virginia.

Geographically, the position of Lexan Ave is directly perpendicular to the Lafayette River. Unlike other data sample locations, Lexan Ave is not as surrounded by land mass and, therefore, is less exposed to car emissions. It can be extrapolated that the decrease in particulate matter is due in part to the lack of vehicle activities within the locality.

As for the dip between 43rd to 46th street, this outline can be explained in that there is a lack of "stand still" traffic between these streets. Vehicles stopping at traffic lights contribute to the overall local pollution with emissions of particulate matter. Therefore, a constant flow of vehicles will not only decrease overall emissions, but disperse unavoidable emissions more evenly.

B. Collected PM Data over Non-Operational Hours

Although the flow of ships never stops, there is a decrease of vehicle traffic after conventional business hours. From the collected data, it is apparent that nighttime concentrations of PM 2.5 and PM 10 stabilize to ~6 $\mu g/m^3$ and ~16 $\mu g/m^3$ respectively.

C. Collected PM Data vs Collected PM Data over Non-Operational Hours

Over these two samples, it can be clearly seen that non-operational hours exhibit lower particulate matter concentrations over a distance. Additionally, non-operational hours offer a more controlled distribution of particulate matter. One of the main contributors to particulate matter emissions is vehicle traffic. The more controlled flat line of nighttime PM near the port exhibits this direction in that there is less vehicle traffic over non-operational hours. Comparatively, during peak business hours, the concentration of particulate matter elevates to a near 20-point differential between PM 10 and PM 2.5. Based on this, it can be inferred that the lack of traffic/operations directly contributes to the improvement of air quality.

D. Collected PM Data vs NOAA Control

In the first graph provided, the average annual particulate matter emissions by year was detailed from a NOAA outpost near downtown Norfolk. While the downtown Norfolk post only began to collect particulate matter data in 1999, 20 years of information is enough to outline the long-term trend. With minor outliers, the annual concentration of particulate matter has decreased over the past 20 years.

The NOAA data for 2019 is between the operational/non-operational hours. It makes sense that the NOAA data is within bounds of the operational/non-operational samples because it represents a yearly average. As the annual 2020 NOAA data for this location is not yet complete, the individually collected concentrations follow this yearly concentration depression.

E. Collected CO_2 Concentration

In the collected comparison between day and night concentrations of CO_2 concentration verses distance from the port entrance, there is an overall tendency for nighttime concentrations to be greater than daytime concentrations.

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One reason for this can be explained in that photosynthesis does not largely occur at night. This allows for a slight concentration build up until the next morning. Overall, the nighttime CO_2 differential tends to be within 5% of daytime concentration.

An interesting aspect of the data collected shows an increase of CO_2 within 1 mile of the port entrance. The nighttime data group shows the most incline with a ~500 $\mu g/m^3$ spike. While not as apparent, the data also shows a slight increase of concentration for daytime samples. Both increases of concentration may be explained as a biproduct of shipping industry.

F. Air Quality Assessment

Air quality along the Port of Virginia can be assessed using current standards. According to the EPA, health standards for PM 2.5 should be less than 35 $\mu g/m^3$ and PM 10 should be less than 150 $\mu g/m^3$. Based on independently collected data, PM 2.5 concentration borderlines the acceptable standard. On the other hand, PM 10 concentration is well below hazardous levels. CO_2 concentration does not pose a serios issue until exposure increase beyond 10,000 $\mu g/m^3$. The collected CO_2 concentration appears to be far below dangerous levels for both night and day readings.

VI. CONCLUSION

Coastal industries provide a tremendous economic influence on the Hampton Roads community. An inconvenient byproduct of this industry is related to the constant release of pollutant emissions. Over the past 20 years, successful legislation has been made to combat unnecessary pollution. While an initiative is being made to mitigate this local exposure, air quality still borderlines EPA's acceptable standards. Based on the trend of decreasing annual pollutant concentration and the continual push for regulations, the Hampton Roads community should be mindful of the hazards of continued industrial development and its impact on air quality but also hopeful for the future of local clean air quality.

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