Baseline Air Quality Assessment of Goods Movement Activities before the Port of Charleston Expansion: A Community–University Collaborative

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ABSTRACT

As the demand for goods continues to increase, a collective network of transportation systems is required to facilitate goods movement activities. This study examines air quality near the Port of Charleston before its expansion and briefly describes the establishment and structure of a community–university partnership used to monitor existing pollution. Particulate matter (PM) concentrations (PM_{2.5} and PM₁₀) were measured using the Thermo Fisher Scientific Partisol 2000i-D Dichotomous Air Sampler, Thermo Scientific Dichotomous Sequential Air Sampler Partisol-Plus 2025-D, and Rupprecht & Patashnick TEOM Series 1400 Sampler at neighborhood (Union Heights, Rosemont, and Accabee) and reference (FAA_{2.5} and Jenkins Street) sites. Descriptive statistics were performed and an ANOVA (analysis of variance) was calculated to find the difference in overall mean 24-hour PM average concentrations in communities impacted by environmental injustice. PM_{2.5} (15.2 µg/m³) and PM₁₀ (27.2 µg/m³) maximum concentrations were highest in neighborhoods such as Union Heights neighborhoods due to more goods movement activities. Nevertheless, there was no statistically significant difference in mean concentrations of PM_{2.5} and PM₁₀ across neighborhood sites. In contrast, mean PM₁₀ neighborhood concentrations were significantly lower than mean PM₁₀ reference concentrations for Union Heights ($p=0.00$), Accabee ($p\leq 0.0001$), and Rosemont ($p=0.01$). Although PM concentrations were lower than current National Ambient Air Quality Standards, this study demonstrated how community–university partners can work collectively to document baseline PM concentrations that will be used to examine changes in air quality after the port expansion brings additional goods movement activities to the area.

Keywords: environmental justice, goods movement, particulate matter, air pollution, Port of Charleston

INTRODUCTION

TO ACCOMMODATE the global demand for international and domestic goods, society depends on a vast network of bridges, rail yards, rail lines, highways, airports, marine ports, border crossings, and distribution centers to facilitate goods movement activities.¹ Although the volume of goods transported is projected to increase exponentially, the most significant changes

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¹National Environmental Justice Advisory Council (NEJAC). Reducing Air Emissions Associated with Goods Movement: Working Towards Environmental Justice. <<http://www3.epa.gov/environmentaljustice/resources/publications/nejac/2009-goods-movement.pdf>>. (Last accessed on October 5, 2015).

have been documented in container ports where shipments escalated roughly 81% over the past decade.² For instance, the Port of Charleston is currently the eighth busiest port in the country,³ consisting of three port terminals on the Charleston peninsula and another on the Wando River.

By 2018, the South Carolina State Ports Authority (SCSPA) plans to build and open a new marine container terminal along the Cooper River on the former Charleston Navy Base in North Charleston, South Carolina (SC).⁴ This facility will add 1.4 million more 20-foot containers that will be processed each year, essentially doubling the Port of Charleston's volume.⁵

The proposed port expansion will result in an additional 1300 transits per year to transport goods,⁶ where each ship may release 500–1000 pounds of air pollution during an average 14-hour stay in the Charleston Harbor.⁷

Marine ports are among the most poorly regulated sources of pollution in the United States, and their goods movement activities are primarily of diesel engines that emit complex mixtures of particulate matter (PM) PM_{2.5}, coarse PM₁₀, volatile organic compounds, nitrogen ox-

ides, sulfur oxides, and other ozone-depleting substances.⁸ The California Environmental Protection Agency has already deemed 40 components of diesel exhaust as cancer causing,¹ thereby posing a significant cancer risk to populations living near diesel emissions sources. Similar risks in cancer are conceivable in Charleston⁹ because the port expansion will increase diesel truck trips by 70% per day, compounding the current estimate of 10,000 vehicle trips/day.¹⁰

With PM being one of the major components of diesel, the collective emissions from truck traffic, marine activity, and other goods movement sources may contribute to noncancer health outcomes. PM is an air pollutant comprising a complex mixture of solid and liquid particles that vary in diameter from $\leq 10 \mu\text{m}$ (PM₁₀) to particles with a diameter $\leq 2.5 \mu\text{m}$ (PM_{2.5}). Research has illustrated the relationship between PM exposure and increased respiratory and cardiovascular health end points, including increased mortality,¹¹ hospital admissions,¹² and emergency department visits.¹³ Studies also suggest that exposure to PM may be associated with decreased lung function, increases in respiratory disease,

²James S. Cannon. U.S. Container Ports and Air Pollution: A Perfect Storm. <<https://www.greenbiz.com/sites/default/files/document/CustomO16C45F97225.pdf>>. (Last accessed on October 15, 2015).

³Susan Piperato. Top 10 Busiest U.S. Ports. <http://nreionline.com/public-infrastructure/top-10-busiest-us-ports#slide-2-field_images-531171>. (Last accessed on January 30, 2014).

⁴U.S. Department of Transportation, Research and Innovative Technology Administration, Bureau of Transportation Statistics. *America's Freight Transportation Gateways* (Washington, DC, 2009), 44–45; Tyrone Richardson. "New Cargo Terminal Taking Shape in North Charleston." *The Post and Courier*, 22 September 2013.

⁵Tyrone Richardson. "New Cargo Terminal Taking Shape in North Charleston." *The Post and Courier*, 22 September 2013.

⁶South Carolina State Ports Authority. Record of Decision. <http://www.navybaseictf.com/documents/Port_EIS_Final_RoD-042007.pdf>. (Last accessed on July 31, 2016).

⁷Stratton Lawrence. "Charleston's Dirty Little Secret." *Charleston City Paper*, 28 November 2007.

⁸Natural Resources Defense Council. Harboring Pollution: The Dirty Truth About U.S. Ports. <<https://www.nrdc.org/sites/default/files/ports.pdf>>. (Last accessed on November 1, 2014).

⁹LaShanta J. Rice, Chengsheng Jiang, Sacoby M. Wilson, Kristen Burwell-Naney, Ashok Samantapudi, and Hongmei Zhang. "Use of Segregation Indices, Townsend Index, and Air Toxics Data to Assess Lifetime Cancer Disparities in Metropolitan Charleston, South Carolina, USA." *International Journal of Environmental Research and Public Health* 11 (2014): 5510–5526.

¹⁰Erik K. Svendsen, Scott Reynolds, Olalekan A. Ogunsakin, Edith M. Williams, Herb Fraser-Rahim, Hongmei Zhang, and Sacoby M. Wilson. "Assessment of Particulate Matter Levels in Vulnerable Communities in North Charleston, South Carolina Prior to Port Expansion." *Environmental Health Insights* 8 (2014): 5–14.

¹¹Claudio Pelucchi, Eva Negri, Silvano Gallus, Paolo Boffetta, Irene Tramacere, and Carlo La Vecchia. "Long-Term Particulate Matter Exposure and Mortality: A Review of European Epidemiological Studies." *Public Health* 9 (2009): 453; Robert D. Brook, Sanjay Rajagopalan, Arden Pope III, Jeffrey R. Brook, Aruni Bhatnager, Ana V. Diez-

Roux, Fernando Holguin, Yuling Hong, Russell V. Luepker, Murray A. Mittleman, Annette Peters, David Siscovick, Sidney C. Smith Jr., Laurie Whitset, and Joel D. Kaufman. "Particulate Matter Air Pollution and Cardiovascular Disease." *Circulation* 121 (2010): 2331–2378; Francesca Dominici, Roger D. Peng, Scott L. Zeger, Ronald H. White, and Jonathan M. Samet. "Particulate Air Pollution and Mortality in the United States: Did the Risks Change from 1987 to 2000?" *American Journal of Epidemiology* 166 (2007): 880–888.

¹²Massimo Stafoggia, Evangelia Samoli, Ester Alessandrini, Ennio Cadum, Bart Ostro, Giovanna Berti, Annunziata Faustini, Benedicte Jacquemin, Cristina Linares, Mathilde Pascal, Giorgia Randi, Andrea Ranzi, Elisa Stivanello, Francesco Forastiere, and the MED-PARTICLES Study Group. "Short-Term Associations Between Fine Coarse Particulate Matter and Hospitalizations in Southern Europe: Results from the MED-PARTICLES Project." *Environmental Health Perspectives* 121 (2013): 1026–1033; Francesca Dominici, Roger D. Peng, Michelle L. Bell, Luu Pham, Aidan McDermott, Scott L. Zeger, and Jonathan M. Samet. "Fine Particulate Air Pollution and Hospital Admission for Cardiovascular and Respiratory Diseases." *The Journal of the American Medical Association* 295 (2006): 1127–1134; Gregory A. Wellenius, Thomas F. Bateson, Murray A. Mittleman, and Joel Schwartz. "Particulate Air Pollution and the Rate of Hospitalization for Congestive Heart Failure among Medicare Beneficiaries in Pittsburgh, Pennsylvania." *American Journal of Epidemiology* 161 (2005): 1030–1036.

¹³Stefanie Ebel Sarnat, Andrea Winquist, James J. Schauer, Jay R. Turner, and Jeremy A. Sarnat. "Fine Particulate Matter Components and Emergency Department Visits for Cardiovascular and Respiratory Diseases in St. Louis, Missouri-Illinois, Metropolitan Area." *Environmental Health Perspectives* 123 (2015): 437–444; Brian J. Malig, Shelley Green, Rupa Basu, and Rachel Broadwin. "Coarse Particulates and Respiratory Emergency Department Visits in California." *American Journal of Epidemiology* 178 (2013): 58–69; Kristi Busico Metzger, Paige E. Tolbert, Mitchel Klein, Jennifer L. Peel, W. Dana Flanders, Knox Todd, James A. Mulholland, P. Barry Ryan, and Howard Frumkin. "Ambient Air Pollution Cardiovascular Emergency Department Visits." *Epidemiology* 15 (2004): 46–56.

and respiratory symptoms such as asthma in children.¹⁴ Other studies have shown that PM contributes to higher cardiovascular mortality risks in elderly patients and populations with comorbidities.¹⁵

With the port expansion underway, exposure to PM concentrations from goods movement activities related to ship and truck traffic emissions may increase or further exacerbate any pre-existing medical conditions in persons living proximal to the port. Residents living near the port may also experience indirect health impacts from traffic congestion, increased noise, and blight.¹⁶ Those most impacted are nonwhite and low-income populations who are differentially exposed to environmental and psychosocial stressors related to goods movement activities.¹⁶

Port communities in Houston, Gulfport, New York, New Jersey, and Charleston have organized to address many of the health concerns that may accompany their respective expansions.¹⁷ In 2005, the Low Country Alliance for Model Communities (LAMC), a community-based organization concerned about environmental injustice, was organized by residents of seven economically distressed neighborhoods in North Charleston.¹⁸ LAMC was primarily established to address potential negative impacts associated with the planned port expansion, particularly increased levels of air pollution because of additional diesel truck traffic in a community disproportionately burdened by environmental hazards.¹⁸

¹⁴James Gauderman, Rob McConnell, Frank Gilliland, Stephanie London, Duncan Thomas, Edward Avol, Hita Vora, Kiros Berhane, Edward B. Rappaport, Fred Lurmann, Helene G. Margolis, and John Peters. "Association Between Air Pollution and Lung Function Growth in Southern California Children." *American Journal of Respiratory and Critical Care Medicine* 162 (2000): 1383–1390; A. Peters, D.W. Dockery, J. Heinrich, and H.E. Wichmann. "Short-Term Effects of Particulate Air Pollution on Respiratory Morbidity in Asthmatic Children." *European Respiratory Journal* 10 (1997): 872–879; Ralph J. Delfino, Henry Gong Jr, William S. Linn, Edo D. Pellizari, and Ye Hu. "Asthma Symptoms in Hispanic Children and Daily Ambient Exposures to Toxic and Criteria Air Pollutants." *Environmental Health Perspectives* 111 (2003): 647–656; Joel Schwartz, Daniel Slater, Timothy V. Larson, William E. Pier-son, and Jane Q. Koenig. "Particulate Air Pollution and Hospital Emergency Room Visits for Asthma in Seattle." *American Review of Respiratory Disease* 147 (1993): 826–831; Gary Norris, Sharon N. YoungPong, Jane Q. Koenig, Timothy V. Larson, Lianne Sheppard, and James W. Stout. "An Association Between Fine Particles and Asthma Emergency Department Visits for Children in Seattle." *Environmental Health Perspectives* 107 (1999): 489–493; Erik R. Svendsen, Karin B. Yeatts, David Peden, Susan Orton, Neil E. Alexis, John Creason, Ronald Williams, and Lucas Neas. "Circulating Neutrophil CD14 Expression and the Inverse Association of Ambient Particulate Matter on Lung Function in Asthmatic Children." *Annals of Allergy, Asthma, & Immunology* 99 (2007): 244–253; Jonathan S. Schildcrout, Lianne Sheppard, Thomas Lumley, James C. Slaughter, Jane Q. Koenig, Gail G. Shapiro. "Ambient Air Pollution and Asthma Exacerbations in Children: An Eight-City Analysis." *American Journal of Epidemiology* 164 (2006): 505–517; Paige E. Tolbert, James A. Mulholland, David L. Macintosh, Fan Xu, Danni Daniels, Owen J. Devine, Bradley P. Carlin, Mitchel Klein, Jenny Dorley, Andre J. Butler, Dale F. Nordberg, Howard Frumkin, P. Barry Ryan, and Mary C. White. "Air Quality and Pediatric Emergency Room Visits for Asthma and Atlanta, GA." *American Journal Epidemiology* 151 (2000): 798–810; K.M. Mortimer, L.M. Neas, D.W. Dockery, S. Redline, and I.B. Tager. "The Effect of Air Pollution on Inner-City Children with Asthma." *European Respiratory Journal* 19 (2002): 699–705; Sverre Vedal, John Petkau, Rick White, and Jim Blair. "Acute Effects of Ambient Inhalable Particles in Asthmatic and Nonasthmatic Children." *American Journal Respiratory and Critical Care Medicine* 157 (1998): 1034–1043; Mei Lin, Yue Chen, Richard T. Burnett, Paul J. Villeneuve, and Daniel Krewski. "The Influence of Ambient Coarse Particulate Matter on Asthma Hospitalizations in Children: Case-Crossover and Time-Series Analysis." *Environmental Health Perspectives* 110 (2002): 575–581.

¹⁵C. Arden Pope III, Matthew L. Hansen, Russell W. Long, Karen R. Nielsen, Norman L. Eatough, William E. Wilson, and Delbert J. Eatough. "Ambient Particulate Air Pollution, Heart Rate Variability, and Blood Markers of Inflammation

in a Panel of Elderly Subjects." *Environmental Health Perspectives* 112 (2004): 339–345; Jennifer L. Peel, Kristi Busico Metzger, Mitchel Klein, W. Dana Flanders, James A. Mulholland, and Paige E. Tolbert. "Ambient Air Pollution Cardiovascular Emergency Department Visits in Potentially Sensitive Groups." *American Journal of Epidemiology* 165 (2007): 625–633; Karen L. Jansen, Timothy V. Larson, Jane Q. Koenig, Therese F. Mar, Carrie Fields, Jim Stewart, and Morton Lippmann. "Association Between Health Effects and Particulate Matter and Black Carbon in Subjects with Respiratory Disease." *Environmental Health Perspectives* 113 (2005): 1741–1746; Karin Yeatts, Erik Svendsen, John Creason, Neil Alexis, Margaret Herbst, James Scott, Lawrence Kupper, Ronald Williams, Lucas Neas, Wayne Cascio, Robert B. Devlin, and David B. Peden. "Coarse Particulate Matter (PM_{2.5-10}) Affects Heart Rate Variability, Blood Lipids, and Circulating Eosinophils in Adults with Asthma." *Environmental Health Perspectives* 115 (2007): 709–714; Henry Gong Jr, William S. Linn, Sheryl L. Terrell, Kenneth W. Clark, Michael D. Geller, Karen R. Anderson, Wayne E. Cascio, and Constantinos Sioutas. "Altered Heart-Rate Variability in Asthmatic and Healthy Volunteers Exposed to Concentrated Ambient Coarse Particles." *Inhalation Toxicology* 16 (2004): 335–343; Arden Pope III, Richard T. Burnett, Michael J. Thun, Eugenia E. Calle, Daniel Krewski, Kazuhiko Ito, and George D. Thurston. "Lung Cancer, Cardiopulmonary Mortality, and Long-Term Exposure to Fine Particulate Air Pollution." *The Journal of the American Medical Association* 287 (2002): 1132–1141; Douglas W. Dockery. "Epidemiologic Evidence of Cardiovascular Effects of Particulate Air Pollution." *Environmental Health Perspectives* 109 (2001): 483–486; Ann-ette Peters, Douglas W. Dockery, James E. Muller, Murray A. Mittleman. "Increased Particulate Air Pollution and the Triggering of Myocardial Infarction." *Circulation* 103 (2001): 2810–2815; Jeffrey Sullivan, Lianne Sheppard, Astrid Schreuder, Naomi Ishikawa, David Siscovick, and Joel Kaufman. "Relation Between Short-Term Fine-Particle Matter Exposure and Onset of Myocardial Infarction." *Epidemiology* 16 (2005): 41–48; Antonella Zanobetti and Joel Schwartz. "The Effect of Particulate Air Pollution on Emergency Admissions for Myocardial Infarction: A Multicity Case-Crossover Analysis." *Environmental Health Perspectives* 113 (2005): 978–982.

¹⁶Andrea M. Hricko. "Ships, Trucks, and Trains: Effects of Goods Movement on Environmental Health." *Environmental Health Perspectives* 114 (2006): A204–A205.

¹⁷Andrea Hricko. "Progress and Pollution: Port Cities Prepare for the Panama Canal Expansion." 120 (2012): A471–A473.

¹⁸Sacoby M. Wilson, LaShanta Rice, and Herbert Fraser-Rahim. "The Use of Community-Driven Environmental Decision Making to Address Environmental Justice and Revitalization Issues in a Port Community in South Carolina." *Environmental Justice* 4 (2011): 145–154.

In addition, LAMC developed a mitigation plan agreement with the SCSA under the National Environmental Policy Act to address impacts of the port expansion.^{17,18,19} As part of the agreement, the SCSA agreed to provide funding to establish and support an ambient air monitoring site in the Charleston Neck area to monitor any changes to the local air quality.¹⁹ The Charleston Neck is where the communities of LAMC are located and is characterized by high-density car traffic, industrial pollution sources, and port-related diesel truck traffic.

In this article, we describe the establishment of a community–university partnership to assess air pollution levels related to goods movement activities (i.e., ship and truck traffic emissions) in impacted neighborhoods in North Charleston, SC. Data are presented on baseline levels of PM_{2.5} and PM₁₀ in partner neighborhoods before the port expansion. The secondary objective is to compare the data with reference site concentrations to determine whether PM levels are elevated in neighborhoods with high goods movement activity.

METHODS

Community–university partnership to explore air pollution issues

Community leaders from LAMC approached researchers at the University of South Carolina (USC) in Columbia, SC, to assist with implementing the environmental monitoring component of the mitigation agreement. We obtained

funding from the National Institute of Environmental Health Sciences (NIEHS) to establish the Charleston Area Pollution Prevention Partnership (CAPs) between LAMC, Rosemont, the South Carolina Department of Health and Environmental Control (SCDHEC), USC, and other entities. The CAPs partners worked collectively to facilitate and perform air monitoring in the three communities under study (Accabee, Union Heights, and Rosemont) and host environmental health workshops for local residents. Additional information regarding the establishment of the CAPs²⁰ and their efforts to address local and statewide environmental health disparities is outlined in other publications.²¹

The community–university partnership used a community-based participatory research (CBPR) framework that combines traditional scientific methods with community engagement, capacity building, citizen science, and translation of research to action. Aside from the use of a CBPR framework, we also incorporated Community-Owned and Managed Research (COMR) principles and a Collaborative Problem Solving (CPS) approach²² to maximally benefit our study community. The COMR model emphasizes the community's right to develop, maintain, and sustain their own research plan,²³ which can be supplemented with a CPS approach that uses multiple stakeholders to address a specific environmental and/or public health problem.²⁴

Air monitoring methods

We measured PM_{2.5} and PM₁₀ at the neighborhood sites using the Thermo Fisher Scientific Partisol 2000i-D Dichotomous Air Sampler, which simultaneously collects fine and coarse ambient PM. Size-selective inlets separated the particulates that were collected on a Teflon filter and shipped to the laboratory after each sample day. The sampling events (i.e., days when all samplers were scheduled to

¹⁹Sacoby Wilson, Herbert Fraser-Rahim, Hongmei Zhang, Edith M. Williams, Ashok V. Samantapudi, Kasim Ortiz, Winston Abara, and Wayne Sakati. "The Spatial Distribution of Leaking Underground Storage Tanks in Charleston, South Carolina: An Environmental Justice Analysis." *Environmental Justice* 4 (2012): 198–205.

²⁰Sacoby Wilson, Dayna Campbell, Laura Dalemarré, Herb Fraser-Rahim, and Edith Williams. "A Critical Review of an Authentic and Transformative Community-University Partnership." *International Journal of Environmental Research and Public Health* 11 (2014): 12817–12834.

²¹Erik K. Svendsen, Scott Reynolds, Olalekan A. Ogunsakin, Edith M. Williams, Herb Fraser-Rahim, Hongmei Zhang, and Sacoby M. Wilson. "Assessment of Particulate Matter Levels in Vulnerable Communities in North Charleston, South Carolina Prior to Port Expansion." *Environmental Health Insights* 8 (2014): 5–14; Sacoby M. Wilson, LaShanta Rice, and Herbert Fraser-Rahim. "The Use of Community-Driven Environmental Decision Making to Address Environmental Justice and Revitalization Issues in a Port Community in South Carolina." *Environmental Justice* 4 (2011): 145–154; Sacoby Wilson, Herbert Fraser-Rahim, Hongmei Zhang, Edith M. Williams, Ashok V. Samantapudi, Kasim Ortiz, Winston Abara, and Wayne Sakati. "The Spatial Distribution of Leaking Underground Storage Tanks in Charleston, South Carolina: An Environmental Justice Analysis." *Environmental Justice* 4 (2012): 198–205; Laura Dalemarré, Sacoby M. Wilson, Dayna Campbell, Herbert Fraser-Rahim, and Edith M. Williams. "Summary on the Charleston Pollution Prevention Partnership Environmental Justice Conference and Summit." *Environmental Justice* 7 (2014): 55–60; Sacoby M. Wilson, Herb Fraser-Rahim, Edith Williams, Hongmei Zhang, LaShanta Rice, Erik Svendsen, and Winston Abara. "Assessment of the Distribution of Toxic Release Inventory Facilities in Metropolitan Charleston: An Environmental Justice Case Study." *American Journal of Public Health* 102 (2012): 1974–1980.

²²Christopher D. Heaney, Sacoby M. Wilson, and Omega R. Wilson. "The West Revitalization Association's Community-Owned and -Managed Research Model: Development, Implementation, and Action." *Progress in Community Health Partnerships: Research, Education, and Action* 1 (2007): 339–349; Sacoby Wilson, Dayna Campbell, Laura Dalemarré, Herb Fraser-Rahim, and Edith Williams. "A Critical Review of an Authentic and Transformative Community-University Partnership." *International Journal of Environmental Research and Public Health* 11 (2014): 12817–12834; U.S. Environmental Protection Agency. EPA's Environmental Justice Collaborative Problem Solving Model. <<http://www.epa.gov/environmentaljustice/resources/publications/grants/cps-manual-12-27-06.pdf>>. (Last accessed on June 15, 2015); Sacoby M. Wilson, Omega Wilson, Christopher Heaney, and John Cooper. "Use of EPA Collaborative Problem-Solving to Obtain Environmental Justice in North Carolina." *Progress in Community Health Partnerships: Research, Education, and Action* 1 (2007): 327–337.

²³Christopher D. Heaney, Sacoby M. Wilson, and Omega R. Wilson. "The West Revitalization Association's Community-Owned and -Managed Research Model: Development, Implementation, and Action." *Progress in Community Health Partnerships: Research, Education, and Action* 1 (2007): 339–349.

²⁴U.S. Environmental Protection Agency. EPA's Environmental Justice Collaborative Problem Solving Model. <<http://www.epa.gov/environmentaljustice/resources/publications/grants/cps-manual-12-27-06.pdf>>. (Last accessed on June 15, 2015).

operate) were successfully performed from July 2012 to April 2013 and mirrored the United States Environmental Protection Agency's (USEPA's) national 1/3 day monitoring schedule for community and reference sites.²⁵

SCDHEC reference monitors

The FAA PM_{2.5} reference monitor was located in a suburban area northwest of the community sites and is part of the SC Ambient Monitoring Network. The Thermo Scientific Dichotomous Sequential Air Sampler Partisol-Plus 2025-D measured PM_{2.5} daily, and the duration of the FAA sampling period corresponded with the USEPA's 24-hour (± 1 hour, midnight to midnight Eastern Standard Time (EST)) Federal Reference Method (FRM) protocol for filter-based samples.²⁶ The PM₁₀ reference monitor located on Jenkins Street in the downtown area of North Charleston, SC, represented urban air pollution levels. Owing to the predominant south-southwesterly wind direction, this site would unlikely be impacted by PM₁₀ emissions related to port activities. The Rupprecht & Patashnick TEOM Series 1400 Sampler, a Federal Equivalent Method (FEM) continuous monitor, measured hourly averages of PM₁₀ aggregated to 24-hour average concentrations. Samples from both monitors were collected and shipped to a gravimetric laboratory twice a week.

Statistical methods

Simple descriptive statistics were used to identify patterns in PM_{2.5} and PM₁₀ concentrations at the neighborhood level for Accabee, Union Heights, and Rosemont. Mean concentrations of PM were calculated and compared with reference and other neighborhood sites using a 1-way ANOVA (analysis of variance) test. All PM concentrations were graphed using Microsoft Excel, including FAA (FAA_{2.5}) and Jenkins Street (JREF₁₀) measurements, to illustrate differences in air pollution levels at study and reference sites. Moreover, the USEPA's National Ambient Air Quality Standards (NAAQS) for annual and 24-hour PM_{2.5} levels were represented on each graph to determine whether these concentrations were exceeded at the monitoring sites.²⁷

RESULTS

Community engagement activities on air pollution

Through the partnership, a series of meetings were held for over a year before the sampling period to discuss

community concerns about air pollution and related health outcomes. The meetings were held at community centers in partner neighborhoods. Residents expressed concerns about PM, made inquiries about local sources of PM, whether current port activities and diesel traffic were contributing to air pollution in their communities, and the diseases such as asthma and cancer that may be caused by exposure to air pollution. Although separate studies have been performed to examine perceptions of cancer risk²⁸ and disparities in actual cancer risk²⁹ in the community, Dr. Scott Reynolds (air pollution scientist with SCDHEC and member of the partnership) cautioned against linking PM levels to health outcomes and redirected the focus to whether levels exceeded the NAAQS.

Community-based air pollution monitoring plan

In accordance with CBPR principles, the partnership developed a community-based monitoring plan to measure PM_{2.5} and PM₁₀ levels. The plan was based on the Quality Assurance Quality Plan developed by SCDHEC for saturation monitoring of PM in the study area.³⁰ LAMC leaders and research team members decided to focus on ambient air pollution monitoring in neighborhoods that would be most impacted by pollution related to the port expansion. These residential neighborhoods included Rosemont in Charleston, SC, and Union Heights and Accabee in North Charleston, SC, located in the Charleston Neck region (Fig. 1).

Rosemont and Union Heights communities are heavily impacted by goods movement activities, particularly diesel truck traffic along Spruill Avenue and Martin Luther King Jr Avenue. The port expansion will result in the addition of an access road and off ramp that runs through Rosemont to accommodate the increase in diesel truck traffic.³¹ Although the neighborhood samplers were placed in predominately African American and low-income communities, North Charleston, SC, actually comprises more whites (~66%) than African Americans (~27%).

Training of community scientists

A group of 10 residents were trained to use the air monitoring equipment in Summer 2012 with three goals

²⁵U.S. Environmental Protection Agency. 2012 Monitoring Schedule. <https://www3.epa.gov/ttn/amtic/files/ambient/pm25/calendar_2012.pdf>. (Last accessed on August 1, 2016); U.S. Environmental Protection Agency. 2013 Monitoring Schedule. <https://www3.epa.gov/ttn/amtic/files/ambient/pm25/calendar_2013.pdf>. (Last accessed on August 1, 2016).

²⁶Judith C. Chow and John G. Watson. Guideline on Speciated Particulate Monitoring. <<http://www.epa.gov/ttnamti1/files/ambient/pm25/spec/driscpec.pdf>>. (Last accessed on October 28, 2015).

²⁷U.S. Environmental Protection Agency. NAAQS Table. <<https://www.epa.gov/criteria-air-pollutants/naaqs-table>>. (Last accessed on August 1, 2016).

²⁸LaShanta Rice, Heather M. Brandt, James W. Hardin, Lucy Annang Ingram, and Sacoby M. Wilson. "Exploring Perceptions of Cancer Risk, Neighborhood Environmental Risks, and Health Behaviors of Blacks." *Journal of Community Health* 40 (2014): 1–12.

²⁹LaShanta Rice, Sacoby M. Wilson, Kristen Burwell-Naney, Ashok Samantapudi, and Hongmei Zhang. "Use of Segregation Indices, Townsend Index, and Air Toxics Data to Assess Cancer Risk Disparities in Metropolitan Charleston, South Carolina." *International Journal of Environmental Research and Public Health* 11 (2014): 5510–5526.

³⁰Sacoby M. Wilson, LaShanta Rice, and Herbert Fraser-Rahim. "The Use of Community-Driven Environmental Decision Making to Address Environmental Justice and Revitalization Issues in a Port Community in South Carolina." *Environmental Justice* 4 (2011): 145–154.

³¹Andrea Hricko. "Global Trade Comes Home: Community Impacts of Goods Movement." *Environmental Health Perspectives* 116 (2008): A78–A81.

FIG. 1. Map of the study area, AC, Accabee; RM, Rosemont; UH, Union Heights.

in mind: (1) teach residents how to use the equipment to ensure community participation throughout the data collection phase of the project, (2) increase community capacity to perform scientific research, and (3) build a pipeline of community scientists who would be available to disseminate air pollution information to other residents and stakeholders as the partnership's efforts to understand exposure and health risks associated with local air pollution increased. Two residents were selected to act as the air monitoring field coordinator during the study period. These residents followed the sampling protocol, dropped off filters to the SCDHEC office following a set schedule, and noted any equipment issues so that the SCDHEC staff could keep the monitors running on schedule.

Air monitoring results

Figures 2–4 are a series of bar graphs that capture mean 24-hour PM_{10} (coarse) and $PM_{2.5}$ particles in Accabee, Union Heights, and Rosemont neighborhoods from July 21, 2012, to April 10, 2013. The $PM_{2.5}$ measurements from our monitors were compared to daily $PM_{2.5}$ samples collected by the FAA sampler and PM_{10} concentrations were compared with the Jenkins Street reference monitor ($JREF_{10}$). The Gethsemane and Rosemont sites began monitoring air quality during the summer (July 21, 2012, and August 1, 2012, respectively), whereas the neighborhood PM measurements for the Accabee site were not collected until October 12, 2012, because of equipment calibration issues. The remaining missing data points throughout the sampling

period were primarily because of an equipment malfunction or miscellaneous void at the sampling sites.

At the Accabee site, the highest mean 24-hour $PM_{2.5}$ levels were collected on January 28, 2013 ($12.3 \mu\text{g}/\text{m}^3$) and the lowest were observed on November 17, 2012 ($0.1 \mu\text{g}/\text{m}^3$) (Fig. 2). Our findings were not synonymous with seasonal $PM_{2.5}$ trends in the southeast because concentrations are typically highest during July–September and lowest during January–March.³²

Regarding PM_{10} levels, the highest mean 24-hour concentrations were also collected on January 28, 2013 ($21.7 \mu\text{g}/\text{m}^3$), whereas the lowest were reported on December 17, 2012 ($7.0 \mu\text{g}/\text{m}^3$). At the site in Union Heights, 24-hour mean PM_{10} and $PM_{2.5}$ concentrations were collected from July 21, 2012, to April 10, 2013 (Fig. 3). The peak concentrations of $PM_{2.5}$ were measured on July 26, 2012 ($15.2 \mu\text{g}/\text{m}^3$) as expected, whereas the lowest concentrations were collected on April 10, 2013 ($4.1 \mu\text{g}/\text{m}^3$) during the second highest season for $PM_{2.5}$ levels. When compared with the FAA $PM_{2.5}$ data, $PM_{2.5}$ measurements collected in Union Heights were higher for roughly 17% of the observations. Peak levels of PM_{10} concentrations in Union Heights were documented on January 28, 2013 ($27.2 \mu\text{g}/\text{m}^3$), whereas the lowest levels were recorded on April 4, 2013 ($7.0 \mu\text{g}/\text{m}^3$).

³²U.S. Environmental Protection Agency. Understanding Particle Pollution. <http://www3.epa.gov/airtrends/aqtrnd04/pmreport03/pmunderstand_2405.pdf>. (Last accessed on June 29, 2015).

FIG. 2. Particulate matter monitoring, Accabee (October 2012–April 2013).

Twenty-four-hour mean concentrations of PM_{10} and $PM_{2.5}$ were collected at the Rosemont site on August 1, 2012 through April 10, 2013 (Fig. 4). The highest $PM_{2.5}$ mean concentrations were reported on January 28, 2013 ($12.9 \mu\text{g}/\text{m}^3$), whereas the lowest were collected on December 17, 2012 ($3.1 \mu\text{g}/\text{m}^3$). Moreover, $\sim 17\%$ of $PM_{2.5}$ concentrations at Rosemont exceeded those collected from the FAA monitoring station. Similar to $PM_{2.5}$, the highest PM_{10} levels were reported on January 28, 2013 ($25.5 \mu\text{g}/\text{m}^3$). January 28, 2013 is a notable observation date because the peak $PM_{2.5}$ and PM_{10} concentrations for the Accabee site were also collected on this day. In contrast, the lowest PM_{10} concentrations were observed on December 29, 2012 ($5.4 \mu\text{g}/\text{m}^3$).

Although none of the measurements exceeded the NAAQS for PM at the monitoring sites, Union Heights had the highest overall mean 24-hour concentrations of $PM_{2.5}$ ($8.2 \mu\text{g}/\text{m}^3$) and PM_{10} ($14.8 \mu\text{g}/\text{m}^3$) when compared with Accabee and Rosemont (Table 1). There was no statistically significant difference in the overall mean 24-hour concentrations of $PM_{2.5}$ ($p=0.53$) and PM_{10} ($p=0.13$) across neighborhood sites. When the neighborhood sites were compared with the reference monitors that corresponded to their particle size, there were significant differences in the overall mean 24-hour averages of PM_{10} for Accabee ($p=0.00$), Union Heights ($p\leq 0.0001$), and Rosemont ($p=0.01$) (Table 2). Specifically, the mean PM_{10} concentrations at the reference

FIG. 3. Particulate matter monitoring, Union Heights (July 2012–April 2013).

FIG. 4. Particulate matter monitoring, Rosemont (July 2012–April 2013).

TABLE 1. OVERALL MEAN PARTICULATE MATTER 24-HOUR AVERAGE CONCENTRATIONS BY MONITOR LOCATION

Site	Monitor	Mean	SD	Observations (N=45)	Missing
Union Heights	PM _{2.5}	8.2	2.8	40	5
	PM ₁₀	14.8	4.0	39	6
Rosemont	PM _{2.5}	7.7	2.6	37	8
	PM ₁₀	13.4	4.1	37	8
Accabee	PM _{2.5}	7.4	3.1	28	17
	PM ₁₀	12.9	4.1	27	18
FAA	FAA _{2.5}	9.3	3.5	43	2
Jenkins Street	JREF ₁₀	16.9	6.3	45	0

PM, particulate matter; SD, standard deviation.

JREF₁₀ site were higher than those at community sites. Although the FAA_{2.5} and JREF₁₀ mean 24-hour PM concentrations did not follow a normal distribution, a Welch's ANOVA test demonstrated that there was no real change in the *p* values presented in Table 2.

DISCUSSION

The purpose of this study was to determine baseline levels of PM_{2.5} and PM₁₀ in LAMC neighborhoods before the port expansion impacted goods movement activities in the area and to compare these levels across neighborhoods with different sources of air pollution. Moreover, we compared community-level data with PM measurements collected at a reference site to assess whether PM levels were higher in neighborhoods with a high concentration of goods movement activities. Our results show marked variations in the mean 24-hour PM₁₀ and PM_{2.5} levels across our study communities.

For example, the range of mean PM_{2.5} concentrations collected in Accabee (0.1–12.3 µg/m³; Fig. 2) and Rosemont (3.1–12.9 µg/m³; Fig. 4) were much lower than the

range of mean PM_{2.5} concentrations measured at the Union Heights site (4.1–15.2 µg/m³; Fig. 3). The higher values obtained in Union Heights may be because of the proximity of the monitoring station to heavier traffic and the port. Although our findings demonstrated that the study communities were in compliance with the NAAQS for PM_{2.5}, our results were still consistent with other studies in that we found higher concentrations of PM in communities located near the port.³³ As most of the mass for PM_{2.5} is attributable to mobile sources (54%) instead of ships (<5%),³⁴ the increase in truck traffic to move goods may significantly impact air quality in LAMC neighborhoods.

³³Daniel Mueller, Stefanie Uibel, Masaya Takemura, Doris Klingelhofer, and David A. Groneberg. "Ships, Ports and Particulate Air Pollution—An Analysis of Recent Studies." *Journal of Occupational Medicine and Toxicology* 6 (2011): 31.

³⁴Maria Cruz Minguillon, Mohammad Arhami, James J. Schauer, and Constantinos Sioutas. "Seasonal and Spatial Variations of Sources of Fine and Quasi-Ultrafine Particulate Matter in Neighborhoods Near the Los Angeles-Long Beach Harbor." *Atmosphere Environment* 2008: 7317–7328.

TABLE 2. ANOVA RESULTS FOR NEIGHBORHOOD AND REFERENCE PARTICULATE MATTER MONITORS

Variable	SS	df	MS	F	p
Neighborhood PM _{2.5} levels	10.3	2	5.1	0.6	0.53
Neighborhood PM ₁₀ levels	69.9	2	34.9	2.1	0.13
Accabee PM _{2.5} *FAA _{2.5}	243.4	24	10.1	4.7	0.19
Union Heights PM _{2.5} *FAA _{2.5}	305.3	34	9.0	4.4	0.05
Rosemont PM _{2.5} *FAA _{2.5}	205.2	31	6.6	1.1	0.55
Accabee PM ₁₀ *JREF ₁₀	363.7	14	30.0	5.0	0.00**
Union Heights PM ₁₀ *JREF ₁₀	536.4	17	31.5	7.9	<0.0001**
Rosemont PM ₁₀ *JREF ₁₀	461.1	17	27.1	3.5	0.01**

*The two variables were analyzed together.

** $p < .05$.

df, degrees of freedom; MS, mean square; SS, sum of squares.

In the case of PM₁₀, similar variations were observed between study communities and none of the samples exceeded the 24-hour NAAQS for PM₁₀. Similar to the PM_{2.5} results, Union Heights recorded the highest range of mean PM₁₀ concentrations (7.0–27.2 µg/m³; Fig. 3) followed by Rosemont (7.0–25.5 µg/m³; Fig. 3) and Accabee (5.4–21.7 µg/m³; Fig. 2). Although all neighborhood mean PM₁₀ concentrations were significantly different from those of the Jenkins Street reference monitor, our results were still lower than those found in similar communities burdened by port activity. We believe that this may be because of the Port of Charleston's smaller size than other ports studied in California, New York, Texas, etc. For example, California's Long Beach Port exceeded the EPA's 24-hour PM₁₀ NAAQS at their Superblock station (171.4 µg/m³) in 2012 as well their own California Ambient Air Quality Standard of 50 µg/m³.³⁵ Nevertheless, California's Long Beach Port is the busiest port in the United States, whereas the Port of Charleston ranks eighth at its current operating capacity.³⁶

The baseline results in this study are particularly important because the communities are already disproportionately burdened by pre-existing environmental stressors that may negatively influence health outcomes.³⁷ Other communities in Houston, Texas, have experienced the same environmental load, where 20% of the highest

emitting industrial facilities are located by the Port of Houston and main shipping channel.³⁸ Furthermore, the communities differentially impacted by goods movement activities are predominately nonwhite and low-income populations.³⁹ Land use decisions for goods movement activities are often made at the local level and may lack community input; however, the USEPA has devised strategies to ensure that communities like Charleston can withstand changes made to the ports.⁴⁰ By conducting a baseline air pollution assessment preport expansion, the LAMC now has data to present to the ports authority that will allow us to work collaboratively to protect the health and quality of life of North Charleston communities.

CONCLUSION

Baseline PM_{2.5} and PM₁₀ concentrations did not exceed the NAAQS during the sampling period. The short sampling period (July–April) did not allow us to collect enough data to reflect seasonal variations in PM concentrations; however, the lack of seasonal data may be less important after the port expansion because PM levels may be more influenced by increases in mobile sources of pollution or by the volume of goods shipped. As PM levels are highly impacted by traffic, another limitation in this study was not measuring traffic volume and density before the port expansion.

Lastly, our air quality monitoring plan only allowed us to document community-level exposures, which does not equate to individual exposures to PM. Nevertheless, this does not mean that PM exposures did not lead to negative health outcomes for local residents. Despite our limitations, we can still use our data to inform other goods movement

³⁵Science Applications International Corporation. Air Quality Monitoring Program at the Port of Long Beach. Annual Summary Report Calendar Year 2012. <<http://caap.airsis.com/Documents/POLB%20-%202012%20Annual%20Monitoring%20Report%20-%20FINAL.pdf>>. (Last accessed on June 5, 2015).

³⁶Susan Piperato. Top 10 Busiest U.S. Ports. <http://nreonline.com/public-infrastructure/top-10-busiest-us-ports%20slide-2-field_images-531171>. (Last accessed on January 30, 2014).

³⁷U.S. Department of Transportation. America's Container Ports: Delivering the Goods. <https://www.rita.dot.gov/bts/sites/rita.dot.gov.bts/files/publications/americas_container_ports/2007/pdf/entire.pdf>. (Last accessed August 5, 2015); Lainie Friedman Ross, Allan Loup, Robert M. Nelson, Jeffrey R. Botkin, Rhonda Kost, George R. Smith Jr, and Sarah Gehlert. "The Challenges of Collaboration for Academic and Community Partners in a Research Partnership: Points to Consider." *Journal of Empirical Research on Human Research Ethics* 5 (2010): 19–31.

³⁸National Environmental Justice Advisory Council (NEJAC). Reducing Air Emissions Associated with Goods Movement: Working Towards Environmental Justice. <<http://www3.epa.gov/environmentaljustice/resources/publications/nejac/2009-goods-movement.pdf>>. (Last accessed on October 5, 2015).

³⁹National Environmental Justice Advisory Council (NEJAC). Reducing Air Emissions Associated with Goods Movement: Working Towards Environmental Justice. <<http://www3.epa.gov/environmentaljustice/resources/publications/nejac/2009-goods-movement.pdf>>. (Last accessed on October 5, 2015); Andrea Hricko. "Progress and Pollution: Port Cities Prepare for the Panama Canal Expansion." 120 (2012): A471–A473.

⁴⁰National Environmental Justice Advisory Council (NEJAC). Reducing Air Emissions Associated with Goods Movement: Working Towards Environmental Justice. <<http://www3.epa.gov/environmentaljustice/resources/publications/nejac/2009-goods-movement.pdf>>. (Last accessed on October 5, 2015).

studies, health and zoning intervention policies and provide additional support for implementation of the mitigation plan agreement. We will continue with our current monitoring plan and conduct a postport expansion follow-up study to determine whether air pollution concentrations have significantly increased in the area. Our future study will also examine changes in individual health status for North Charleston, SC, residents because a baseline community health assessment is already underway.

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