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The Imperial County Community Air Monitoring Network: A Model for Community-based Environmental Monitoring for Public Health Action

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Summary: The Imperial County Community Air Monitoring Network (the Network) is a collaborative group of community, academic, nongovernmental, and government partners designed to fill the need for more detailed data on particulate matter in an area that often exceeds air quality standards. The Network employs a community-based environmental monitoring process in which the community and researchers have specific, well-defined roles as part of an equitable partnership that also includes shared decision-making to determine study direction, plan research protocols, and conduct project activities. The Network is currently producing real-time particulate matter data from 40 low-cost sensors throughout Imperial County, one of the largest community-based air networks in the United States. Establishment of a community-led air network involves engaging community members to be citizen-scientists in the monitoring, siting, and data collection process. Attention to technical issues regarding instrument calibration and validation and electronic transfer and storage of data is also essential. Finally, continued community health improvements will be predicated on facilitating community ownership and sustainability of the network after research funds have been expended. https://doi.org/10.1289/EHP1772

Introduction

Communities and regulatory agencies are discovering the utility of small, low-cost environmental sensors that are able to provide real-time information on air pollution (Jiao et al. 2016; Snyder et al. 2013; Yi et al. 2015). These sensors hold great promise for individuals, communities, schools, and other interested parties by providing timely information that can supplement regulatory data used to reduce toxic exposures and influence environmental health policy and programs. Using these new technologies presents challenges in ensuring scientific validity of the data and visualizing and communicating scientific information in a comprehensible manner.

The Imperial County Community Air Monitoring Network (the Network), one of the largest community-based air monitoring networks in the United States, is an innovative model that addresses these challenges through a community, academic, nongovernmental, and government partnership that integrates knowledge and priorities from community and academic research perspectives. In this community-engaged process, community members play key roles in determining study design, siting and deploying monitors, and data collection. The Network is now producing real-time particulate matter data from 40 low-cost sensors throughout the county.

Background

A Community Affected by Air Pollution

Imperial County in southern California is home to a primarily Latino population (82%) and has some of the highest rates of unemployment and poverty in the nation (U.S. Census 2010). The county is mainly desert and agricultural, with a range of air pollution sources—such as field burning, the U.S.–Mexico border crossing, unpaved roads, and various industrial facilities—that contribute to periods lasting longer than 6 months when Imperial County exceeds the California standard for particulate matter (PM) with an aerodynamic diameter of 10 μm or less (PM_{10}) (CARB 2012). Historically, Imperial far surpasses all other California counties as having the highest rates of both emergency hospital visits and hospitalizations for asthma among school-age children (CEHTP 2017). El Centro, California, located in the Imperial Valley, is the city with the fifth-worst air quality in the U.S. (ALA 2016). Exposure to PM_{10} is associated with increased respiratory disease, decreased lung function, and asthma attacks in susceptible individuals (Anderson et al. 2012). According to the California Air Resources Board, in 2015, the last year in which data were available, the Salton Sea air basin, where Imperial County is located, had 128 d that exceeded the state standards for PM_{10} (https://www.arb.ca.gov/adam/topfour/topfour1.php). This finding means that, for more than one third of the year, residents may be at risk of breathing outdoor air that exceeds the maximum amount of PM that would not harm public health. Even when air quality is within state standards, the health of the population will likely suffer, as arguably no health threshold level exists for PM; for example, an analysis of daily time series data for the 20 largest U.S. cities for 1987–1994 found no threshold for particulate air pollution on daily mortality (Daniels et al. 2000), and Vaduganathan et al. found that increased levels of PM_{10}, even below the current limits set by the European Union, were associated with excess risk for admissions for acute cardiovascular events (Vaduganathan et al. 2016).

Community Needs for Local-level Air Quality Information

Governmental regulatory air monitors are designed to measure ambient air in communities to ensure that federal and state air-quality standards for the protection of public health are met. However, regulatory monitoring does not have the spatial resolution to provide information to the public in the specific communities where they live, work, and play. Further, regulatory monitors are not designed to report on episodic elevated events (i.e., high-concentration events may be qualified as "exceptional events" and removed from regulatory consideration), which are of concern to

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communities due to acute health events that occur during peak concentrations.

These limitations play out in Imperial County, where understanding, awareness, and effective response to air pollution trends have been hindered by the fact that there are only five regulatory PM monitors for a county that spans over 4,000 square miles and is home to 175,000 individuals. Residents have noted that these monitors often do not seem to reflect the air quality in their local communities, voiced concerns that the monitoring data are sometimes not displayed during elevated events, and identified the need for more air monitors.

Opportunities with Next Generation Air Sensor Technology

Recent advances in small portable and personal air monitors or sensors, which are low cost in comparison with conventional monitors, potentially may provide higher temporal and spatial resolution of air quality data than currently exists from regulatory networks (Jerrett et al. 2015; Duvall et al. 2016; Han et al. 2017; Jovašević-Stojanović et al. 2015; Volckens et al. 2016). The accessible cost, ease of use, and improving accuracy of these technologies position them to play an important role in efforts by communities and researchers to identify sources and trends in air quality that may inform policies and plans to reduce emissions and exposures. Both personal and community responses to these new data can be important public health actions that may emerge from monitoring.

To address community concerns about air quality, a collaborative of community, academia, nonprofit, and government partners formed the Imperial County Community Air Monitoring Project (the Project). Funded by the National Institute for Environmental Health Science's Research to Action Program, the Project used an innovative approach to facilitate community participation and decision-making throughout the development and deployment of the Network and to address concerns about scientific validity and sustainability.

Project Partnerships and a Community Engagement Structure

A crucial component of our approach was to establish an equitable and inclusive community engagement structure that ensured participation at multiple levels throughout the project by various community representatives. The initial step of identification of study partners occurred naturally through a long-standing relationship between Comite Civico del Valle (CCV), a community-based organization in Imperial County, and the California Environmental Health Tracking Program (CEHTP), a program of the nongovernmental Public Health Institute, in collaboration with the California Department of Public Health. The third main study partner, the Seto research group at University of Washington (UW), was identified through relationships with CEHTP, as were other academic partners affiliated with University of California at Los Angeles and George Washington University, who served in an advisory capacity. Distinct roles for the partnering organizations were established from the start. CEHTP provided epidemiological, community engagement, health education, and project-management expertise. UW provided exposure assessment expertise, equipment customization and assembly, and monitor-operation and validation capabilities. CCV provided local community knowledge and relationships and community outreach and organizing expertise, and CCV was ultimately responsible for interfacing with monitor sites and maintenance of the monitoring network. UCLA provided expertise to the community and academic partners on the health effects of air pollution, and George Washington University provided technical consultation on the monitoring of ambient particles.

The project engaged with residents in Imperial County via the establishment of a Community Steering Committee (CSC), recruitment of community participants to help site monitors, and identification of local sites to serve as hosts for the air monitors. The CSC—composed of local leaders and residents concerned about the environment—worked with the Project staff on all aspects of study design and implementation, provided feedback on data communication, and participated in the development of actions to reduce exposures and pollution sources. Government regulatory agencies (in this case, the local air pollution control agency, the California Environmental Protection Agency (California EPA), and the U.S. Environmental Protection Agency (U.S. EPA), were engaged through participation on a Technical Team, composed of local government, academic, and other technical experts. The technical team was convened semiannually to provide technical advice and expertise on the exposure assessment methodologies and calibration results. Government agencies were contacted to provide portable reference monitors for co-location studies, to provide technical assistance to communities and the researchers, and to receive feedback on community needs.

Defining the Goals for Community Air Monitoring

Components of establishing a community-based air monitoring network are shown in Figure 1. Because it was essential to have an established research question or surveillance need to guide the Project's activities, this was determined at the start with partners to ensure responsiveness to community needs. The study partners defined broad goals for the Network that included the ability to use the air monitoring data to inform community members about air quality in real time, as well as to generate data that are appropriate for conducting spatial analysis to identify air pollution hot spots and trends. We also continued to refine the goals by incorporating priorities of the CSC and community participants, determined through individual key informant interviews and group discussions to learn about community air quality information needs, uses, sources, and barriers. In turn, these goals provided guidance as we designed the Network and prepared to share monitoring data with the community. In this manner, the study protocol was developed with significant input from the community partner. Furthermore, at that time, the project partners and CSC helped to develop a project-evaluation plan to assess how well these goals were achieved. The evaluation plan included surveys of CSC members, community participants, and other users of the air monitoring data; web analytics; and key informant interviews of project partners.

Preparing the Network Equipment and Data Collection Infrastructure

The monitor selected for this study, a modified Dylos DC1700 (Dylos Corporation), was tested in the lab and field for limits of detection, responses to particles of varying composition, ability to accurately size particles, and precision between multiple monitors at multiple field sites with different environmental conditions, such as temperature and humidity. The Dylos is a light-scattering particle counter, and as such, particle counts were converted to mass concentrations to align with health recommendations that are usually based on the latter. Algorithms to convert counts to mass were developed based on co-location of the instruments with government reference instruments in the region, modeling the relationship between counts and mass and using this relationship to estimate mass concentrations. The monitor system included the Dylos particle sensor with four size bins (>0.5 μm, >1.0 μm, >2.5 μm and >10 μm), temperature and relative humidity sensors, and a microcontroller to allow wireless real-time

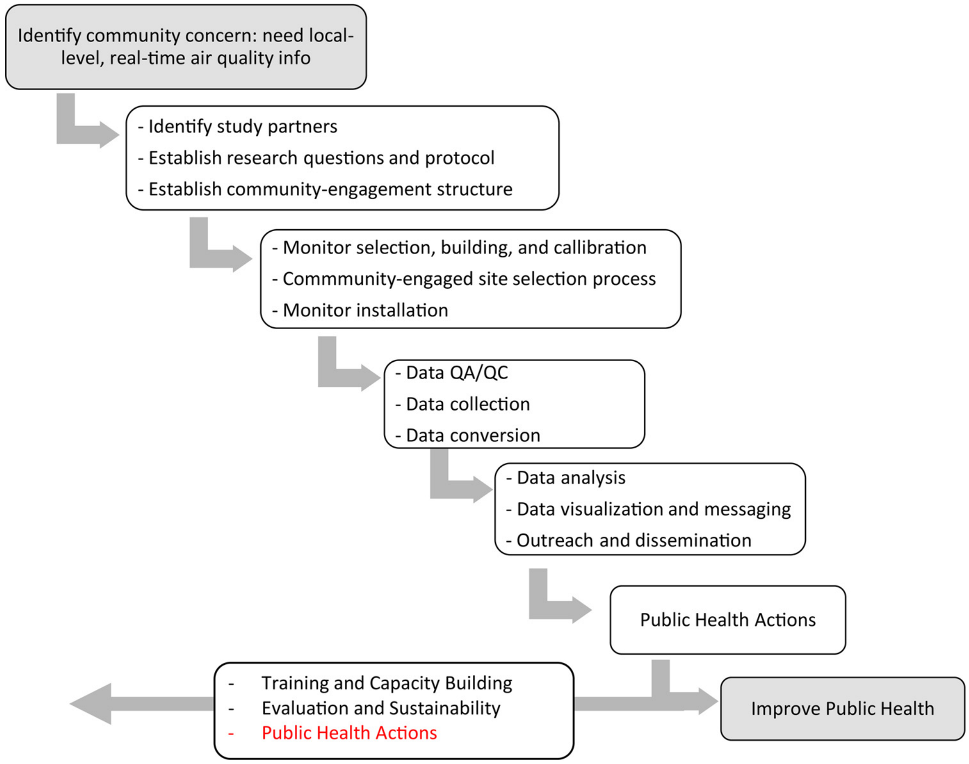

Figure 1. Components of establishing a community-based air monitoring network.

data transfer to the Internet. The monitor components were housed in a box with a cooling fan to sustain optimal sensor performance under Imperial County's harsh summer conditions (Figure 2).

Monitors were validated and calibrated with reference monitors. In our case, the California EPA participated by providing access to their Calexico, California, site, where they operate federal reference and federal equivalent methods for measuring PM, as well as co-locating portable Beta-attenuation particulate matter monitors at sites that we selected for our community air monitors. Additionally, data collection and data transfer protocols were established, along with quality control plans. This process included addressing issues such as establishment of data feeds, data averaging over time, and data completion checks, as well as formatting data for display and hosting the Web services that allow the public to view the data in real time.

Designing and Deploying the Network

Monitor siting was accomplished by having community members identify, collect data about, and prioritize potential monitor locations in impacted communities throughout the county. The participants in this prioritization process included the CSC and additional community residents who were recruited for this aspect of the project. To facilitate these community members' meaningful participation in the monitor siting process, the project team provided basic training in air monitoring science, including explanation of technical criteria (e.g., electrical power availability, wireless connection capability, absence of obstructions, secure location) for monitoring siting. This community-engaged process was used to identify locations for the first 20 monitors. An iterative process was used in which monitoring data from the first set of 20 monitors helped determine sites for the second set. The selection of the second 20 monitor locations was guided by the research staff, with input from the CSC, to ensure that monitors were located in areas where a spatially representative model could be constructed using land use regression techniques (Briggs et al. 1997). CCV played a critical role in recruitment of monitor hosts. CCV staff members were also trained to deploy the monitors and conduct routine maintenance and troubleshooting.

Producing Community-relevant and Accessible Information

Researchers and the community members discussed which air quality measures were most useful and how the data would be visualized and communicated to the public. The CSC was presented with several options for data presentation to determine the most understandable and useful approach. The existing community website and data platform titled Identifying Violations Affecting Neighborhoods (IVAN) was redesigned and built out to include the data from the Network, called IVAN Air Monitoring (IVAN-Imperial.org/air). The Project staff developed messaging about interpreting the data, information on air quality and health, and technical information on the monitors and pollution levels, which is also posted on the IVAN website.

Moving Data to Action

Ultimately, the goal of the Network is to provide data and information to community residents to help them engage in individual and community actions to improve health. CCV has extensive knowledge and expertise in outreach, education, advocacy, and organizing. By involving the CSC and other community residents throughout the Project, CCV was more readily able to engage them in ongoing actions than in the past. To support the deployment and utilization of the Network, the Project team developed a two-phase public health action-planning process in which the CSC and other community participants were trained in community action planning strategies, identified and prioritized public health concerns, and developed action plans to address those concerns. With the completion of the Network, the second phase of public health actions will focus specifically on air quality, which

Figure 2. Air monitor system including modified Dylos particle sensor with four size bins (>0.5 μm, >1.0 μm, >2.5 μm and >10 μm), temperature and relative humidity sensors, and a microcontroller.

may include actions such as outreach to school communities about air quality and health; devising plans for schools to shelter in place during a poor-air-quality days, especially for students with asthma; sharing data trends with local officials to advocate for regulatory action; and training schools with a community monitor to use a flag system to notify the school community about the current air-quality level.

Ensuring Sustainability

This Network was designed from the outset to be community owned and operated, which will require that the community has the resources, knowledge, and capacity to sustain it. A critical component of supporting an ongoing network is the operation and maintenance of the monitoring equipment, as well as upgrading of software and hardware as needed. As part of ongoing project activities, CCV staff has already received training and assumed responsibility for monitor installation, as well as in troubleshooting monitor hardware and software issues. Furthermore, although technical expertise from a consultant on retainer can provide periodic review to ensure the scientific accuracy of the project, the Network should not have to rely on external technical infrastructure. For example, project data were initially stored on UW data servers but have now been migrated to a cloud service provider so that ownership of the data and the server software may be transferred to the community before the conclusion of the initial grant. This step is critical to ensure sustainability of the program and accessibility of the data after the grant funding period ends. Finally, a key component of sustainability is the continuation of community action planning and community-training activities. The CSC provides an existing structure through which community members can participate directly in the outreach, dissemination, and use of air monitoring data in the broader community. CCV and the CSC can also play a role in community-member mentoring, so that the next generation is interested and prepared to operate the Network.

Who should financially sustain a community-based air monitoring network? Although the community will own the Network and has an interest in its continued operation, they have limited access to funding streams and few available resources. Government agencies may be motivated to maintain and ensure quality data from such projects, as these data help fulfill their mission to provide useful data for community members and can supplement information from regulatory monitors. One example in California is the California Air Resources Board's Supplemental Environmental Project Policy (available from a file linked at https://www.arb.ca.gov/enf/seppolicy.htm). This policy "allows community-based projects to be funded from a portion of the penalties received during settlement of enforcement actions." Policies like these can provide some continued support for air monitoring network sustainability.

Best Practices

Several main themes emerge from this project that can be applied to other settings. First, a clearly defined purpose for monitoring must exist, with an understanding of how data may inform action. Roles and responsibilities of all study partners need to be clear from the onset; if this is done correctly, it will ensure that critical functions are covered and adequately funded, it will manage expectations and avoid miscommunication, and it will identify opportunities for knowledge transfer and capacity building. The community, researchers, and government agencies all have an important role to play, and the project resources should be equitably distributed among them. Scientific information must be presented in an accurate and accessible manner and tailored to the cultural and socioeconomic attributes of the community in question. Data must be understandable and useful for the public to apply in public health campaigns. Next-generation environmental monitors, although relatively easy to install, should not be considered reliable and accurate without rigorous calibration and testing; monitors later may experience technical issues, such as connectivity problems that may affect data completeness. Further, due to dust accumulation on the lens of the particle counter, measurement drift can occur over time; therefore, a regular maintenance schedule is essential. In addition, sustaining a project after dedicated funding ends is difficult; therefore, emphasis on community involvement and training during the project period, as well as novel fundraising and interest from regulatory agencies, can ensure that the project continues to collect useful data into the future.

Conclusion

Current availability of real-time and neighborhood-scale data on PM levels can be used as an agent of change. Residents are now equipped with data that they can use to better identify when and where residents are safe outside; to change personal behaviors to reduce exposures; and to advocate for policy changes that more aggressively reduce PM sources. Community engagement and uses of citizen science are becoming more common in influencing public health practice (Den Broeder et al. 2016). In Imperial County, we have emphasized the importance of the development of a sustainable air-monitoring network that is community owned and operated and producing data that are valid for community and traditional research. The project has increased community knowledge and capacity about the process required to set up and maintain monitors, and community partners are now empowered to initiate and collect air data for themselves. With this new information, understanding, and capacity, the community is better prepared to engage and collaborate with government around air monitoring and policy than in the past. Increased availability of actionable independent data and technical capacity to operate the hardware and software network components allow residents to have greater control over their lives and enhance the health of their community members.

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