

How Industrial Emissions in Harris County Impact Asthma Rates and Excess Deaths

2023



ACKNOWLEDGEMENTS

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GLOSSARY

Particulate Matter (PM): The term for a mixture of solid particles and liquid droplets found in the air. Some particles, such as dust, dirt, soot, or smoke, are large or dark enough to be seen with the naked eye. Others are so small they can only be detected using an electron microscope. These particles come in many sizes and shapes and can be made up of hundreds of different chemicals. Some are emitted directly from a source, such as construction sites, unpaved roads, fields, smokestacks or fires. Most particles form in the atmosphere as a result of complex reactions of chemicals such as sulfur dioxide and nitrogen oxides.

Particulate Matter 2.5 (PM2.5): Fine inhalable particles, with diameters that are generally 2.5 micrometers and smaller.

Sulfur Dioxide (SO_2) : One of a group of gases called sulfur oxides (SOx). While all of these gases are harmful to human health and the environment, SO2 is of greater concern. The largest sources of SO2 emissions are from fossil fuel combustion at power plants and other industrial facilities.

Nitrogen Oxides (NOx): A family of poisonous, highly reactive gases. These gases form when fuel is burned at high temperatures. NOx pollution is emitted by automobiles, trucks and various non-road vehicles (e.g., construction equipment, boats, etc.) as well as industrial sources such as power plants, industrial boilers, cement kilns, and turbines.

Point Source: Any single identifiable source of pollution from which pollutants are discharged, such as a factory smokestack, fossil fuel fired power plants, smelters, industrial boilers, petroleum refineries, and manufacturing facilities. Collectively, air pollution from these sources are categorized as 'Point Source Emissions' to differentiate them from the pollution released by vehicles, agricultural operations, construction, mining, forest fires, and smaller-scale commercial and industrial sources - which are classified into their own categories.

Emissions Inventory: Industrial facilities are expected to calculate all of their pollution and report them to the Texas Commission on Environmental Quality (TCEQ) in an annual emissions inventory. These emissions are not directly measured but rather calculated using engineering estimates and are thus inherently conservative. While they do host significant limitations, these emission inventories serve as a starting point for estimating risks to local residents.

When used in conjunction with air dispersion modeling, they can be used to calculate the annual concentration of a pollutant that a residence, school, or other receptor may be exposed to after a year's worth of its release from a facility.

Criteria Air Pollutants: Some of the largest quantities and most frequently emitted chemicals released into the air include federal designated "criteria air pollutants" such as: sulfur dioxide (SO2), nitrogen oxides (NOx), and particulate matter (PM) among others. Point source emissions contribute one of the largest proportions of these pollutants in the Houston region compared to other categories.

Excess Mortalities/Excess Hospitalizations: Mortalities or hospitalizations that can be attributed to the risk cause being studied (in this case - industrial air pollution), and are thus considered excess or additional relative to baseline mortalities or hospitalizations, under the context of the study.

Toxic Release Inventory (TRI): A database managed by the EPA that tracks the management of certain toxic chemicals that may pose a threat to human health and the environment. U.S. facilities in different industry sectors must report annually how much of each chemical is released to the environment and/or managed through recycling, energy recovery and treatment.

Atmospheric Dispersion Modeling: Dispersion modeling uses mathematical formulations to simulate the atmospheric processes that disperse air pollutants or toxins emitted by sources such as industrial plants, vehicular traffic or accidental chemical releases. It is performed with computer programs that use data, algorithms, and mathematical representations of physical and chemical processes to simulate real-world effects and to solve the mathematical equations that govern the pollutant dispersion. Based on emissions and meteorological inputs, a dispersion model can be used to estimate the ambient concentrations of air pollutants at selected downwind receptor locations.

Health Impact Concentration-Response Functions: These functions statistically estimate the relationship between exposure to air pollutants and health outcomes such as mortality and morbidity burdens, with concentrations of pollutants acting as a surrogate for outdoor exposure.

EXECUTIVE SUMMARY

Petroleum refineries, power plants, chemical plants, manufacturing facilities, and other large factories and industries are significant sources of air pollution in the Greater Houston area and Harris County as a whole. These 'point sources' release large amounts of chemicals into the air that include criteria air pollutants such as: sulfur dioxide (SO₂), nitrogen oxides (NOx), and particulate matter (PM) among others.



Photo Credit: RoschetzkyIstockPhoto/Getty Images

Criteria air pollutants have serious health effects, especially on those residing nearby. Exposure to NOx, SO₂, and PM in particular exacerbate respiratory and cardiovascular diseases such as asthma, with chronic exposure contributing towards death (or "mortality"). In Houston, historical discrimination in housing, land-use and zoning policy have ensured that communities of color suffer the greatest exposure to industrial pollution and its subsequent health effects. These environmental injustices, while present throughout most of the nation, manifest with greater severity in Greater Houston. This area is home to over 500 facilities listed in the EPA's Toxic Release Inventory that collectively release more pollution than facilities present in the top five U.S. Metropolitan economies all combined.

The mission of Air Alliance Houston (AAH) is to reduce the public health impacts of air pollution. The pollution emitted from refineries, chemical plants, and other point sources are primary sources of concern. AAH works to better understand the contribution of industrial point source emissions to poor air quality and adverse health outcomes in local communities.

To that end, we sought to take a closer look at some of the point sources with the largest releases of air pollution in Harris County and ask a series of questions:

• What quantities of NOx, SO2, and PM2.5 do these sources release into the air during a representative year according to their own annual emission inventories?

• What are the average cumulative concentrations of these pollutants at residences, schools, and other sensitive land uses after their release into the air by those sources?

• What excess health impacts does exposure to these sources' pollution contribute towards at the zip code level?

• What would the monetary valuation of all those excess health impacts sum up to?

This study used the TCEQ's 2018 point source emissions inventory to determine the top 20 emitters of NOx, SO₂, and PM2.5 in Harris County. This provided us with 47 individual facilities in total. Once emission data for each pollutant from each facility was compiled, we utilized the AERMOD atmospheric dispersion modeling system to simulate the concentrations of NOx, SO₂, and PM2.5 in the air caused by the reported emissions from the 47 facilities of concern. The modeling results revealed that the highest annual average concentrations of PM2.5 were observed in Baytown and Deer Park, highest SO₂ levels were observed in Manchester/Harrisburg, Galena Park, Jacinto City, Cloverleaf and Northshore; and highest NOx levels were observed in Deer Park and Channelview.



Photo Credit: Air Alliance Houston

Next, the model outputs were used in health impact concentration-response (CR) functions to calculate the excess mortalities and asthma hospitalizations caused annually at a zip code level by exposure to these levels of PM2.5, SO₂, and NOx in the air from the 47 facilities' pollution. These values were also used to estimate the monetary impacts of the excess health burden.

The results were concerning:

• Cumulatively, all zip codes within our study area recorded approximately 33 additional deaths per year caused by PM2.5 emissions from the facilities of concern.

• Furthermore, excess mortality from PM2.5 pollution also comprised 99.99% of the total monetary valuation of all adverse health effects (\$313,488,635.91).

The results underscored the relationship between industrial air pollution and adverse health effects, especially within surrounding communities. The top two emitters of PM2.5, ExxonMobil Baytown Refinery and Olefins Plant are located in Baytown - the same area with the highest modeled concentrations of PM2.5 and highest excess mortality rates. Similarly, the zip codes housing and neighboring the facilities with the highest emissions of SO₂ and NOx - Deer Park, Cloverleaf, Channelview, Galena Park, Jacinto City and Sheldon - experienced the highest concentrations of these pollutants and recorded the highest incidence of adverse health outcomes.

This study demonstrates that these patterns are not merely happenstance, but that there is a correlation between high concentrations of air pollution emissions, elevated levels of exposure within surrounding communities as the pollution settles, and eventual negative health outcomes that may manifest due to that exposure. Moreover, it highlights the acute disproportionality of impact experienced as certain zip codes suffer far greater public health consequences compared to others.

Other elements that make these results concerning is the extremely conservative nature of all of the calculations and modeling conducted. For example, the study only focuses on a singular year's worth of emissions from only the top 20 point source emitters of 3 specific pollutants in a city and county inundated with countless sources and categories of air pollution. While a conservative approach was done intentionally to make sure the results reflect a baseline, the fact that excess deaths still numbered as high as 33 within only a portion of the county and the subsequent monetary valuations reaching as high as \$313 million despite all of these parameter constraints is cause for concern.

Taken together, the results suggest that current levels of air emissions from point sources such as industrial facilities, chemical plants, and refineries are far too high and must be lowered through improvements in industrial control technology and best management practices (BMPs), stricter regulations that lower the annual permitted quantities of pollution, and an overall strengthening of our environmental laws. However, the fact that the industries studied represent a significant fraction of point source emissions in the Houston area also means that any effort in reducing emissions from these 47 specific facilities alone would go a long way in reducing PM2.5, NOx, and SO₂ emissions from point sources in the entire county.

INTRODUCTION

This report seeks to examine the health impacts and related costs that are associated with particulate matter 2.5 (PM2.5), sulfur dioxide (SO₂), and nitrogen oxides (NOx) air pollution released by 47 of the largest point source industrial facilities in Harris County, Texas.¹ It documents how these emissions contribute to adverse health effects in surrounding communities, particularly excess mortality and asthma hospitalizations. To explore this connection between air pollution and health burdens, the study collected industrial air emission inventories, conducted air dispersion modeling, and utilized health impact concentration response (CR) functions to calculate the excess health impacts caused annually by exposure to PM2.5, SO₂, and NOx air pollution from these specific facilities of concern.² Further analysis also helped us determine the cumulative annual valuation of the calculated excess health impacts.

METHODS

Data Collection and Aggregation

The industrial facilities of interest were selected by determining the top 20 point sources of each PM2.5, SO₂, and NOx within Harris County. These emission quantities were obtained from the Texas Commission on Environmental Quality's (TCEQ) emissions inventory for 2018.³ This was chosen as a representative year to study rates of industrial pollution prior to the effects of COVID-19 on industrial and general human activity. Since large industrial facilities usually emit several different pollutants, there was significant overlap between the top 20 emitters of each of the three pollutants. The final list therefore consisted of 47 distinct facilities of interest.

For definition of point source see: National Geographic. Point Source and Nonpoint Sources of Pollution. Encyclopedic Entry. Link.

² Milando, C.W.; Martenies, S.E.; Batterman, S.A. Assessing concentrations and health impacts of air quality management strategies: Framework for Rapid Emissions Scenario and Health impact ESTimation (FRESH-EST). Environment International 2016, 94, 473-481. Link.

³ Texas Commission on Environmental Quality (TCEQ). Point Source Emissions Inventory; TCEQ: Austin, TX, USA, 2018. Link.
⁴ Texas Commission on Environmental Quality (TCEQ). Central Registry Query - Regulated Entity Search; TCEQ: Austin, TX, USA, 2018. Link

The air emission inventory of each of these facilities was then obtained from the TCEQ's central registry, utilizing their regulated entity search.⁴ Within each facility's air emission inventory, the individual point sources (stacks and flares) with the highest emission of each PM2.5, SO₂, and NOx were identified, along with their respective emission quantities (in tons per year) for each pollutant.⁵ These individual emission points located within each facility were compiled and aggregated until their cumulative emissions equaled or exceeded 70% of the entire facility's total reported emissions for the year - for each pollutant.⁶

Upon the conclusion of this data collection, the total individual point sources for each pollutant (across all 47 facilities) stood at:

PM2.5: 306 SO2: 178 NOX: 344

A public information request (PIR) was then submitted to the TCEQ to obtain the stack and flare characteristics of these point sources at each facility, such as their geographic coordinates, height, temperature, diameter, and exit velocity.

Visualization of Sources and Magnitude

The point sources compiled across all facilities were plotted onto a map using their obtained geographic coordinates. Due to the magnitude of point sources present (over 800), a spatial aggregation process was manually undertaken to further simplify the necessary air dispersion modeling required. During this process, clusters of point sources belonging to the same facility, located in the same general area of that facility's compound, and hosting relatively similar height and diameter, were reallocated to the largest emitting point source among them and all of their emissions added cumulatively to that source. This process was performed manually, to ensure that representativeness was taken into account and maximize the accuracy of aggregations and allocations. This ensured that modeling time and complexities were significantly reduced while simultaneously ensuring accuracy was not compromised. Below is a post-aggregated map visualizing the emitters of each pollutant, symbolized by size to represent the magnitude of emissions.

⁶ Fugitive emission sources were not included, due to their greater shared characteristics with an area source as opposed to a point source - which we preferred due to modeling and time constraints ⁶ This was done due to restrictions on data collection capacity and to reduce modeling complexity. Compiling every single point source on the facility, obtaining their emissions values, and running air emissions modeling on each of them across all 47 facilities would have expended significant time and resources that were unavailable for this project. For this reason, only the most highly polluting point sources at each facility were targeted for further study.



Fig. 1: Emitters of PM2.5



Fig. 2: Emitters of SO₂



Fig. 3: Emitters of NOx



Photo Credit: Air Alliance Houston

Air Dispersion Modeling

The AERMOD system developed by the American Meteorological Society/US Environmental Protection Agency (EPA)Regulatory Model Improvement Committee was used to model air dispersion of the PM2.5, SO₂, and NOx pollution quantities collected. To run, the model requires numerous parameters: the quantities of each pollutant emitted by the target facilities, the prevailing wind direction and speed averaged over the entire year, as well as any effects of underlying topography. Upon completion, we were able to obtain the modeled ground-level concentration of PM2.5, SO₂, and NOx at each receptor location covering much of southeastern Harris County. We chose to maintain this geographic focus for our receptors due to the concentration of the 47 facilities of concern within the same area, especially along the Houston Ship Channel, as seen below.



Fig. 4: Locations of all point source emitters as visualized within AERMOD

Health Impact Calculation

Calculating health impacts required some further aggregation. The pollutant concentrations measured by all receptor sites within a single zip code were averaged together to obtain a single average concentration per zip code for each pollutant: PM2.5, SO₂, and NOx. Once the average pollutant concentration was calculated for each pollutant within every zip code, we utilized a log-linear health impact function displayed below:

$\Delta Y_{u} = Y_{0,u} (1 - e^{-\beta Cu}) P_{u}$

where:

y_{0,u} = unit-level health outcome baseline incidence rate

 β = Concentration Response (CR) coefficient for the pollutant-outcome pair

C_u = unit concentration for unit u

P_u = relevant exposed population in geographic unit u

 ΔY_{u} = estimated number of cases in geographic unit u attributable to ambient concentration C_{u}

Based on the availability and confines of our data, we selected the zip code as the geographic resolution for unit u, and also chose to focus specifically on all-cause mortality and asthma hospitalizations as target health outcomes for analysis. The unit-level health outcome baseline incidence rate ($y_{0,u}$) for allcause mortality was obtained from Texas Death Certificate Data, prepared by the Texas Department of State Health Services, Center for Health Statistics (obtained through a public information request).⁷ The baseline incidence rate for asthma hospitalizations were collected from the City of Houston's Public Health Data Portal.⁹ This source, as well as the US census, also provided us with data on relevant exposed population sizes within each zip code (P_u).⁹ The CR coefficients (β) for each pollutantoutcome pair were obtained from the tables provided in "Supplemental Materials: Disease and health inequalities attributable to air pollutant exposure in Detroit, Michigan" by Martenies et. al.¹⁰ The unit concentrations (C_u) were averaged at a zip code level from AERMOD calculations. To evaluate the impacts of PM2.5 pollution we focused on all-cause mortality. Asthma hospitalization was chosen to evaluate the impacts of SO₂ and NOx pollution since these two pollutants, asthma hospitalization also provided the broadest age-group (0-64) for potential study, compared to other health outcomes.

Once the value for each variable above was obtained for each zip code, we were able to calculate the estimated number of adverse health outcomes (ΔY_u) in each zip code attributable to the concentration of PM2.5, SO₂, and NOx modeled.

⁺ Texas Department of State Health Services. Vital Statistics - Death Records 2010-2020. Center for Health Statistics. Texas DSHS: Austin, TX. USA, 2021. Link.

⁸ Houston State of Health Data Portal. Conduent Healthy Communities Institute. Community Dashboard. 2021. Link. Link.
⁹ U.S. Census Bureau. Population estimates. American Community Survey 1-year estimates: US Census Bureau: Suitland. MD. USA. 2019. Link.

¹⁰ Martenies, S.E.; Milando, C.W.; Williams, G.O.; Batterman, S.A. Supplemental Materials: Disease and health inequalities attributable to air pollutant exposure in Detroit, Michigan. International Journal of Environmental Research and Public Health 2017, 14. x. Link.

RESULTS

Average Modeled Pollutant Concentrations from Industrial Emissions

Particulate Matter 2.5:



Fig. 5: Annual average zip code-level concentrations of PM2.5

Annual average zip code-level PM2.5 concentrations ranged from 0.08 to 2.35 ug/m3. The zip codes with the highest concentrations were:

77520 (2.35 ug/m3)

77536 (1.68 ug/m3)

These zip codes are located in the Baytown and Deer Park communities respectively.

Sulfur Dioxide:



Fig. 6: Annual average zip code-level concentrations of SO2

Annual average zip code-level SO2 concentrations ranged from 0.012 to 2.22 ppb. The zip codes with the highest concentrations were:

77012 (2.22 ppb) 77547 (2.06 ppb) 77029 (2.03 ppb) 77015 (1.97 ppb)

These encompass the communities of Manchester/Harrisburg, Galena Park, Jacinto City, Deer Park, Cloverleaf, and Northshore.

Nitrogen Oxides:



Fig. 7: Annual average zip code-level concentrations of NOx

Annual average zip code-level NOx concentrations ranged from 0.34 to 5.88 ppb. The zip codes with the highest concentrations were:

77049 (5.88 ppb) 77536 (4.85 ppb) 77530 (4.33 ppb)

These encompass communities within Deer Park and Channelview.

Excess Health Impacts

Baseline Incidence Rates:

Before delving into the excess health impacts caused by air pollution from the facilities, it is important to establish the pre-existing rates of health risk and vulnerability present within the population. The following maps highlight three of these vital statistics: population density, baseline mortality rate, and baseline asthma hospitalizations. For the latter two statistics, we adjusted the crude rates by the relevant exposed population (as defined by the health impact functions) to account for differences in population between each zip code. Thus, the baseline mortality rate displayed below represents the annual cases of deaths per adult aged 30+ per 100,000 and the baseline asthma hospitalization rate represents the number of annual asthma hospitalizations per person with asthma aged 0-64.



Fig. 8: Population density by zip code



Fig. 9: Baseline mortality rate by zip code



Fig. 10: Baseline exposed population adjusted asthma hospitalization rate by zip code

By establishing these baseline statistics, it becomes easier to compare the pre-existing population vulnerability with the excess health burden created by air pollution from the studied facilities of interest.



Photo Credit: Air Alliance Houston

Particulate Matter 2.5:

The health outcomes from emissions of PM2.5 released by the target facilities were calculated in terms of excess additions to baseline mortality rates within each zip code. The highest adverse mortality outcomes were recorded within the 77520 zip code, encompassing part of the Baytown area.



Fig. 11: Estimated annual excess mortality cases per zip code attributable to change in ambient concentration caused by emissions of PM2.5

Sulfur Dioxide:

The health outcomes from modeled emissions of SO_2 released by the target facilities were also calculated in terms of excess additions to baseline rates of asthma hospitalizations within each zip code. The highest adverse mortality outcomes were recorded within:

77015

77536

These areas encompass the Deer Park and Cloverleaf communities.



Fig. 12: Estimated annual excess asthma hospitalization cases per zip code attributable to change in ambient concentration caused by emissions of SO2

Nitrogen Oxides:

The health outcomes from modeled emissions of NOx released by the target facilities were also calculated in terms of excess additions to baseline rates of asthma hospitalizations within each zip code. The highest adverse mortality outcomes were recorded within:

77536

77049

77015

These areas encompass the Deer Park and Cloverleaf communities and parts of Channelview and Sheldon as well.



Fig. 13: Estimated annual excess asthma hospitalization cases per zip code attributable to change in ambient concentration caused by emissions of NOX

Health Impact Valuation

To estimate the monetary impacts of the excess health burden caused by exposure to PM2.5 pollution in this study, we utilized valuations from the US EPA's BenMAP program.¹¹ To determine the average cost for an asthma hospitalization, we relied on research conducted by the American Thoracic Society and researchers from the Centers for Diseases Control and Prevention (CDC) whose study pointed towards a value of \$529 for a single hospitalization. However, the study also notes that this is far from the only cost incurred by asthma-related medical expenses:

="The annual per-person medical cost of asthma was \$3266, of which: \$1830 was for prescriptions \$640 for office visits \$529 for hospitalizations \$176 for hospital outpatient visits \$105 for emergency department (ED) care."12

Pollutant	Health Endpoint	Cases Per Year	Total Dollar Valuation (2010\$)
PM2.5	All-cause mortality (Krewski et al. 2009) ¹³	32.5	\$313,488,635.91
SO ₂	Asthma Hospitalization (Sheppard et. al 2003) ¹⁴	0.5	\$264.50
NOx	Asthma Hospitalization (Linn et. al 2000) ¹⁵	1	\$529
	Total Valuation		\$313,489,429.41

Table 1. Annual human health effects and monetary valuations associated with air pollution impacts from facilities of concern in Harris County

Thus, we estimate the total valuation of these health impacts associated with PM2.5, SO₂, and NOx air pollution from these facilities to be over \$313 million per year.

¹ Thurston, G.D. Written Report of George D. Thurston regarding the Public Health Impacts of Air Emissions from the Wheelabrator Facility. 2017. Link

¹² Nurmagambetov, T. et al. "The Economic Burden of Asthma in the United States, 2008-2013." Annals of the American Thoracic Society vol. 15,3 (2018): 348-356. Link ¹³ Krewski, D.; Jerrett, M.; Burnett, R.T.; Ma, R.; Hughes, E.; Shi, Y.; Turner, M.C.; Pope III, C.A.; Thurston, G.; Calle, E.E. et. al. Extended follow-up and spatial analysis of the American Cancer Society study linking particulate air pollution and mortality. Res. Rep. Health Eff. Inst. 2009, 5–114. Link.

⁴ Sheppard, L. Ambient air pollution and nonelderly asthma hospital admissions in Seattle, Washington, 1987–1994. Revis. Anal. Time-Ser. Stud. Air Pollut. Health 2003, 227–230. Link 15 Linn, W.S.; Szlachcic, Y.; Gong, H.; Kinney, P.L.; Berhane, K.T. Air pollution and daily hospital admissions in metropolitan Los Angeles. Environ. Health Perspect. 2000, 108, 427–434. Link

DISCUSSION

The results demonstrate that PM2.5, SO_2 , and NOx air emissions from these 47 facilities alone place severe burdens on the residents of Harris County. It also highlights the acute disproportionality of these burdens as the vast majority of health impacts are experienced by residents living in the county's eastern side along the Ship Channel. In doing so, the results of this study also highlight the entrenched environmental justice implications involved in industrial pollution.

PM2.5 and Excess Mortality

Excess mortality from PM2.5 pollution comprised the greatest proportion of the cumulative health burden recorded across the study area. This was true particularly in the city of Baytown - on the easternmost side of Harris County - which recorded the highest modeled concentrations of PM2.5 and also the greatest number of excess mortality within a single zip code. Cumulatively, all zip codes within our study area recorded approximately 33 additional deaths per year caused by PM2.5 emissions from the facilities of concern. Furthermore, excess mortality from PM2.5 pollution also comprised the overwhelming share (99.99%) of the total monetary valuation of all adverse health effects calculated in Table 1 as well. This is due to a convergence of several factors. First, the baseline incidence rate for all-cause mortality is expectedly much higher compared to asthma hospitalization incidence rates. Furthermore, the CR coefficient is higher for PM2.5 caused mortality (0.00545) than any of the other pollutant-outcome pairs studied (0.00332 and 0.0014). The relevant exposed population for each health-outcome calculation was also significantly different since the health impact functions calculating asthma hospitalizations only utilized those populations within each zip code that already suffered from asthma (between ages 0-64), whereas mortality calculations utilized the entire population within each zip code (aged 30+). The varying age groups were governed by the respective health impact function being used, as seen in Table S1 of Martenies et. al.¹⁶

The average PM2.5 concentrations and the sizes of relevant exposed populations within each zip code played the greatest role in the distribution of the severity of health impacts observed across the study area. The top two emitters of PM2.5: ExxonMobil Baytown Refinery and Olefins Plant were sited in the Baytown area, with the third largest emitter being Shell's Deer Park Plant. Subsequently, the areas with

¹⁶ Martenies, S.E.; Milando, C.W.; Williams, G.O.; Batterman, S.A. Supplemental Materials: Disease and health inequalities attributable to air pollutant exposure in Detroit, Michigan. International Journal of Environmental Research and Public Health 2017, 14, x. Link.

the highest modeled concentrations of PM2.5 and also the highest excess mortality were the zip codes housing these very same facilities as well as those immediately surrounding them.

To contextualize these results within broader rates of mortality due to pollution, we consulted the Global Burden of Disease, Injuries and Risk Factor Study (GBD). GBD quantifies health loss from hundreds of diseases, injuries, and risk factors, so that health systems can be improved and disparities eliminated.¹⁷ According to the GBD Compare Interactive Tool, ambient particulate matter pollution in Texas is attributable for approximately 15 deaths per 100,000 people, in more recent years:



Fig. 14: Death rate in Texas attributable to ambient particulate matter pollution from 1990-2019

If we scale this rate to the zip codes encompassed within our study area above (hosting a total population of 3,065,292), ambient particulate matter pollution can be approximated to be responsible for 460 deaths per year. The results from this study reveal that PM2.5 emissions from these highest polluting facilities are responsible for approximately 33 deaths within the study area. Subsequently, it concludes that eliminating these emissions would prevent those 33 mortalities, translating to approximately 7.1% of the 460 deaths attributable to particulate matter air pollution.



Fig. 15: Average annual PM2.5 concentrations in the Houston metropolitan statistical area

Additionally, the recent average annual PM2.5 concentration in the Houston area is approximately 10 µg/m³.¹⁸ ¹⁹ Reductions of 7.1% would reflect the approximate population weighted exposure to PM2.5 pollution across our study area from these facilities as well, and therefore a reduction of 0.7 - 1 ug/m3 in PM2.5 population weighted exposure would result from eliminating emissions from these facilities.²⁰ A reduction in emissions would subsequently result in a reduction in mortality, which translates to approximately 33 deaths. These calculations, which used AERMOD and dispersion modeling, are confirmed by rough rates provided by GBD Compare, a global burden of disease calculator.

¹⁸ Fitzpatrick, A. "Houston air quality is improving but still among the worst in nation." AXIOS Houston. May 15, 2023. Link

¹⁹ Understanding Houston - Environment, Air and Water Quality: Particle Pollution. (Data compiled from EPA: National Air Quality: Status and Trends of Key Air Pollutants; EPA: Air Quality - Cities and Countries). Link. ²⁰ Population weighted means that more people are exposed to binder concentrations in denser zin codes, so to assess the "cumulative exposure" in the population, we need to weight the PM2.5

²⁰ Population weighted means that more people are exposed to higher concentrations in denser zip codes, so to assess the "cumulative exposure" in the population, we need to weigh the PM2.5 concentrations in each zip code by the relative population

NOx and SO, Pollution

The same correlation is observed with SO₂ and NOx emissions as well. The zip codes housing and bordering the facilities with the highest emissions of SO2 and NOX experienced the highest concentrations of these pollutants. They subsequently recorded the highest incidences of adverse health outcomes linked to those pollutants as well, in this case, asthma hospitalizations. These were clustered within the communities of Deer Park, Cloverleaf, Channelview and Sheldon. It is worth noting that while Cloverleaf and Channelview themselves do not house any significantly large emitters of SO₂ and NOx, being directly downwind of the county's largest emitters results in them experiencing disproportionately high adverse health outcomes. Similarly, Galena Park and Jacinto City - both largely residential communities that do not house major polluters directly within their boundaries - observe high levels of modeled pollutant concentrations and adverse health impacts as well due to their downwind location and proximity to the largest polluters.

Repeating the same evaluations with NOx and SO2 pollution reveals further benefits to regulating air emissions from these facilities. According to readings recorded by TCEQ's regulatory air monitors, the annual average NOx concentration in Harris County over recent years is approximately 13 ppb:



Fig. 17: Average annual SO2 concentrations in Harris County 2017-2020 (Source: TCEQ's Texas Air Monitoring Information System - TAMIS Web Interface)

While NOx emissions from these facilities produced varying concentrations both within and across zip codes, the cumulative population weighted exposure can be approximated to 0.63 ppb across the study area. Reducing emissions from these facilities alone would thus produce a 4.8% reduction in average community exposure to NOx pollution within our study area, with some zip codes experiencing greater reductions and some less, depending on their baseline concentration and exposed populations.

With regards to SO2, we see relatively greater proportions. According to readings recorded by TCEQ's regulatory air monitors, the annual average SO2 concentration in the county over recent years is approximately 0.56 ppb:



Fig. 17: Average annual SO2 concentrations in Harris County 2017-2020 (Source: TCEQ's Texas Air Monitoring Information System - TAMIS Web Interface)

The cumulative population weighted exposure to SO2 emissions of these facilities can be approximated to 0.28 ppb. Thus, reducing emissions from these facilities alone would produce a 50% reduction in average community exposure to SO2 pollution within our study area.

The health effects of both of these pollutants have been well established. NOx pollution present in the air (which includes nitrogen dioxide, nitric oxide, and other nitrogen oxides) even at low levels causes eye, nose, throat and lung irritation resulting in coughing, shortness of breath, fatigue, and nausea. Exposure to low levels can also result in fluid building up in lungs as long as 1 to 2 days after exposure.²¹

NOx pollution also contributes to acid rain formation, ozone pollution, and smog formation which each have their own set of adverse health effects as well. SO2 when inhaled reacts with the moisture of mucous membranes to form sulfurous acid (H_2SO_3), which is a severe irritant. This contributes to airway resistance and increased difficulty breathing. Other health effects include severe irritation of the eyes, skin, and respiratory tract. Bronchospasm, pulmonary edema, pneumonitis, and acute airway obstruction can occur. Even at very low concentrations, inhaling SO_2 can aggravate chronic pulmonary diseases, such as asthma and emphysema.²² People with asthma, particularly children, are sensitive to these effects of SO_2 . SO₂ emissions that lead to high concentrations of SO_2 in the air generally also lead to the formation of other sulfur oxides (SOx). SOx can react with other compounds in the atmosphere to form small particles. These particles contribute to particulate matter (PM) pollution. Thus, the health effects of SO_2 are not limited to its direct exposure, but also encompass its contribution to PM pollution as well, which hosts its own set of adverse health effects.²³

Thus, regulating these largest sources of NOx and SO₂ pollution will have a significant effect on reducing average concentrations from the baseline level which will reduce community exposure, lead to lower health exacerbations such as asthma, and bring benefits with regards to respiratory health and general well being.

Limitations

The conservative nature of all our calculations must be underscored to place these results in further context. To begin with, due to the constraints of our project's scope, we chose to focus only on a few dozen of the highest polluters within Harris County and three of the most commonly emitted pollutants of concern. There are hundreds of industrial facilities present within the county and most, if not all of them (including the 47 we studied) release many more chemicals into the air than just PM2.5, SO₂, and NOx alone. Their complete emission inventories also include a slew of Hazardous Air Pollutants (HAPs) such as benzene, toluene, and xylene, which possess their own health effects and subsequent valuations.

Furthermore, according to the TCEQ's point source emissions inventory, the following amounts of PM2.5, NOx and SO₂ were released in Harris County from all point sources in 2018, compared to the cumulative emissions from the facilities of concern analyzed in this study.²⁴

²² Agency for Toxic Substances and Disease Registry (ATSDR). Medical Management Guidelines for Sulfur Dioxide. Toxic Substances Portal; ATSDR: Atlanta, GA. USA. 2023. Link.
²³ Environmental Protection Agency (EPA). Sulfur Dioxide Basics - Sulfur Dioxide (SO2) Pollution. EPA: Washington D.C. USA. 2023. Link.

²⁴ Texas Commission on Environmental Quality (TCEQ). Point Source Emissions Inventory; TCEQ: Austin, TX, USA, 2023. Link.

Pollutant	Study Facilities (TPY)	All Point Sources (TPY)
PM2.5	2,483.5	3,963.1
NOx	11,404.3	16,272.8
SO ₂	5,509.6	7,140.5

Table 2. 2018 TCEQ Point Source Emissions Inventory for Harris County

The industries studied thus represent a significant fraction of the total annual emissions of each pollutant from point sources in the Houston area. Thus any effort in reducing emissions from these specific facilities would go a long way in reducing PM2.5, NOx, and SO₂ emissions from point sources in the entire county as well due to their substantial contribution to the cumulative amount. However it is important to note that point source emissions are a subset of total emissions from all sources - which include non-point source emissions such as area sources, mobile sources, and biogenic sources of emissions as well.²⁵ With the exclusion of fugitive emission sources due to modeling constraints, only in a few cases did the facility's cumulative emissions from point sources fail to reach 70% of the facility's total emissions. The total emissions released into the air and the concentration values obtained at receptor sites are therefore underestimated.

In sum, the omission of these additional facilities and types of pollution from our study means that the results and takeaways highlight only a fraction of the health impacts and associated economic burden caused by industrial air pollution in Harris County.

Furthermore, the costs associated with asthma hospitalizations vary greatly due to several variables such as the severity of the asthma attack, the presence of underlying medical conditions, and other factors such as insurance coverage, hospital type, medications, etc. While we decided on a conservative estimate from research conducted by the CDC, it must also be acknowledged that costs may vary greatly from our utilized value of \$529, to as high as \$5000 per hospitalization.²⁶ Thus, the health impact valuation obtained through our calculations must be regarded as a baseline. Additionally, due to the limitations of publicly available health data, we could not obtain disease incidences at a resolution finer than the zip code scale, which limits the level of detail these results are able to provide on a block group, census tract, or neighborhood level.

²⁵ Texas Commission on Environmental Quality (TCEQ). Sources of Air Emissions; TCEQ: Austin, TX, USA, 2023. Link.

²⁶ Nurmagambetov, Tursynbek et al. "The Economic Burden of Asthma in the United States, 2008-2013." Annals of the American Thoracic Society vol. 15,3 (2018): 348-356. Link



Photo Credit: Air Alliance Houston

Finally, this research report and its conclusions must not be viewed as a comprehensive analysis of the effects of pollution in Harris County from all industrial sources, but as a foundational study. We sought to capture a snapshot of the public health consequences caused by a single representative year of air pollution from only the county's top industrial emitters. In doing so, we hope to call attention to the severity of these consequences caused by only a fraction of industries despite largely conservative research parameters, as well as the disproportionality of impact experienced across the county.

CONCLUSION

The results of this study highlight the impacts of industrial pollution on the health and well-being of residents in east Harris County. In particular, those residing within the communities of Baytown and Deer Park suffered the greatest health impacts in the form of excess mortality due to PM2.5 pollution from the county's largest emitters. It also highlights the magnitude of NOX and SO2 pollution from these facilities and their contributions to asthma hospitalizations in the county as well. These results offer a preliminary insight into air pollution exposure within Harris County and prompt further research expanding upon its findings. In particular, studying the incidence rates of different types of diseases and health outcomes (beyond mortality and asthma hospitalization rates) as well as the excess burden contributed by additional types of air pollution exposure beyond those studied could shed further insights into the full scope of adverse health and economic consequences experienced by residents exposed to industrial air pollution.

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