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Environmental Health Insights

Assessment of Particulate Matter Levels in Vulnerable Communities in North Charleston, South Carolina prior to Port Expansion

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ABSTRACT

INTRODUCTION: The Port of Charleston, one of the busiest US ports, currently operates five terminals. The fifth terminal is being planned for expansion to accommodate container ships from the proposed Panama Canal expansion. Such expansion is expected to increase traffic within local vulnerable North Charleston neck communities by at least 7,000 diesel truck trips per day, more than a 70% increase from the present average rate of 10,000 trucks per day. Our objective was to measure the current particulate matter (PM) concentrations in North Charleston communities as a baseline to contrast against future air pollution after the proposed port expansion.

METHODS: Saturation study was performed to determine spatial variability of PM in local Charleston neck communities. In addition, the temporal trends in particulate air pollution within the region were determined across several decades. With the BGI sampler, PM samples were collected for 24 hours comparable to the federal reference method protocol. Gravimetric analysis of the PM filter samples was conducted following EPA protocol.

RESULTS: The range of the PM_{10} annual average across the region from 1982 to 2006 was 17.0–55.0 μg/m^3. On only two occasions were the records of PM_{10} averaged above the 50.0 μg/m^3 national standard. In the case of $PM_{2.5}$, the annual average for 1999–2006 ranged from 11.0 to 13.5 μg/m^3 and no annual average exceeded the 15.0 μg/m^3 $PM_{2.5}$ annual standard.

CONCLUSIONS: Although ambient PM levels have fallen in the Charleston region since the 1960s due to aggressive monitoring by the stakeholders against air pollution, local air pollution sources within the North Charleston neck communities have consistently contributed to the PM levels in the region for several decades. This baseline assessment of ambient PM will allow for comparisons with future assessments to ascertain the impact of the increased truck and port traffic on PM concentrations.

KEYWORDS: air pollution, air quality, urban, community, port, particulate matter, environmental justice

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Introduction

The North Charleston community is an integral part of the primary industrial corridor for the metropolitan Charleston region. It is a mixed industrial and residential area in the city of North Charleston bounded on the east and west by the Cooper and Ashley rivers, respectively. A large naval base was active within the area for decades, until it closed in the 1990s.[1–2] The relatively recent redevelopment of the former naval base, the planned expansion of the Port of Charleston by the South Carolina State Ports Authority (SCSPA), and the related modifications of the major transportation systems have raised concerns about the current and future levels of particulate matter (PM) and their impacts on air quality in the local communities.

The planned North Charleston port expansion. The Port of Charleston is currently one of the largest container ports in the United States based on the container traffic and is ranked the 39th busiest port by cargo volume.[3] Currently there are five terminals operated by the SCSPA in the Port of Charleston network: (1) the North Charleston terminal in the northern part of the city, (2) the Wando Welch terminal in the northwest end of Mount Pleasant, (3) the Veterans terminal incorporating the existing docks at the closed naval base, (4) the Union Pier, and (5) the Columbus Street terminals, both in east and central Charleston. The primary container port terminals are North Charleston and Wando Welch, whereas Veterans and Columbus Street are designated as project cargo port terminals. The Union Pier is now used mostly for cruise operations (Fig. 1).

The Panama Canal is currently being enlarged to support its use by larger Pacific-fleet container ships. Many sea ports along the eastern seaboard of the United States are hoping to accommodate the larger "Panamax" ships after the completion of the Panama Canal expansion. Due to the close proximity of the Port of Charleston to the major distribution centers in the eastern United States, deep water port accessibility, relatively low hurricane risk compared to Gulf of Mexico and Florida ports, and proximity to the Panama Canal, the SCSPA believes that the Port of Charleston is uniquely positioned to solicit this new business.[4,5] Thus, there is a plan to expand the Port of Charleston by approximately 25% through the introduction of a new deep water container terminal in North Charleston at the old naval base (Fig. 2).[4]

However, with the approved expansion of the North Charleston terminal on the former naval base, currently scheduled for completion in 2017, the port-related transportation activities will likely lead to an increase in the ambient levels of PM and other air pollutants within the neighborhoods adjacent to the new container terminal. There is expected to be an additional 7,000 new truck trips per day, a 70% increase in the present rate of 10,000 trucks per day on area roads to support the distribution of the ships' containers.[4]

The expansion being planned for the naval base terminal has been met with opposition from residents in adjacent neighborhoods hitherto vulnerable by the siting of a chemical plant, a cement factory, and possibly a 20-acre coal pile proposed by the nearby Kinder Morgan facility. Many environmentalists have concluded that the terminal will clog the already congested I-26 with trucks (more than 9,000 trucks in a 16 h period) and add to the PM level that is already hovering below the EPA's acceptable limit.[1] Ship, rail, and diesel truck emissions have been shown to be significant contributors to local particulate air pollution,[6,7] which can eventually lead to adverse health risks such as asthma and heart disease.[2,8–11]

Community organizing and local air pollution. In 2005, the Low Country Alliance for Model Communities

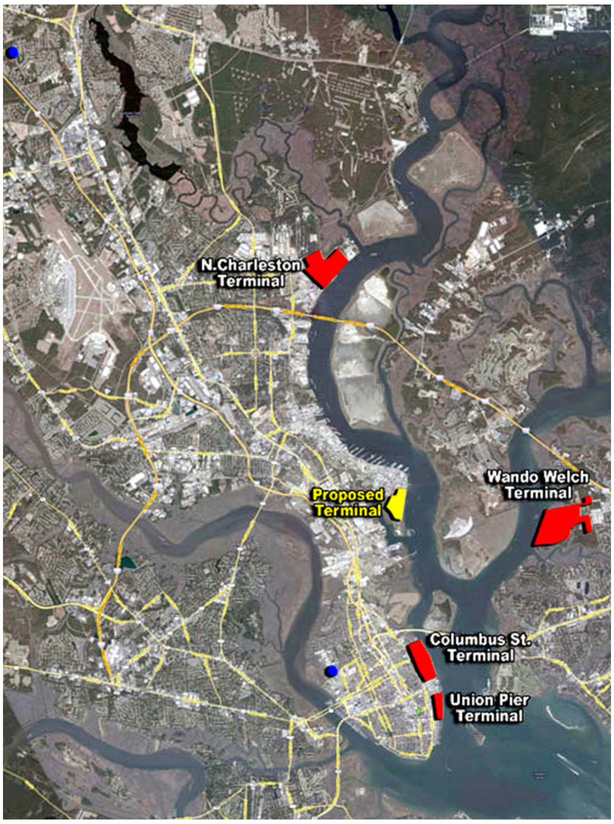

Figure 1. Charleston, SC peninsula indicating areas of port activity and SC ambient monitoring network sites. The blue dots represent air monitoring sites within the study communities. The red areas represent the study communities.

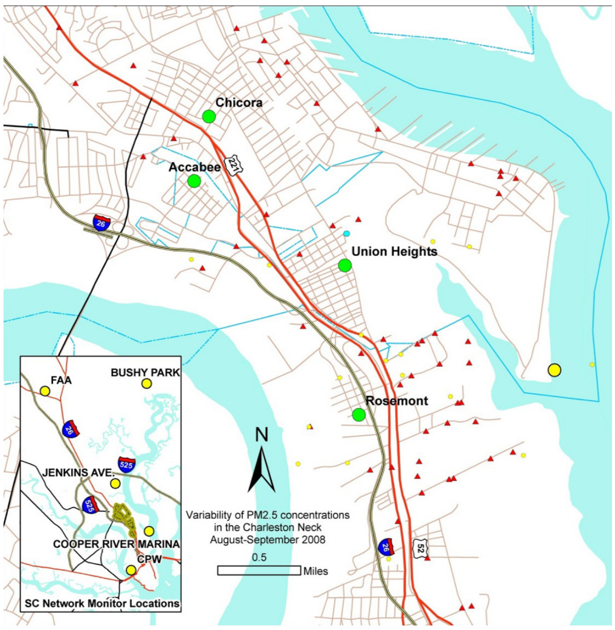

Figure 2. Air quality monitoring saturation study area: North Charleston and South Carolina (2008). Large yellow dots: current SCDHEC air monitoring stations; large green dots: planned project monitoring sites; small red triangles: air emission sites registered with SCDHEC; small yellow dots: discontinued ambient monitoring sites; small blue dots: Howard Heights saturation/FRM site.

(LAMC), a community-based organization concerned about environmental injustice, was organized by the residents of seven economically distressed neighborhoods in North Charleston.[12–15] LAMC was primarily organized to address potential negative impacts associated with the planned port expansion, particularly, increased levels of air pollution due to additional diesel truck traffic in a community with the underlying environmental health disparities.[12,13,15] LAMC developed a mitigation plan agreement with the SCSPA under the National Environmental Protection Act (NEPA) to address the impacts of port expansion with a focus on four core areas of concern for the community: (1) housing, (2) economic development, (3) environmental monitoring, and (4) education.[12–15] As part of the mitigation agreement, the SCSPA agreed to provide funding to establish and support an ambient air monitoring site in Charleston Neck to help monitor any changes in the local air quality.[13]

The planned redevelopment of the old naval base including the planned port expansion has raised major concerns about the current and future air quality in the region by LAMC leadership, residents, and other stakeholders. Many individuals in LAMC and partner neighborhoods have questioned whether the current Charleston air quality monitoring network captures air pollution data that represent the Charleston Neck area and its high concentration of car traffic, stationary industrial pollution sources, and port activity including the diesel truck traffic. As part of the mitigation agreement, South Carolina Department of Health & Environmental Control (SCDHEC) was commissioned to determine the best location for an air quality monitoring site to represent the area's air quality before, during, and after the expected changes in the area.

LAMC then partnered with the University of South Carolina (USC) and SCDHEC in a community—university—government (CUG) partnership to address the environmental justice and health issues in the Charleston region. USC researchers obtained funding from the National Institute of Environmental Health Sciences (NIEHS) for the partnership to perform a baseline environmental assessment before the port expands and build community capacity to address local environmental health and justice issues[11–14] using the community-based participatory research (CBPR) framework.[16–20] The initial partnership known as the Charleston Area Pollution Prevention Partnership (CAPs) was expanded to include the Rosemont community, the University of Maryland—College Park, Tulane University, and other groups.[11–14] Studies by the CAPs team have shown a differential burden of toxic release inventory (TRI) facilities and leaking underground storage tanks (LUSTs) in metropolitan Charleston including North Charleston across race/ethnicity and socioeconomic status at the census tract level.[12,14–15,17,21] These studies present a strong rationale for the need for research on the air quality issues for the overburdened communities near the port-related activities in the Charleston region.

The primary objectives of this study were to (1) determine the spatial variability of PM concentrations in the residential areas of Charleston Neck impacted by environmental injustice and (2) collect sufficient information to provide representative measurements of PM in the Charleston Neck communities before the new port development for the siting of a long-term air pollution monitor in the area using a saturation approach. In addition, we performed this study to compare these newly collected saturation data with the temporal trends in air pollution within the region over several decades since air monitoring was initiated in the late 1960s.

Methods

Charleston air quality trends. There has been little monitoring of spatial and temporal variation of the impact of port activities in the Charleston region. During the study period, there were three monitors run by the SCDHEC collecting either $PM_{2.5}$ and/or PM_{10} data in the study area. One PM_{10} site is located in Jenkins Street in the downtown area of North Charleston, which represents urban exposure levels. Owing to the predominant south—southwesterly wind direction, this site would rarely be expected to be impacted by PM_{10} emissions related to port activities (Fig. 3). Daily $PM_{2.5}$ samples are collected by the South Carolina (SC) ambient monitoring network at a suburban location northwest of the project area (FAA) and a downtown urban site south of the Neck communities in Fishburne Avenue in the city of Charleston (CPW). We used simple descriptive statistics to present trends in PM.

Air monitoring saturation study. The United States Environmental Protection Agency (USEPA) encourages state and local air pollution control agencies to conduct short-term, multi-site pollutant monitoring studies using a technique known as saturation monitoring. Saturation monitoring are typical non-federal reference method (FRM) (ie, not the method required for regulatory monitoring), small portable samplers that are readily set up, operated, and easy to site. In addition, because they are relatively inexpensive, it is possible to "saturate" an area with these monitors to assess air quality in areas where high concentrations of pollutants are possible. Saturation monitoring may be used to determine "hot spots"—areas of relatively high particulate concentration. The saturation study data provide preliminary information for representative, long-term sampler siting in the Charleston Neck area and assist in the evaluation and development of a more representative monitoring network for vulnerable communities concerned about industrial and mobile sources of air pollution.

Saturation study location. The saturation study area included the North Charleston Neck communities of Accabee, Chicora/Cherokee, Howard Heights, and Union Heights (Fig. 2). PM concentrations were measured in these four LAMC neighborhoods to obtain a daily time-integrated average using FRM omni PM samplers (BGI, Waltham, MA).

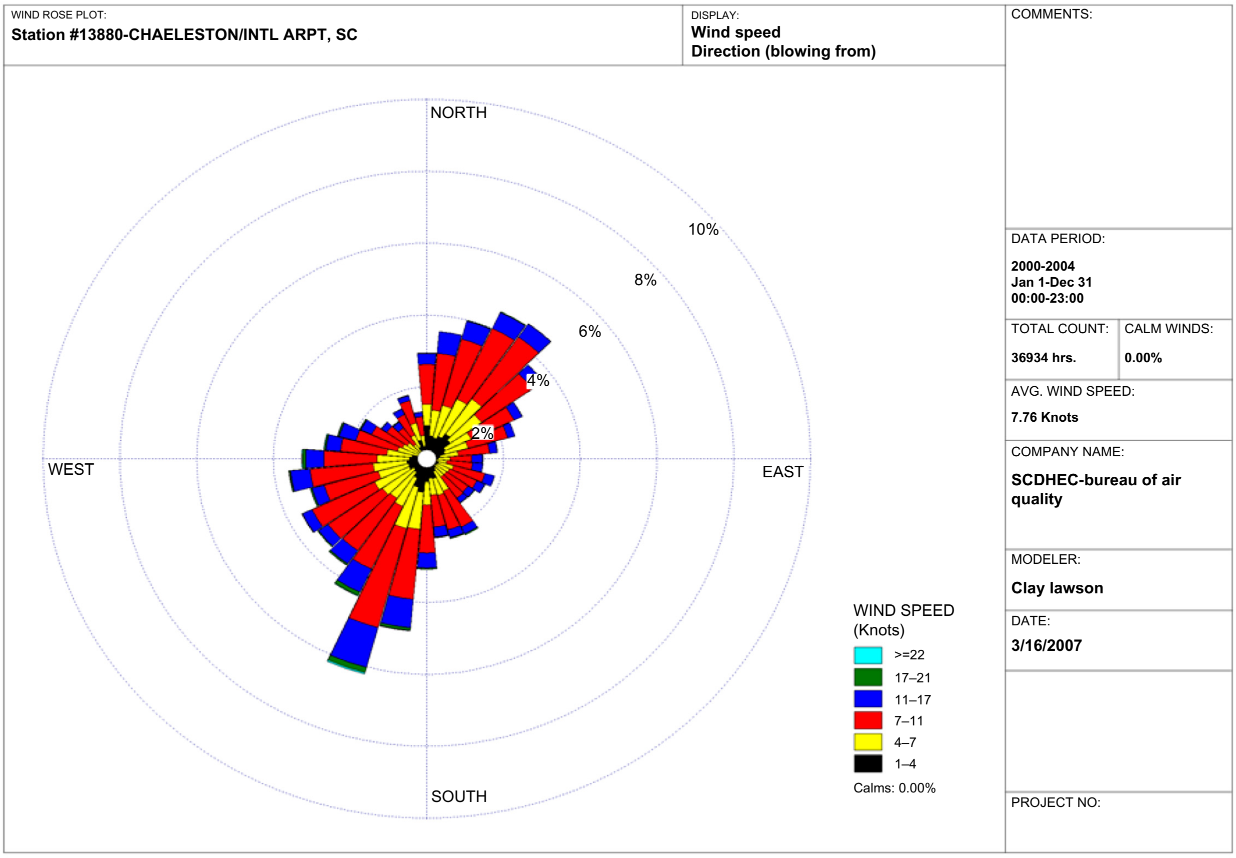

Figure 3. Charleston seasonal windrose (2007).

The sampling locations were planned with the cooperation of the Neck communities using the CBPR framework.[17–20,22]

Air monitoring methods. The methods used in the air monitoring studies were presented in more details in the previous studies.[5] In brief, the BGI sampler is a filter-based system that collects particulate on 46.2 mm PTFE membrane media at a volumetric sampling rate of 5.04 L/min. The BGI sampler can collect samples for 24 h. Samplers were placed in each selected neighborhood to monitor PM levels and to provide data for spatial variability. The BGI samplers had been previously evaluated by SCDHEC to estimate the precision and bias compared to an FRM sampler. The data quality did not meet the FRM requirements, but were sufficiently precise to meet the project goal of determining spatial and temporal variation in the ambient levels of $PM_{2.5}$ in and across LAMC neighborhoods and enable comparison to other locations in the Charleston PM monitoring network.

Sampling events—days when all samplers were scheduled to operate—coincided with the national 1-in-3-day monitoring schedule. Sampling began after the measurement system evaluation was complete on the first scheduled sampling day after a site was installed. Sampling was planned to collect approximately 20 sample sets to allow sufficient samples (based on the sampling precision) to reasonably compare the concentration means and variability. The duration of each sample collection event was 24 h (±1 h, midnight to midnight EST), consistent with the FRM protocol. Start and stop times were controlled by the individual sampler controllers.

The flow calibration for the low volume saturation samplers was performed on site after installation and flow audits were conducted approximately every 2 weeks and at the conclusion of the project sampling to verify sampler performance and total flow calculations. Gravimetric analysis of the PM filter samples was performed consistent with that used for all FRM PM samples collected in the South Carolina Ambient Monitoring Network Quality Assurance Project Plan (SCDHEC, 1998).[5]

Statistical analyses. For any sample to be considered valid and acceptable for use, the sampler must have operated for 24 ± 1 h, with no impact on the sample from an unusual event or local activity, such as a nearby fire, scheduled flow audits meeting the criteria specified for the sampling method, and all instrumental quality assurance meeting the criteria specified by the analytical method. Samples collected concurrently at a majority of the project saturation samplers (31 valid sample sets) were collected over the project period to allow comparison of the concentration means with confidence that differences in the means were not as a result of atypical conditions. Comparisons of the mean ambient concentrations of PM at each site were reported as an indicator of the variability in concentrations across the study area during the project period.

Results

Pollution trends. Figure 3 depicts the 2007 seasonal windrose pattern for the Charleston region. It validates the theory that the resulting pollution in the study communities was due to local sources and not the regional wind pattern. Figures 4 and 5 present the annual PM_{10} and $PM_{2.5}$ average means from the current and historic monitoring sites. Few of the monitors shown in the figures are within the project area. For PM_{10}, the range of annual averages across the monitors from 1982 to 2010 was 17.0–55.0 μg/m^3. Comparing the level of PM_{10} annual average with the NAAQS annual standard of 50.0 μg/m^3, only on two occasions were annual PM_{10} averages above the level of the standard. For $PM_{2.5}$, the range of annual averages across the monitors from 1999 to 2010 was 11.0–13.5 μg/m^3. Our annual $PM_{2.5}$ averages did not exceed the 15.0 μg/m^3 $PM_{2.5}$ national annual standard. However, when we reviewed the daily average data from the limited monitoring, SCDHEC reported that the Charleston area had a 24 h $PM_{2.5}$ average of 28.0 μg/m^3 in 2006, close to the current 24 h standard of 35.0 μg/m^3.

Saturation study results. The SCDHEC saturation study found that the day-to-day concentration variation at all the sites in the Neck closely tracked those recorded by the SC ambient network samplers. The contribution of the local sources to the ambient particulate concentrations likely contributed to small differences in the relative concentration between the monitored communities (Fig. 6). A modification in the monitoring plan was made to take advantage of a saturation monitor that could not be accommodated in one community. The sampler was placed to investigate relatively higher concentrations seen in the early samples from the Union Heights site in more detail. Data from the additional location in Howard Heights provided evidence that the differences in concentration between sites may be related to the sampler proximity to traffic.

The opportunity was also taken to add an FRM sampler collocated with the Howard Heights saturation sampler. The FRM data confirmed that concentrations in the Neck area were consistently higher than those reported by either of the two existing SC ambient network samplers. The average of the maximum differences between the monitored communities for the study period (August–December 2008) was approximately 3.0 μg/m^3. The highest relative concentrations were measured at the samplers closest to the main surface roads through the communities.

The air saturation study indicated that the expansion of the Charleston port will likely contribute to an increase in the concentration and spatial variability of the $PM_{2.5}$ in the local communities. The level of increase in each community will be dependent on the volume, type, and proximity to the transportation systems that move the cargo to and from the port. The importance of a baseline $PM_{2.5}$ concentration in these communities is explained by the fact that the more highly polluted areas would have even higher pollution levels after the port expansion, making pollution assessment more difficult, because the baseline values will not be available without the type of study we have conducted.

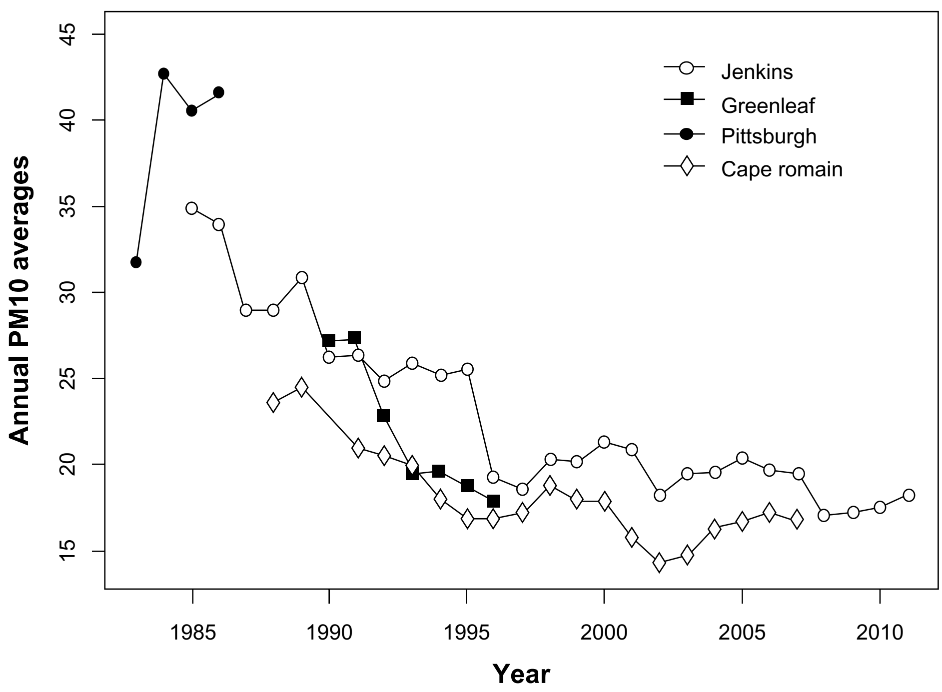

Figure 4. Trend in annual PM_{10} averages in Charleston across ambient monitoring stations (1980–2012).

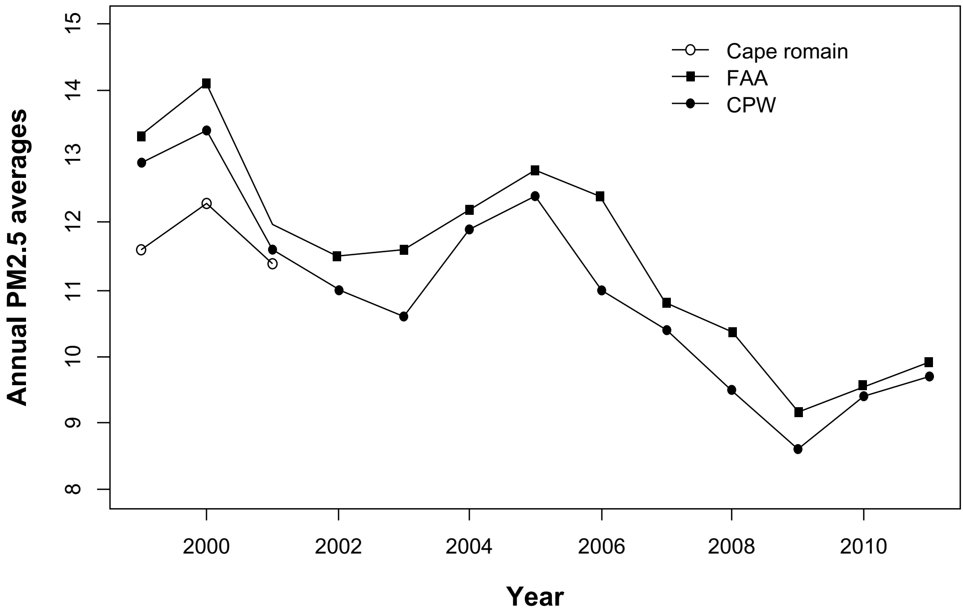

Figure 5. Trend in annual $PM_{2.5}$ averages in Charleston across ambient monitoring stations (1998–2012).

No measured concentrations exceeded the level of the 24 h NAAQS or indicated a potential exceedance of the annual standard but confirmed that the Neck area communities have higher particulate exposure than either the central Charleston district closer to the ocean or the suburban district further inland. The average difference between the North Charleston FRM-monitored concentrations at Howard Heights averaged 0.5 $\mu g/m^3$ higher than the suburban network (FAA) sampler for the monitored period.

Discussion

Our results indicate that the variability in exposures between the North Charleston Neck communities was measurable and most likely attributable to local sources. Figure 7 indicated that the variability trends are due to local sources of pollution and not as a result of long-range regional wind patterns.[6,23,24] It is difficult to study the differential health effects of particulate air pollution from long-range transport and local sources within much of the eastern United States due

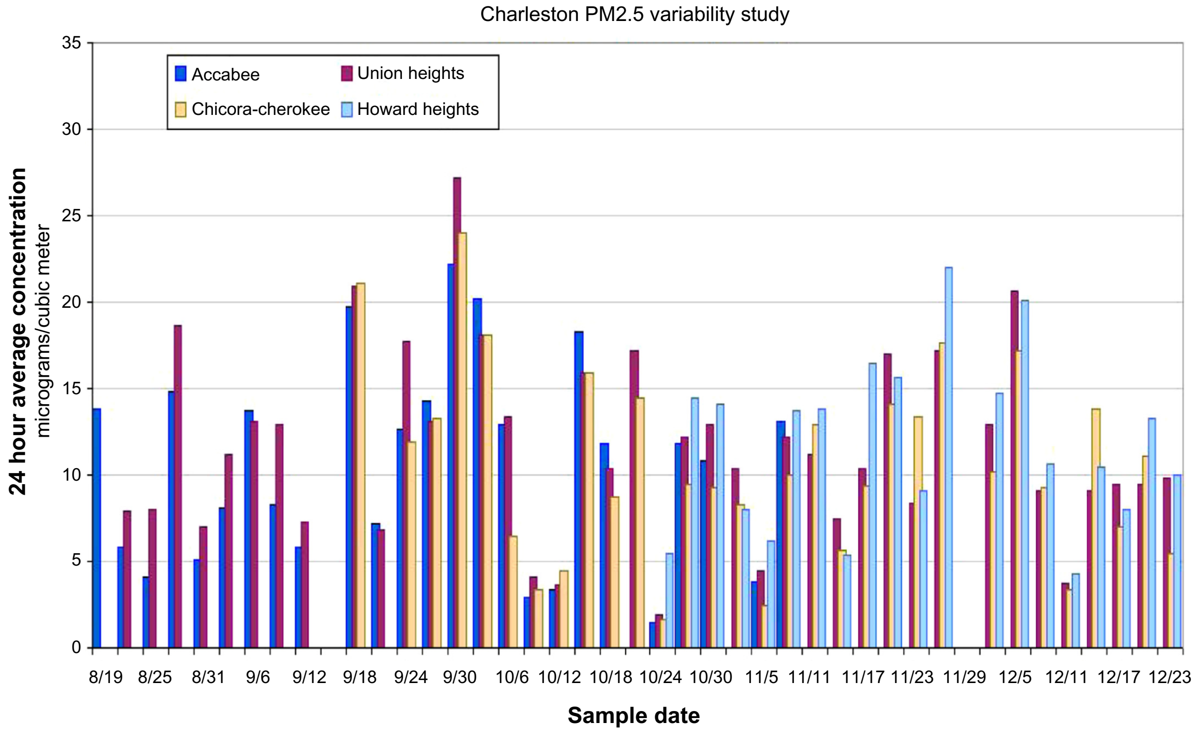

Figure 6. Results of particulate matter saturation study for Charleston Neck communities in 2008.

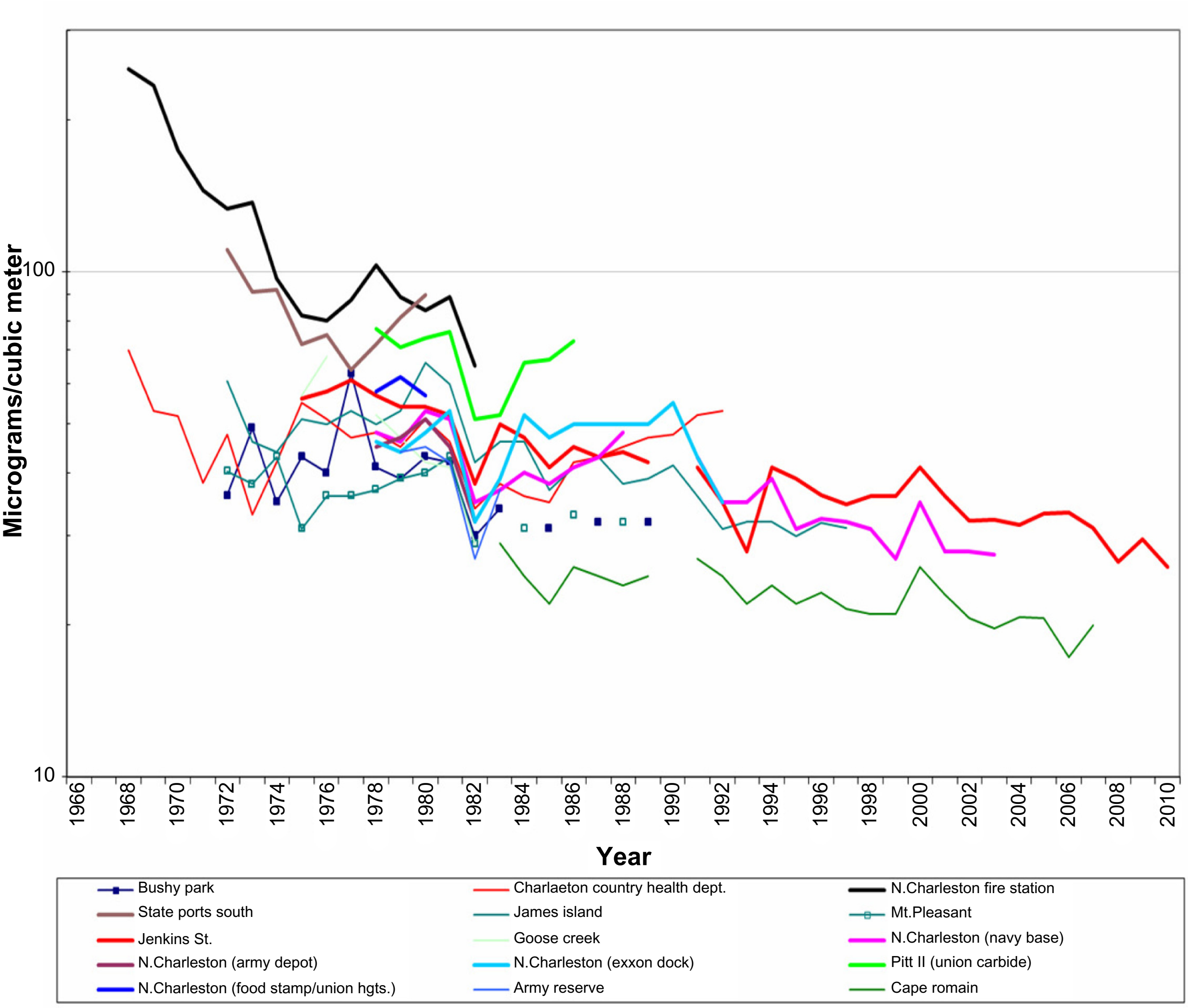

Figure 7. Log-plot of geometric mean total suspended particulate concentrations from air quality monitoring stations in the Charleston metropolitan area, South Carolina (1968–2010).

to strong westerly wind patterns that transport air pollution across vast distances. Therefore, studies in cities that are geographically isolated or subject to unique weather patterns can allow for better assessments of health effects associated with locally produced air pollution.[25] Unlike many port cities along the eastern United States, North Charleston Neck communities have predominant local wind patterns that essentially originate offshore (Fig. 3). Therefore, they can be considered a model to study air pollution exposures predominantly due to local air pollution sources, with relatively little influence of long-range transport of air pollution from other geographic regions of the United States. The upwind areas provide relatively low ambient concentrations due to the proximity to the Atlantic Ocean.[26]

Figures 4 and 5 show the various trends of PM_{10} and $PM_{2.5}$ over a period of 25 years. The average maximum concentration for $PM_{2.5}$ was 13.5 µg/m^3. The higher values can be explained by multiple sources of $PM_{2.5}$ in the study location and the time of the year the study was conducted. The expansion of the Port of Charleston, according to the EIS,[4] will increase ambient concentration of $PM_{2.5}$ from the present 13.5 µg/m^3 to an average of 47.0 µg/m.[3,6,25,27] A huge percentage of this increase in $PM_{2.5}$ ambient concentration will come from the ocean-going ships that emit approximately 1.4 million metric tons of PM annually.[25,28–30] Considering the short- and long-term health effects of PM among the exposed populations and the impact of increased port traffic as a point source of air pollution among the port communities, this study is of significant public health and scientific importance.[24,27,31]

Figure 6 shows the variability of increase in $PM_{2.5}$ concentrations within the LAMC communities. Similar concentrations were recorded in Southern California Air Basin[7,24] and south-eastern United States,[6,32] indicating that there was a greater risk of exposure to PM in urban communities and residential areas along major highways when compared to rural and mountainous areas with low PM concentrations. Our results also showed a rise in the PM_{10} concentration between 2005 and 2010 (Fig. 4), which may suggest increasing pollution activities from local sources. In addition, a decline in the trend of $PM_{2.5}$ concentration from 2006 to 2009 was recorded in Figure 5. This decline may be due to aggressive air quality improvement activities in the study communities by SCDHEC during these periods. Also, SCDHEC has been issuing permits and enforcing caps for acceptable emission limits on PM_{10} and $PM_{2.5}$ concentrations to all the stakeholders, thereby preventing excessive emission of these particles during the period when the decline was recorded.

However, PM_{10} concentration in the Charleston region has been increasing since 2010. Such increases may be due to increasing port activities. A similar recent trend was reported by Ault et al.[29] where PM_{10} measurements in La Jolla, CA increased 2–4 times. Estimated PM contribution from ocean-going vessels ranged from 8.8% at the sites closest to the port to 1.4% at those sites 80 km inland.[33,34] The effect of the air pollution including PM is due to the nature of the emissions and other chemicals that are released to the environment from these vessels.[34,35] This further corroborates the postulation that increased port-related activities has the potential to increase PM concentration in communities located in close proximity to the port.

The port expansion along waterways in Charleston will undoubtedly bring added economic resources; however, the new industrial and commercial activities have the potential to increase air pollution in low-income, primarily people of color, communities adjacent to the port, which is an environmental justice concern.[13–15,17] The Charleston area has 14% of its population with incomes below the federal poverty line and 25% in the low socioeconomic category.[12–15,17] The expansion of the Charleston port without proper evaluation of the potential adverse effects on the environment may increase the burden of pollution in an already vulnerable region.[13–15,27] Also because increased shipping activities will potentially increase road traffic volume,[1,26] our results can serve as a template to future pollution due to increased traffic volume from diesel trucks as demonstrated in the study conducted in the Boston area.[24,36,37]

Although our study did not include the assessment of the potential adverse health outcomes among the residents in the study communities, the previous research[1,38] suggest that higher mortality and morbidity are associated with high PM levels in the urban areas. Especially of great concern are the cardiovascular risks associated with exposure to high levels of $PM_{2.5}$ in the study communities.[38]

According to our results, the $PM_{2.5}$ concentrations ranged from 3.4–28.3 $\mu g/m^3$. Stratton[1] found that each 10 µg increase in PM concentration corresponded to a 76% increase in cardiovascular mortality risk. This means that with the current PM concentration, there might be a potential for elevated cardiovascular risks among the 600,000 residents in metropolitan Charleston.[37–39]

Overall, these studies support the hypothesis that increases in port activities will increase atmospheric levels of PM (especially $PM_{2.5}$) and other air pollutants within the North Charleston Neck communities from different local sources including stationary and mobile sources.[37,40,41] Importantly, our results can be utilized by the stakeholders for cost-benefit analysis of $PM_{2.5}$ due to port expansion and other sources.[23,39,42,43]

Conclusion

It has been established from various studies that an increase in goods movement activities will increase pollutant emissions to the atmosphere surrounding seaports.[32,44] Increased exposure to such air pollution can have a potential adverse effect on the health status of adjacent neighborhoods and individuals living in close proximity to these heavily trafficked sites.[9,26,28,38,45]

Previous studies have shown a differential burden of TRI facilities, LUSTs, and other environmental hazards[12–15,17,39] in metropolitan Charleston based on race/ethnicity and socioeconomic status of populations at the census tract level. Overburdened communities of color and low-income populations are most likely to be impacted by the increased environmental burden, raising an environmental justice concern.

A limitation of our study was the focus on PM alone. Future assessment will expand the scope of air pollution studies from increased port activities to the measurement of the spatial variability of NO_x concentration and volatile organic compounds (VOCs) as recommended by the previous research.[44] The planned North Charleston port expansion is a welcome development for many because it will provide jobs for the local residents and add economic infrastructure and opportunities for the local communities. However, as shown by our results, the potential for local increases in air pollution should be considered by stakeholders, especially policymakers, to ensure that adequate attention is given to the pollution trends and environmental health concerns of the residents in the Charleston Neck communities.[11,39,45] In the long term, these considerations will help accelerate emission reduction from goods movement activities.[34,35,42,46]

Our recommendations include more comprehensive monitoring of the ambient air quality in the region to ensure that this port expansion does not exacerbate current burden, exposure, and health disparities. We also encourage additional research and data gathering through participatory action research with respect to the North Charleston port expansion by the relevant authorities.

Author Contributions

Conceived and designed the experiments: ERS, SR, EMW, HF-R, HZ, SMW. Analyzed the data: OO, HZ, SR. Wrote the first draft of the manuscript: ERS, SR, OO, SMW. Contributed to the writing of the manuscript: ERS, SR, OO, EMW, HF-R, HZ, SMW. Agree with manuscript results and conclusions: ERS, SR, OO, EMW, HF-R, HZ, SMW. Jointly developed the structure and arguments for the paper: ERS, SR, OO, SMW. Made revisions and approved final version: ERS, OO, SMW. All authors reviewed and approved of the final manuscript.

DISCLOSURES AND ETHICS

As a requirement of publication the authors have provided signed confirmation of their compliance with ethical and legal obligations including but not limited to compliance with ICMJE authorship and competing interests guidelines, that the article is neither under consideration for publication nor published elsewhere, of their compliance with legal and ethical guidelines concerning human and animal research participants (if applicable), and that permission has been obtained for reproduction of any copyrighted material. This article was subject to blind, independent, expert peer review. The reviewers reported no competing interests. The authors are grateful to Braelin Carter for assisting with proofreading of the manuscript.

Abbreviations

SCDHEC: South Carolina Department of Health & Environmental Control
LAM-C: Low Country Alliance for Model Communities
USC: University of South Carolina
SPA: State Ports Authority
FRM: federal reference method
TSP: total suspended particulate
PM_{10}: particulate matter less than 10 μm in diameter
$PM_{2.5}$: particulate matter less than 2.5 μm in diameter
FAA: Federal Aviation Administration.

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