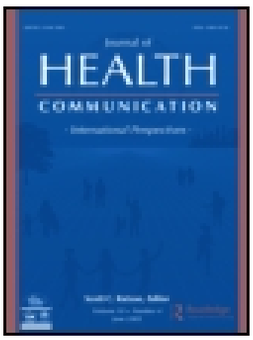

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Public Awareness of Air Pollution and Health Threats: Challenges and Opportunities for Communication Strategies To Improve Environmental Health Literacy

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Accurate, timely information can be a powerful tool to mitigate harmful effects of air pollution. While national guidelines for environmental risk communication – based on risk and crisis communication principles – exist, little is known how these are operationalized, nor about the effectiveness of existing communication efforts. Moreover, a growing literature on environmental health literacy suggests that communication about environmental risks must move beyond individual behavior education to empower communities to mobilize to reduce environmental threats. This study aimed to identify and critically evaluate public sources of information about the causes and controllability of air pollution and its health effects, and potential disparities in information reach and utility. The case study triangulated data from three sources: Systematic analysis of the public information environment, interviews with regional expert stakeholders, and interviews with community residents. Three themes emerged: 1) Lack of clarity about responsibility for communicating about air quality (*information sources*), 2) Existing air quality communication strategies lack critical information including risk mitigation behaviors and long-term health impacts (*information quality)*, and 3) Existing air quality communications fail to reach vulnerable populations (*information reach*). This study demonstrates that air quality communication is lacking yet crucially needed. Information about air pollution and health risks focuses on individual risk behaviors but is disseminated using channels that are unlikely to reach the most vulnerable populations. We discuss opportunities to improve the reach and impact of communication of air quality health risks, an increasingly important global priority, situating our argument within a critical environmental health literacy perspective.

Air pollution is the leading environmental toxin (Landrigan et al., 2017), attributed to diseases responsible for an estimated 16% of premature deaths globally. The World Health Organization declared air pollution an unequivocal carcinogen (Loomis et al., 2013). Other adverse health effects include asthma attacks, acute and chronic bronchitis, respiratory symptoms, pneumonia, increased risk for acute myocardial infarction, loss of work and school days, and premature death (Hall, Brajer, & Lurmann, 2008; Samet & Krewski, 2007). Air pollution is a function of complex systems, and solutions to the problem also require multilevel intervention (Landrigan et al., 2017). Accordingly, the construct of environmental health literacy (EHL), with roots in health literacy (Nutbeam, 2008) and risk communication (Glik, 2007), is fundamentally about understanding the link between environmental exposures and health (Finn & O'Fallon, 2017). The construct has evolved from a focus on individual-level educational processes to conceptualization as an evolving process and public health philosophy that considers strategies for empowering individuals to use communication to control environmental exposures (Finn & O'Fallon, 2017; Gray, 2018).

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Communication is a tool for achieving all stages of EHL. At the individual level, communication can be used to achieve functional EHL by providing education (*i.e.*, communication of factual information about health risks) as well as information that can motivate individuals to engage in behaviors to mitigate the health risks of air pollution (Glik, 2007; Guidotti, 2013; Johnson, 2012; Silk & Totzkay, 2018). At the interactive level, communication can help to build skills that increase self-efficacy. Finally, in terms of critical health literacy, communication can be used to effect structural change by conveying the causes of air pollution that can be used to advocate for policies that reduce air pollution (Palmedo, Dorfman, Garza, Murphy, & Freudenberg, 2017).

Despite the potential for communication to mitigate the health risks of air pollution through improved EHL, little is known about the extent and effectiveness of air pollution communication. From the perspective of audiences and citizens, the mass media are recognized as sources of information about air quality (Cisneros et al., 2017; Feinberg et al., 2016). Yet a recent content analysis of wildfire-related air quality press releases and public complaints published in regional newspapers found that both were poorly correlated with actual air quality (Cisneros & Schweizer, 2018), suggesting that misperceptions about air quality risks abound among the media and public. Further complicating the landscape of air pollution and

Table 1. Public communication sources about air quality in California's San Joaquin Valley

Program	Distributed by	Description	Target Audience	Websites	Visual
Air Quality Index (AQI)	Unites States Environmental Projection Agency	Provides information about Air in the following 4 categories: Air Pollution, Indoor Air, Greenhouse gases, and Acid Rain. Under the Air There are current air quality conditions using AQI.	All parts of society and communities, individuals, businesses, and state, local and tribal governments in the U.S.	www.lung.org	
Real Time Air Advisory Network (RAAN)*	San Joaquin Valley Air Pollution Control District	RAAN uses Air Quality System (AQS) and also geographic information system (GIS), each District has an hourly ozone and PM 2.5 monitor to its own geographic zone or catchment.	Communities, families, students, workplaces, and agriculture departments in San Joaquin Valley.	www.healthyairliving.org www.calcleanair.org www.valleyair.org	 No single visual
Real-Time Outdoor Activity Risk (ROAR) Guidelines	San Joaquin Valley Air Pollution Control District	Outdoor activity guidelines broken down for each level of RAAN hourly data	Schools and caregivers	www.valleyair.org	No single visual
Air Quality Flag Program	Unites States Environmental Projection Agency (Air Now)	Each day an organization raises a flag that corresponds to how clean or polluted the air is. The color of the flag matches EPA's Air Quality Index (AQI): green, yellow, orange, red, and purple.	U.S. schools districts, parents, community members and children.	www.AirNow.gov	
Air Quality Flag System	San Joaquin Valley Air Pollution Control District	Each day a school raises a flag that corresponds to how clean or polluted the air is. The color of the flag matches EPA's Air Quality Index (AQI): green, yellow, orange or red.	San Joaquin Valley Schools, parents, community members and children.	www.valleyair.org	

* Includes health guidelines on unhealthy days; this is provided so that schools can use this information to adjust physical activities to help reduce exposure to air pollution, while still keeping people active.

health risk communication is the nature of the information conveyed in the public media: Entertainment programming, for example, exaggerates for dramatic effect (Frayling, 2005; Moore, 2016). Finally, while standards for effective communication of environmental risks exist, the extent to which these are followed by official organizations is unclear. For example, the U.S. Environmental Protection Agency (EPA) has published guidelines for the effective communication of environmental risks (Petersen, Stein, Berol, Usherson, & Parez, 2002); these include: Using websites showing a variety of data visualization tools; engaging local news media, local officials, and schools; and tailoring information to the unique needs of extra sensitive populations such as children and those with certain chronic diseases. EPA's recommendations are consistent with what is known about best practices in risk communication, which also emphasize the need for tailored message and dissemination strategies to reach multiple, diverse populations, along with specific and actionable information (Covello, 2003; Glik, 2007). Yet despite such recommendations, a recent study of news coverage of environmental risks found that there was insufficient efficacy information, limiting the actual practical value of the media to inform publics about such risks (Parmer et al., 2016).

Moreover, implementation of the EPA's guidelines is left to individual state and local agencies, which may deploy their own or adaptations of the EPA's data visualization and interpretation tools, depending on their needs. While there is evidence that audiences recognize local governments' air quality indices (typically modeled after the EPA's Air Quality Index (AQI)), as valid risk information sources (Oltra & Sala, 2016), a recent systematic review found little evidence for the effectiveness of such indices at inducing recommended behavior changes during bouts of poor air quality (D'Antoni, Smith, Auyeung, & Weinman, 2017). This finding raises questions about how publics perceive and use air quality information sources. Globally, the efficacy of air pollution alerts has been questioned, with one recent study demonstrating minimal behavioral and health effects (Chen et al., 2018). Additionally, some of the recommendations provided by the EPA over a decade ago have been challenged by more recent constructions of effective risk communication strategies for diverse populations (Finn & O'Fallon, 2017). Finn and O'Fallon (2017) have thus called for additional research that contextualizes the public's existing understanding of environmental risk – which is shaped by distortions in entertainment media as well as by ostensibly objective news reporting – in order to understand and advance environmental health literacy. Specifically, they call for more research to understand: the effectiveness of communication strategies to increase audiences' environmental health literacy; approaches to measuring the success of such strategies, including consideration of the level of cultural acceptance of environmental risk messaging among ethnic minority and low socioeconomic position populations; and examination of the larger cultural context such as how media informs public understanding of environmental risks.

Thus, this study was guided by the following aims: 1) Document existing communication sources and techniques about the causes and controllability of air pollution and its health effects (*i.e.*, strategies to achieve environmental health literacy for diverse audiences); 2) Evaluate these public sources of information; and 3) Identify potential disparities in information reach and utility. Because air pollution is local and air quality varies seasonally and throughout the day, effective risk communication about air quality must provide local and real-time information, tailored to the needs of the audiences in each community. We therefore present an in-depth case study of one highly-polluted region as an exemplar that can provide insights for other communities (Ganesh & Smith, 2017) to achieve environmental health literacy.

Setting

California's San Joaquin Valley (SJV) comprises 7% of the state and is home to 4 million people. The region regularly exceeds state and federal Ozone (O_3) and particulate matter (PM) standards (Meng et al., 2010) and includes four of the ten most polluted cities in the nation in terms of year-round and short-term particle pollution (American Lung Association, 2017). The high susceptibility of the SJV to air pollution can be attributed to the combination of weather conditions and the topography – a narrow bowl surrounded by mountains which trap emissions from vehicles traveling along the north-south arteries (Fugazi et al., 2018). Pollutants from Sacramento to the north, the San Francisco Bay Area to the northwest, and Los Angeles to the south – as well as from Asia – also travel to and remain trapped in the Valley (Lighthall & Capitman, 2007; Meng et al., 2010). Weather includes frequent temperature inversions, hot summers, and foggy winters, additionally contributing to the formation and collection of air pollutants (Lighthall & Capitman, 2007).

The impact of air pollution on SJV residents' well-being is enormous: Exceeding federal ozone standards has been estimated to cause 460 premature deaths annually, primarily through the exacerbation of cardiovascular disease in older adults, and the annual cost of unhealthy levels of ozone and particulate matter has been appraised above $3 billion (Hall et al., 2008). Poor air quality exacerbates poor overall health in the SJV. For example, asthma and respiratory problems are endemic in the SJV (Meng et al., 2010) – one in six children will be diagnosed with asthma before the age of 18 (Joint Center for Political and Economic Studies, 2012). Moreover, poor air quality contributes to disparities in health outcomes, since SJV communities with the highest respiratory risk are comprised disproportionately of low-income and majority-Hispanic neighborhoods (Fugazi et al., 2018).

Methods

Using a case study approach (Yin, 2014), we present air quality communication resources and needs using triangulated data from three sources: (1) a systematic analysis of existing communicators and communication strategies, (2) interviews with stakeholders, and (3) interviews with community residents.

Regional Air Quality Communication Inventory and Assessment

We first conducted a census of air quality communications, entities who have responsibility or interest in communicating about air quality and health, and experts in air quality assessment and control. We identified organizations that communicate about air quality in the region, starting with an online search for "Air Quality" and "San Joaquin Valley". We explored the resultant governmental and non-profit agencies' websites for organizational structure and key stakeholders to discover additional organizations of interest. This process was executed until saturation was achieved and no new organizations were identified (Yin, 2014).

We then evaluated the content and reach of existing communication strategies by recording the following notes for each organization: source of air quality data, target audience, communication tools, and methods of communication dissemination (Table 1).

Expert Stakeholder Interviews

The interview guide was designed to compare experts' awareness and opinions of air pollution information sources with those of community members. We identified regional experts using a snowball sampling approach (Yin, 2014), beginning with a core of university-affiliated experts. Each interview ended with a referral for other potential informants. This sample was augmented through direct outreach to experts in non-profit organizations and in local, county and state-level government. Saturation was achieved after 10 interviews with air quality experts representing academia, the local air pollution regulatory body, the enforcement arm of the regulatory agency, community health care, and advocacy.

Community Resident Interviews

Following the first round of expert interviews, we developed an interview guide to assess residents' perceptions of air pollution and associated health risks. Additionally, we sought insights about the reach and utility of public sources of air quality and health information. We interviewed mothers of school-aged children for practical and theoretical reasons. Since children are particularly susceptible to adverse health effects of air pollution, some local communication strategies target schools (Shendell et al., 2007). We conceptualized the existing air quality information environment as broadly as possible and as such wanted to ensure that the people we spoke with had the possibility of being exposed to as many different existing air quality communication strategies as possible. From a theoretical perspective, motivated audiences are likely to be aware of and to use health information sources (Grasso & Bell, 2015; Ramírez et al., 2013). Mothers are highly motivated to search for health information on behalf of their children, and therefore likely to be aware of information resources pertaining to children's health. We conducted 26 semi-structured interviews (mean age 39.6 ± 8.4; 61.5% Latina) in English (n = 10) and Spanish (n = 16). Participants were recruited from community sites in Central California using a purposive sampling approach (Yin, 2014) to identify mothers with at least one child aged 5 and under. Saturation was achieved after 24 interviews. Participants provided oral consent following an explanation of the study's purpose, risks, and benefits. The University of California, Merced Institutional Review Board approved this study. Interviews were audio recorded, professionally transcribed, and double-coded for key themes developed through an iterative inductive and deductive process (Neuendorf, 2002), and analyzed using NVIVO (Bazeley & Jackson, 2013).

Results

Results are based on an integrative analytic approach (Yin, 2014). We begin with a description of the communication landscape and then discuss results thematically, weaving in evidence from different methods.

The Air Quality Communication Landscape

Across the US, the primary tool for communicating the health risks of air pollution is the EPA's Air Quality Index (AQI). The AQI is based on the National Ambient Air Quality Standards for pollutants considered to be harmful to health and the environment (Air Quality Index (AQI), 2014; U.S. EPA, 2007). Raw measurements of each of the five pollutants monitored under Clean Air Act requirements are converted into a separate value; the highest is reported as the AQI value for the day. A six-category numeric scale, often color coded, indicates increasing levels of health concern (Air Quality Index (AQI), 2014; Cairncross, John, & Zunckel, 2007).

The California Air Resources Board (CARB) oversees local air pollution control districts across the state, using funds from state and federal grants, motor vehicle fees, and permit fees, to regulate the air quality in each district by implementing control measures to meet federal requirements. The SJV frequently fails to meet some of the Clean Air Act standards and the local pollution control district was in the news throughout 2016–17 for advocating for a relaxation of the standards to the Trump administration (Klein, 2016). Thus, advocacy communication was in the opposite direction of what might be expected to improve health.

According to our analyses of publicly-available documents and interviews with employees, communication with the public is not a primary responsibility of the Valley Air District. However, an important dimension of their outreach involves communication programs that are intended to reach specific audiences, including schoolchildren, parents, businesses, and adult community members.

The signature program is the Real-Time Air Advisory Network (RAAN), developed through a partnership between the SJVACD, UCSF-Fresno, and the American Lung Association of Central California. RAAN was the first in the U.S. to provide automated notification of poor local air quality (Valley Air District, 2014). Monitors in designated zones record information about air quality hourly, and send as a text-message or email to registered residents Whereas RAAN reports hourly information, the AQI reports a single daily forecast. The reason for reporting "real-time" data is that fluctuations in air pollution throughout the day vary greatly from the AQI predicted forecast. These ongoing measures are supposed to help residents

(especially school children, or teachers on behalf of children) decide when it is safe[1] to go outdoors. But it is unclear whether these programs are really helping people (Cisneros et al., 2017).

Accompanying RAAN is ROAR (Real-Time Outdoor Activity Risk), designed to ensure that children and school officials are mindful of outdoor playtime when air quality was poor, since outdoor physical activity increases exposure to air pollution, especially if respiratory rate is elevated (Sinharay et al., 2018). For each RAAN level, ROAR guidelines recommend a specific "safe" duration of exercise and indicate when sensitive individuals should avoid outdoor play when participating in recess, physical education, athletic practice and training, and scheduled sporting events. It is worth noting that the trade-offs between the benefits and costs of vigorous physical activity in highly polluted areas is still being resolved (Thurston & Newman, 2018).

Another outreach program was the *Spare the Air* campaign, which ran during the summers of 1994 through 2008. Official "Spare the Air Days" were determined when air quality was predicted to be unhealthy or unhealthy for sensitive groups in adjacent counties. On "Spare the Air Days," residents were advised to stay indoors during peak ozone times between 3 pm and 7 pm, and encouraged to postpone emission-causing activities in favor of alternatives such as: ride-sharing, taking public transportation, walking or biking, linking trips, using electric briquette igniters instead of fluid, and using water-based paints and solvents instead of oil-based products. A 2005 evaluation (Lighthall & Capitman, 2007) of the campaign found disappointing effects: Only 17% of participants were aware that the day of the survey was a *Spare the Air Day* and only 5% of drivers reported having reduced at least one trip in response to the *Spare the Air* program. Results also revealed that residents were generally aware of air pollution, but less aware of why it existed and how they could become involved in the solution.

In contrast with the low levels of awareness and behavior change resulting from the *Spare the Air* campaign in the SJV, a virtually identical campaign in the San Francisco Bay Area has been credited with shifting transportation choices from driving individual cars to the use of public transportation (Cutter & Neidell, 2009). The differential effectiveness of the same campaign may be explained by contextual differences: The Bay Area has a well-developed alternative transportation infrastructure, as well as an environmentally-aware population with high incomes and education levels compared with the SJV, where the high-poverty population has few options for alternative transportation or the ability to curtail activities – for example, farmworkers are unable to avoid being outdoors (U.S. Census Bureau, 2017). Additionally, since the SJV has some of the worst air pollution in the country, the number of alerts that were delivered due to frequent poor-air quality days in the SJV was much higher than the Bay Area. Thus, information overload may have created message fatigue among residents, who have fewer resources and alternatives to draw on, perhaps weakening the program's messages (Graff Zivin & Neidell, 2009).

The 2005 survey findings, along with input from a task force created to improve SJV air quality levels before the 2024 federal deadline, inspired the launch of *Healthy Air Living*, an aggressive media messaging and community involvement program. The multi-faceted, bilingual (English and Spanish) campaign encourages individuals and organizations in the SJV to make a single change daily to improve air quality. The accompanying *Healthy Air Living* Schools Program uses schools as communication channels to reach parents, caregivers, teachers, and staff. When schools sign up for *Healthy Air Living*, they also get the No Idling Campaign, which has a specific behavioral focus: For parents and caregivers to turn off their vehicles while dropping off and picking up their children. The *Healthy Air Living* campaign uses a variety of channels, including a website with games, curricula, and activities for children (www.healthyairliving.org), television and internet radio commercials, and small media print materials such as posters and brochures (available in Spanish and English) to promote RAAN and increase awareness of air quality.

The final component of the Healthy Air Living campaign is the "Air Alert" notification, disseminated though television, radio, print, and media outlets across the 8 counties in the Valley when increasing ozone layers threaten to exceed 1-hour federal health standards. An "Air Alert" could last between several hours to several days. This system remains in use in 2018.

An accompanying winter air program, "Check Before you Burn," which begins annually on November 1 and features daily wood-burning forecasts on the SJVAPCD's website, still exists. The wood-burning status is available on the SJVAPCD's website, via a daily email for registrants, and through a toll-free phone number. Wood-burning rules also are usually reported along with the weather updates on television and radio news.

In addition to the Valley-specific resources, SJV residences may receive air quality information from statewide communication campaigns organized by the CARB. These include a website (ww2.arb.ca.gov) and web-based educational outreach program (*The Know Zone)* with resources about air quality and air pollution prevention specifically created for children, students, and teachers.

Information Sources

Expert stakeholders were familiar with the air quality communication landscape and distinguished between two types of sources: expert information sources (those used by experts like themselves) and public information sources (those used by the general population). The expert sources were those that provided direct measurement of air quality sensor data, such as the EPA and local air quality board websites, email alerts and mobile phone apps produced by the same organizations. In contrast, public information sources were defined as those that reported on air quality data procured from the expert sources:

[1]The term "safe" is used here and in the following paragraph in recognition of how it is used in public communications. However, since there is no threshold for acceptable exposure to air pollution, the determination of what is a "safe" level is a matter of judgment about what is acceptable risk rather than a statement of absolute certainty. This matter gets to the core of challenges in communicating about environmental health risks. We thank an anonymous reviewer for pointing this out.

Television, radio, and print news coverage of daily air quality forecasts. Experts perceived the public sources as "watered down" and lacking the detail that they would prefer. Although we interviewed experts for their particular area of expertise, because they are also residents of the region and at risk of negative health effects, they were doubly motivated to obtain high-quality, local, relevant air quality information and to critique the information available.

There was a disconnect between the intended audiences for air quality information sources and the perception of intended audiences, and this was reflected in the actual use of the information sources by different audiences. Experts did not think the "expert" sources were used by lay publics, even though these are the sources intended for the public, according to the agencies that produce those information sources. Consistent with expert perceptions, residents were generally unaware of all sources.

Neither residents nor expert stakeholders were able to name organizations responsible for communicating air quality information in the region. When asked who they thought was responsible for communicating air quality information, most replied that they did not know, or that "the government" was responsible.

Information Quality

Participants expressed widespread dissatisfaction with the quality of information available about local air pollution and health risks. Experts noted that all sources lacked messaging that made explicit the link between air quality and health. Communication of air quality was perceived as limited to reports of the quality of the air, not health implications. Although many of the communication sources make some declaration of health risks – for example, "the air is considered unhealthy for sensitive groups" is standard language in radio news broadcasts of air quality – these are perceived as insufficiently informative. Residents and expert stakeholders alike indicated a desire for specific information about acute health risks of daily air quality. Experts also noted a desire for communication about long-term health risks associated with chronic exposure to certain pollutants.

Another frequently mentioned limitation of existing communication efforts was the omission of efficacy information. This is consistent with a prior content analysis of regional newspapers, which similarly found that health-related news articles failed to include efficacy messages (Ramírez, Estrada, & Ruiz, 2017), as well as well as with a content analysis of national news reports about environmental health risks (Parmer et al., 2016). In the present study, informants described feeling overwhelmed and powerless in the face of risk information without corresponding suggestions for strategies to mitigate health risks such as protective health behaviors.

Expert informants also criticized existing air quality information sources as insufficiently translating science for general publics. As one expert noted, "They send out what the AQI is, but it doesn't specifically say what it means – they expect people to comprehend it themselves and draw conclusions from A to B." Current air pollution risk communication relies heavily on the concentration of air pollutants. However, experts perceived this information to be hard to understand and identified a need for better translation of the science to the general public. This is particularly necessary in light of the confusion engendered by differences in personal observations compared with objective measurement of air quality and compounded by a lack of understanding of the air pollution mechanisms that produce negative health effects. As one resident described: "Well, when you're looking at multiple sources, you've got different people and [organizations] telling you different things. Just recently, actually, it felt like a good day. It felt clean, and I've got friends saying, "Oh, there's smoke in the air." We've got the, you know, Valley org saying that it's fine. And it changes throughout the day. Yeah, it can be confusing, for sure." This description is representative of how one-third of resident informants described the challenge of managing multiple, contradictory information sources.

Another challenge highlighted in this quote is the role of sensory stimulation (Johnson, 2012) – the personal, objective assessment of the quality of the air. When discussing causes of air pollution, almost half of the causes brought up by participants consisted of fires or burning, even though fires and burning contribute relatively little to the adverse air quality in the SJV (Cisneros & Schweizer, 2018; Hall et al., 2008). Similarly, residents – but not experts – confounded high-pollen days, which are bad for allergies but do not contribute to long-term negative health outcomes, with "bad air days" as measured by environmental pollutants.

Information Reach

Consensus emerged between experts and residents that critical information was not reaching the most vulnerable populations. Awareness of two major regional air quality strategies was low among residents: Only a couple were aware of the Real-Time Air Advisory Network (RAAN) – which is available via phone and internet only. Just over half of the resident informants were aware of the school flag program. Furthermore, only a quarter actively looked at the school flag program, and just two reported having used RAAN.

Access to technology was the most significant barrier to information reach: The two major formal communication tools (RAAN/ROAR and AQI forecasts) – those relied upon by expert informants – are web- and mobile phone-based. The SJV comprises vulnerable populations that rely on traditional media sources such as television and radio for health information and are unlikely to use the internet and mobile phone apps for health (Gonzalez, Sanders-Jackson, & Emory, 2016; Lopez, Gonzalez-Barrera, & Patten, 2013; Powe, 2015).

Language was the other major technical barrier to information reach. The majority of air quality communication sources are available only in English; some are available also in Spanish, but none are available in the other widely spoken languages in the SJV, including Hmong or indigenous Mexican languages.

Who are the Right Target Audiences and What Do They Need to Know

Beyond the technical challenges in reaching vulnerable populations, information reach was perceived as inadequate due to ambiguity in understanding of the appropriate

audiences for air quality information sources. For example, when asked who should be the target audience of communication efforts to reduce the adverse health effects of air pollution, the majority of experts mentioned kids and caregivers, consistent with current efforts that focus on these risk groups. Several experts mentioned that current risk communication effectively targets schools. Additional risk groups mentioned were individuals with respiratory problems, elderly, and people working outside. However, some experts also indicated that current communication efforts focus too much on people with respiratory problems. They argued that a focus on people with respiratory problems makes it too easy to ignore the risks to the general public, particularly of long-term, chronic exposures on cardiovascular disease and cancer. As such, they argued for a strategic reevaluation of "vulnerable groups" to include everyone in the region.

Despite demonstrating a strong understanding of the systemic factors that contributed to poor air quality in the region, neither residents nor experts described systems-level information needs or change-making audiences (*i.e.*, policymakers). Instead, both groups' construction of communication needs pertaining to air quality and health risks focused on individual-level risk mitigation strategies, even though these are difficult to enact for many vulnerable groups and do not address the underlying causes of poor air quality. This is consistent with studies in other health contexts: Even when structural factors are recognized as barriers to good health, it is easier to frame responses in terms of individual behavior changes (Lundell, Niederdeppe, & Clarke, 2013).

Discussion

In this case study, we found that despite published guidelines for conveying environmental health risks, air quality communication is lacking yet critically needed in one of the nation's most polluted and vulnerable regions. Results indicate that communication of air quality is disconnected from the public, focuses on individual-level behaviors that do little to reduce air pollution levels, yet is hard to understand and lacks actionable steps individuals can take to mitigate their risk. Thus, despite privileging an approach to achieving functional environmental health literacy over interactive or critical environmental health literacy, the execution failures suggest none of those objectives are currently met.

Specific opportunities to improve air quality communication include improved translation of the science of air quality. For example, while current reports include the levels of specific pollutants or oversimplification that "air quality is poor," residents and experts in this community prefer non-technical explanations of poor air quality. This could include addressing specific negative outcomes (*i.e.*, acute symptoms or increased risk of specific diseases associated with chronic exposure to poor air quality) as well as specific measures that may protect against these outcomes, at multiple levels, including individual behavior change and advocacy. This latter point is critical, since recommendations from stakeholders and residents alike focused on individual risk mitigation behaviors, but ignored the structural factors that create the health hazards.

These results also support an argument recently articulated about the ways in which communication inequality contributes to health disparities; in this case, the lack of efficacy tools amid confusing information, resulting simultaneously in perceptions of insufficient information and confusion, may exacerbate health disparities (Ramirez & Arellano Carmona, 2018). Further, consistent with a contemporary environmental health literacy approach (Finn & O'Fallon, 2018), messages should aim to engage the public as part of the solution.

There is an equally strong need to disseminate this information appropriately and effectively across culturally and linguistically diverse communities and particularly among low-literacy populations.

Limitations and Strengths

Results should be interpreted in light of methodological limitations. The use of three distinct original data sources and methods, and analytic approach integrating results from the distinct data sources, aimed to address the limitations inherent in small sample sizes, but nonetheless we do not claim to have conducted a representative survey of either experts or residents. Specifically, our sample of community residents left out speakers of languages commonly spoken in the region, including Hmong and indigenous Mexican languages, who may have additional concerns about air quality risks and communication.

Despite the limitations, our approach provides advantages over single-method studies. Specifically, the case study approach provided an in-depth examination of how communication is used to disseminate risk information in a particularly vulnerable region, and allowed for triangulation of evidence across data sources.

Conclusions

Communication about air quality has the potential to reduce the adverse effects of air pollution through generating awareness and catalyzing public opinion in support of policies for air pollution reduction and through education for individual risk mitigation behaviors; all are components of environmental health literacy. Understanding the extent to which existing communication strategies are aligned with those objectives can inform future efforts to improve population health associated with poor air quality. This study demonstrates the need for improved communication about air quality and health risks at multiple levels to achieve environmental health literacy.

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