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ABSTRACT: Institutional design for local air quality management is an underdeveloped area for research and practice. Although the United States has more than a century of organizational experience managing air quality at the Federal level, the recent years have seen a surge of interest in addressing municipal-scale solutions. Without information about the institutional designs, governance structures, and implications of localizing air quality management, practitioners may face challenges reducing population exposure to air pollutants. We offer a US national perspective on managing local air quality by assessing and surveying 117 local air quality authorities identified by the National Association of Clean Air Agencies. The results expose many commonalities and differences among local air quality management agencies across the United States. We find that the authority type and motivations for creating the local air quality agency drive much of the organization structure and capacity to fulfill mandates. The results further provide a means for evaluating the opportunities and challenges for creating local air quality agencies, while recognizing the factors that support effective institutional designs.

KEYWORDS: local air quality management, urban planning

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Introduction

Improving the quality of the air we breathe is quickly becoming one of the grand challenges facing society. As predictions of the rapid rise of urban populations combine with a legacy of polluting land uses, the exposure of humans to degraded atmospheric conditions is leading to dozens of international and national studies that highlight harmful effects to human health and well-being.[1–4] While exposure to poor air quality is one of the leading causes of respiratory and cardiovascular illnesses,[5] especially among vulnerable populations,[6] it is also very costly to nations and communities. Based on the analysis of just 2 air pollutants (ozone and fine particulate matter), Fann et al[7] attributed more than 130 000 deaths a year to pollution in the United States, and others[8] attribute more than $150-billion worth of annual damages to air pollution alone.

Recognizing these challenges, countries and regions around the world are actively designing and refining air quality regulations to address the human health and economic impacts from degraded air. Most notable are the advances made in European countries over the past 2 decades. Laudable improvement to national and local air quality policy offers several insights into the potential pathways that can reduce public exposure to degraded air quality. The European Union (EU) passed a series of air quality directives between 1996 and 2008 aimed at reducing concentrations of certain pollutants in the ambient air throughout Europe.[9] The directives mandate national and subnational air quality planning, so as to scale governance to match the biophysical level of environmental pollution. European Union member states implement the directives through national law that defines a plan for the assessment and management of air quality.

In Germany, the EU air quality directives are transposed into national law that designates legal responsibility for implementation to the *Länder* (sub-national/state) level, as well as the local level that includes regional governmental regions, rural districts, and cities and municipalities. The *Länder* provides the infrastructure for the practical application of the directives, through processes of analyzing and monitoring air quality, as well as developing measures for addressing pollutant exceedances when necessary.[10] It is the responsibility of the local levels below the *Länder* to shape and implement concrete policy measures to address pollutant exceedances. This is because local authorities "can draw on environmentally relevant lay or local knowledge through participation mechanisms" (p. 1314).[10]

The United Kingdom has a twin-track approach to air quality management, complying with the EU directives, but also their own UK Environment Act 1995. Legislation through the Environment Act 1995 stipulated the development of an Air Quality Strategy, which made the national and local governments responsible for creating and implementing a framework for managing air quality, respectively.[11] While the Strategy identified national measures to address large-scale issues (ie, standards for vehicle fuel quality, engine technology, and combustion emissions), it placed much of the responsibility for improving air quality on local governments: an approach based on the principle that "sources are best managed at the lowest administrative level to ensure resources are efficiently and proportionately targeted taking account of local conditions" (p. 661).[12] Local governments thus have the responsibility of assessing both current and future air quality based on emissions from various sources (ie, transport, industrial, and other

significant sources), and where predictions indicate potential exceedances of national standards, the local government is required to designate Air Quality Management Areas (AQMA) and prepare air quality management plans that compliment action taken at the national level.[1,13]

Although European nations have been rapidly advancing opportunities for addressing human exposure to degraded air, promulgating regulations occurs in the socio-political context of each nation, and in the case of the United States, local authorities. In the United States, effective management is hampered by a regulatory framework that manages air quality at regional and national scales. Although many of the drivers behind air quality management are similar between European countries and the United States (eg, smoke pollution and industrial emissions), the design and implementation of air quality policy differs substantially. The aim of this research is to describe the history and structure of governance under US conditions, and to bridge the gap between the practice and research of local air quality management in the United States. We begin by providing a brief history of US air quality management, and then move on to discuss our research approach and findings regarding the evaluation of the structure and effectiveness of local air quality authorities across the nation. We discuss of the commonalties and differences among local air quality authorities and how those features influence air quality management. We conclude with a discussion of the biases and limitations of this study and the potential for future research.

History of air quality management in the United States

The United States has a long history of air quality management, driven initially by smoke pollution in industrial cities. Highly volatile bituminous coal fueled the metabolic cycle of urbanization and industrialization, resulting in the emission of smoke, as well as other air pollutants such as fly ash. As a result, urban air pollution became both a nuisance and a known health hazard as early as the late 19th century.[14,15] Like water supply and human waste disposal, smoke pollution was considered primarily a local problem; however, substantive action to control smoke took a backseat to water and waste treatment.[16] The lower positioning of air quality on the environmental agenda is attributable to several factors, namely, the lack of a clear understanding of the health impacts of smoke pollution, the absence of available and cost-effective control technologies to mitigate smoke emissions, as well as the perception that smoke pollution equated to prosperity, production, and progress.[16,17]

It was not until the 1940s that control of smoke pollution became politically acceptable in American cities. The cities of St. Louis and Pittsburgh were the first to pass air quality statutes, doing so in 1940 and 1941, respectively, each driven by intensive media campaigns and the support of community, labor, and business groups, as well as important public figures.[16–18] Los Angeles created a county-level air pollution control office in 1945 and a special Air Pollution Control District with enforcement powers in 1947.[14] Also, in 1947, California became the first state to pass a statewide law, which authorized counties to regulate air pollution. Largely due to the precedent set by California, and other pressing local air quality challenges, several other states passed air pollution regulation in the 1950s, and by 1963, 14 states had enacted statewide laws. However, state governments struggled to effectively address air pollution as they did not have the authority to control pollution generated in upwind states and stringent unilateral regulations risked industrial flight. Thus, many states merely passed enabling acts (eg, require permits for air pollution emissions and maintenance of enforcement bureaus) leaving enforcement to local agencies.[14]

The occurrence of a series of severe air pollution episodes beginning in the 1940s provoked nationwide public concern and forced air pollution onto the national agenda. In 1948, a dense smog in Donora, Pennsylvania, lasted several days, sickening more than 40% of the population and killing 20 people. In 1952, a similar event killed an estimated 12 000 people over 5 days in London, and another killed at least 200 people in New York City in 1953.[14,19] Continued smog in Los Angeles made national headlines in the late 1940s and due to increasing intensity precipitated the expenditure of millions of dollars by the City and County of Los Angeles and later by the State of California to determine the cause and find a cure.[20]

Although these events and the resulting public interest and rising influence of environmental advocacy groups played a key role in the nationalization of air pollution control, they were not the only driving force. As select cities and states began strengthening their air pollution regulations, key industries acquired a new interest in promoting uniform and moderate federal standards to pre-empt more stringent and inconsistent state and local standards.[21] The automobile industry is a prime example, which initially fought auto emission regulations and then pushed for uniform national standards when it became clear that states would act individually to limit emissions. Many state governments also supported the adoption of uniform national air quality standards, as such standards forced upwind states to comply and prevented industries from moving to states with looser standards.

The first federal air pollution law passed in 1955 (Figure 1), which identified air pollution as a national problem and required the US Congress to offer technical expertise and financial assistance to support state and local initiatives. The Clean Air Act (CAA) of 1963 was the first federal legislation aimed at *controlling* air pollution.[22] In the following years, the CAA underwent a series of amendments, progressively shifting federal policy from support of state and local initiatives to a nationalized framework for air pollution regulation. The Clean Air Act Amendments of 1970 (CAAA) greatly expanded the federal mandate, taking power from the

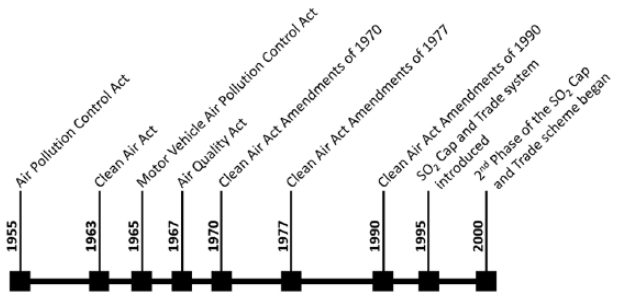

Figure 1. History of federal air quality regulation in the United States.

states and placing it in the hands of the newly formed federal Environmental Protection Agency (EPA). The 1970 CAAA introduced a 2-prong approach to air quality management: the establishment of national ambient air quality standards for 6 primary pollutants (Table 1), and the introduction of non-attainment area designation to regions failing to achieve the air quality standards.[24] To achieve these standards, the 1970 CAAA required each state to write its own State Implementation Plan (SIP) explaining how air pollution will be monitored and addressed in the state, and the EPA was tasked with the responsibility evaluating and approving (or disapproving) the SIPs.[25] Further amendments to improve and enhance the CAA were passed in 1977, 1990, 1995, and 2000, which primarily aimed to rectify issues of addressing non-attainment.

Local air quality management. The series of statutes leading up to and including the CAAA of 1970 established a primarily federal role in air pollution control in the United States. That said, the federal mandates encouraged states to assume as much as possible of the regulatory burden of air quality control, and thus, federal grants and subsidies stimulated the formation of many state and subsequently, local air pollution control programs. In this regard, US air pollution policy relates to that of Europe, where states are granted responsibility for implementing national (or multi-national in the case of the EU) directives. However, an important distinction between the European approach to local air quality management and that practiced in the United States is the influence placed on the role of local knowledge and resources with respect to addressing local air quality challenges. The EU air quality directives, and, independently, the UK Environment Act 1995, specifically require national legislation be implemented at the local level. In the United States, the federal CAAA stipulates that each state develop an SIP outlining how the state will control air pollution to meet the national ambient air quality standards, but no requirement is made of local implementation. Therefore, although the SIPs must be approved by the federal EPA, states have independent authority in their approach to air quality control and implementation. In many cases, states, noticing the importance of local decision-making, created local air quality authorities to bring the regulated community into compliance with the national ambient air quality standards and as such, included the development of local air quality authorities in the SIP presented to and approved by the federal EPA.

The number of local air quality authorities has continued to increase since the passing of the CAA in the 1970s. As of 2017, 117 local air quality authorities were affiliated with the National Association of Clean Air Agencies (NACAA),[26] the prominent national, non-partisan, and non-profit member-based association focused on air quality management. National Association of Clean Air Agencies' members are the primary agencies working to control and regulate air pollution in a given area. The 117 local air agencies practice air quality management in 26 states (Figure 2).

Of the 117 local air quality authorities associated with the NACAA, 71 are run by a single county, 19 are multi-county or city-county (further referred to as "regional" authorities), and 27 are municipal (covering the population of a single municipality). Approximately 36.4% of the US population lives within the jurisdiction of a local air quality authority, and 19 of the largest 20 cities by population have local authorities.[27] That said, less than half of the fastest growing US cities have local air quality authorities (population of 100 000 with growth between 2010 and 2015 greater than 10%). The projected increase in the urban populations combined with air pollution challenges unique to metropolitan areas (ie, complex industrial emissions, increased vehicular emissions, disproportionate exposure to historically marginalized populations, and to name a few) has led to a surge of interest in local air quality management. Although federal and state regulations aim to improve ambient air quality, they often fail to address the pollution challenges specific to urban regions.

Although some of these local air quality authorities have legal jurisdiction to enact and enforce air pollution regulation, most authorities enforce the rules and regulations set by the state and/or develop their own non-regulatory approaches to air quality management. Therefore, where the European approach to air quality management is standardized across local regions, US local air quality management is disparate in nature. Our research aims to improve local air quality management by offering a national perspective about the institutional design and practice of existing local authorities. We argue that the design of future local air quality management should be based on the experience of existing authorities, and in that effort, the structure and practice of local air quality management in the US context must first be understood. In this effort, we ask 3 research questions: (1) what are the primary characteristics of local air quality authorities (eg, drivers, governance structures, and regulatory and non-regulatory mechanisms employed)? (2) how do practitioners of existing air quality authorities perceive the effectiveness of their programs? and (3) how can the experience of established authorities be used to enhance and improve local air quality management in the United States? By administering a national survey of the 117

Table 1. National Ambient Air Quality Standards per the 1970 CAAA.[23]

POLLUTANT	PRIMARY/ SECONDARY	AVERAGING TIME	LEVEL	FORM
Carbon monoxide (CO)	Primary	8 hours	9 ppm	Not to be exceeded more than once per year
		1 hour	35 ppm	
Lead (Pb)	Primary and Secondary	Rolling 3 month average	0.15 µg/m^3	Not to be exceeded
Nitrogen dioxide (NO_2)	Primary	1 hour	100 ppb	98th percentile of 1 hour daily maximum concentrations, averaged over 3 years
	Primary and Secondary	1 year	53 ppb	Annual mean
Ozone (O_3)	Primary and Secondary	8 hours	0.070 ppm	Annual fourth-highest daily maximum 8 hour concentration, averaged over 3 years
Particulate matter (PM) $PM_{2.5}$	Primary	1 year	12.0 µg/m^3	Annual mean, averaged over 3 years
	Secondary	1 year	15.0 µg/m^3	Annual mean, averaged over 3 years
	Primary and Secondary	24 hours	35 µg/m^3	98th percentile, averaged over 3 years
PM_{10}	Primary and Secondary	24 hours	150 µg/m^3	Not to be exceeded more than once per year on average over 3 years
Sulfur dioxide (SO_2)	Primary	1 hour	75 ppb	99th percentile of 1 hour daily maximum concentrations, averaged over 3 years
	Secondary	3 hours	0.5 ppm	Not to be exceeded more than once per year

Abbreviation: CAAA, Clean Air Act Amendments of 1970.

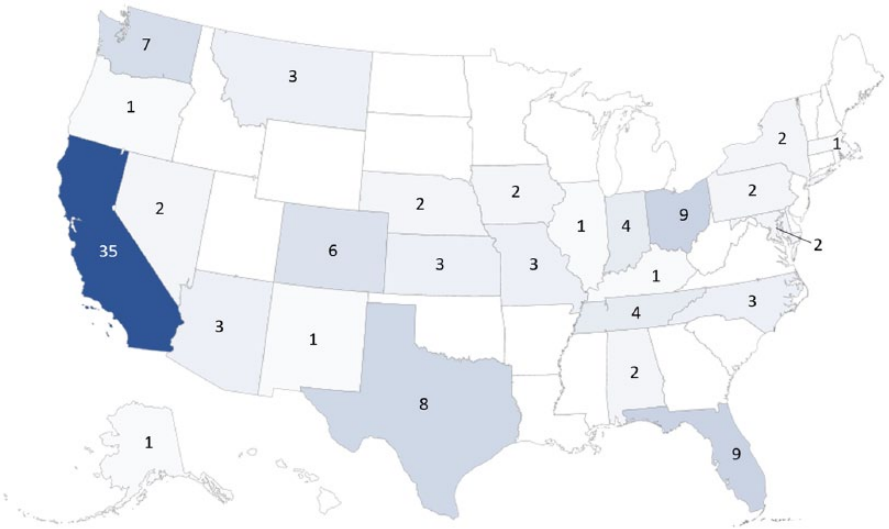

Figure 2. Number of local air quality authorities per state (NACAA). NACAA indicates National Association of Clean Air Agencies.

local air quality agencies associated with the NACAA, we describe the structure and process of implementing local air quality management in the United States. The research findings bridge the gap of both the practice and research of local air quality management and provide an understanding about the governance of local air quality authorities that can be used to enhance air quality management in the United States.

Research Methods

Survey structure

We performed a 2-phase survey methodology to collect information regarding the structure and practice of localized air quality management in the United States. The first phase involved strategic outreach to 17 of the local air quality authorities associated with the NACAA to seek participation in an

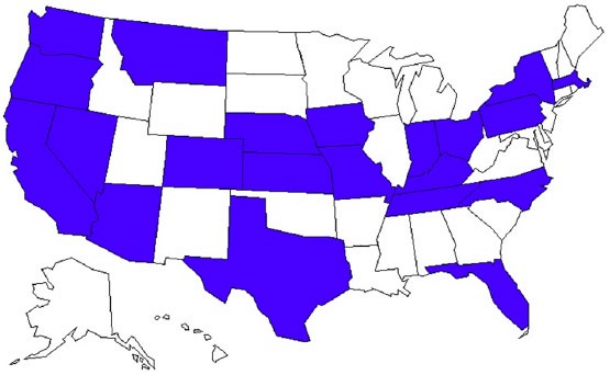

Figure 3. States represented by survey resondents.

open-ended survey regarding the authority. We selected the 17 authorities based on their broad geographic distribution, diverse governance structures and practices, as well as history and rational for inception. The survey questions were of narrative format and fell into the following general subjects: (1) history and drivers behind the initiation of the authority; (2) organizational structure including employment, revenue, and budget; (3) primary pollutants of concern and regulatory and non-regulatory mechanisms employed; and (4) measures of effectiveness, as well as perceived program effectiveness. Based on the results of the first survey, we generated a second, more concise survey to send to the remaining 100 local authorities listed with the NACAA. Questions in the latter survey covered the same subjects as the first, but followed a more closed-ended format for the sake of data analysis (Appendix 1). Our 2-phase approach allowed for the collection of rich, detailed information from a subset of local air quality authorities, which helped to identify common attributes and generate the fixed-choice questions for the complete list of possible participants.

Survey recruitment

The NACAA provides contact information for representatives of each local air quality authority, and we verified this information with authority websites prior to recruiting representatives to participate in the surveys. We sent an introductory email to each authority representative describing the study and to ensure they were the appropriate representative to participate. We then sent a follow-up email, which included access to the online survey platform. Participants were asked to complete the survey within a 2-week period, and we sent 2 reminder emails as the deadline approached. We also contacted unresponsive representatives via telephone in an additional effort to recruit participation.

Results

Survey response

Of the 17 local authorities strategically chosen to participate in the first phase of surveying, 14 completed the survey, an 82% response rate. The second survey was sent to the remaining 100 agencies, of which 44 completed the survey. In total, we asked all 117 local authorities associated with the NACAA to participate in the survey and received a total response rate of 50%, representing regions from throughout the United States (Figure 3). Our analysis treated many of the survey questions separately because of the narrative nature of the first survey and more close-ended responses from the second survey. At the same time, we use the narrative responses from the first survey to contextualize the trends observed in the second survey.

We discretized responses based on the population covered by each air quality authority as well as the authority type (Table 2) to enable us to investigate relationships between these basic authority properties and other design and management characteristics.

Origins of local air quality authorities

The earliest 2 authorities were established before 1910, of which one of these authorities explained that the program was initially created to deal with industrial emissions and railroad smoke. Roughly 72% of authorities, however, were established in the 1960s and 1970s; likely as a result of the federal mandates. Few authorities have been established each decade since then, with the most recent implemented in 2009. Four authorities have been established since the year 2000, all of which are municipal authorities.

More than half of respondents (57%) indicated more than 1 driver behind the initiation of their authority. Stationary sources were the primary driver behind the initiation of most local authorities (selected by 80% of respondents), followed by state policies (48%), and community concerns (30%). More than half (54%) of respondents who selected stationary sources as a primary driver further explained that their local air quality authority was implemented to address emissions from combustion burning, industrial plants, and/or wood stoves. Based on explanations provided by respondents who selected state policies as a primary driver, it is evident that several states encourage or even legally require local governments to form their own local air quality management programs. For instance, respondents from California legislature passed a law in 1970 that required the formation of county districts to control air pollution from all sources except motor vehicles. Similarly, the Washington State Clean Air Act of 1968 provided the structure and laws to establish local clean air agencies. The 1969 Montana Clean Air Act allows local governments to form their own air quality programs and each program can determine the level of comprehensiveness and have primacy over all parts of the program with the exception of large industrial sources. Respondents who selected community concerns as a primary driver of the local authority further explained that conditions such as geography, seasonal pollution, and local industry prompted strong citizen support for the formation of the local air quality program. Twelve percent of respondents indicated other primary drivers, which were further explained to include

Table 2. Population ranges represented by respondents.

POPULATION RANGE	NUMBER OF SURVEY RESPONDENTS	AUTHORITY TYPE	NUMBER OF SURVEY RESPONDENTS
150 000 and below	6	City	12
150 000-350 000	11	County	30
350 000-500 000	14	Regional	15
500 000-1 000 000	14		
Above 1 000 000	12		

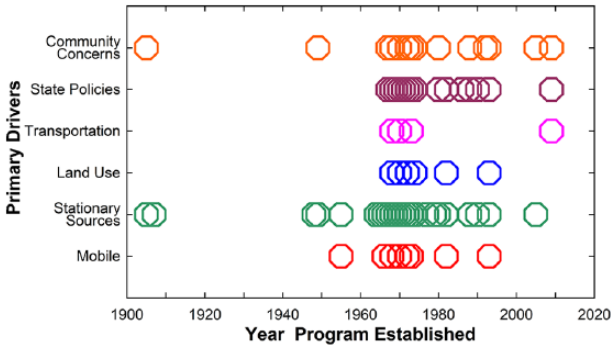

Figure 4. Primary drivers of local air quality authorities over the course of history.

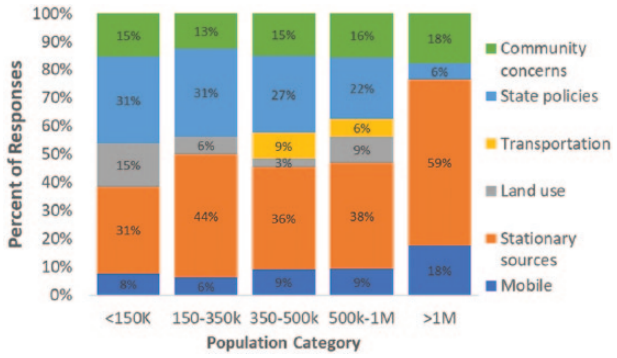

Figure 5. Primary drivers based on population category.

the Federal Clean Air Act, changing National Ambient Air Quality Standards (NAAQS), and air quality in neighboring counties.

Evaluating program drivers over the course of history (Figure 4) shows that the earliest local air quality authorities were driven by stationary sources as well as community concerns. Stationary source emissions that spurred early local governance included wood stove smoke, industrial emissions, as well as combustion of fossil fuels for heat and/or power. Community concern over the health impacts of smog and other air pollutants added additional pressure to local agencies to take measures to address air quality. Following the federal of the 1960s and 1970s, some state policies led to the initiation of local programs to ensure compliance with the Clean Air Act on a local level that was seen as more able to address local pollution sources. In addition, the absence of mobile source regulation in the federal mandates drove local authorities to adopt control strategies and initiatives aimed at reducing carbon emissions from vehicles. Land use and transportation planning have driven local air quality authorities to seek mitigations for air quality impacts from facility siting and transportation system design, respectively. The latest local authorities developed have primarily been driven by community concerns, state policies, and transportation.

The motivation for the development of a local air quality authority also depends on the size of the population represented by the authority. As displayed in Figure 5, stationary sources are the primary driver for all population categories, but particularly so for authorities that cover populations greater than 1 million. Mobile sources are also a primary driver of this population category, more so than the other population categories. That said, land use and state policies do not appear to be leading drivers for authorities covering larger populations. Interestingly, transportation was only noted as a primary driver from authorities who represent populations between 350 000 to 500 000 and 500 000 to 1 million.

Authority structure

Several survey questions aimed to gain a solid understanding of the structure of local air quality authorities. The following section presents the results of questions regarding general authority oversight and governance, budget and employment, as well as primary divisions.

Governance. The majority of respondents (63%) indicated multiple oversight units, most of which have an executive director in addition to another type of oversight. Evaluating governance based on the authority type (Figure 6) indicates that roughly 80% of regional authorities are governed by an executive director, nearly 60% also have a board of directors, 40% have an advisory council, and about 13% have a control board. Similarly, approximately half of city and county authorities have an executive director, and fewer are governed by the other sources. The percentages in Figure 7 do not sum to 100 due to the fact that most authorities have multiple governance bodies. Respondents were also asked to note if their

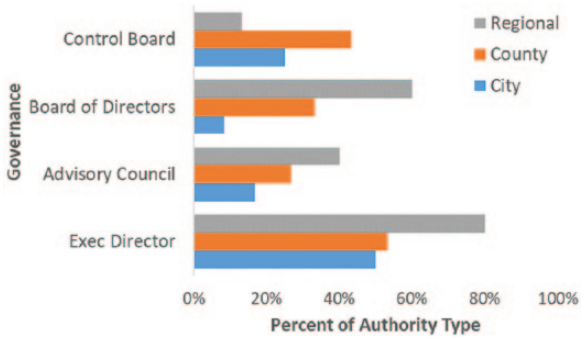

Figure 6. Governance structure based on authority type.

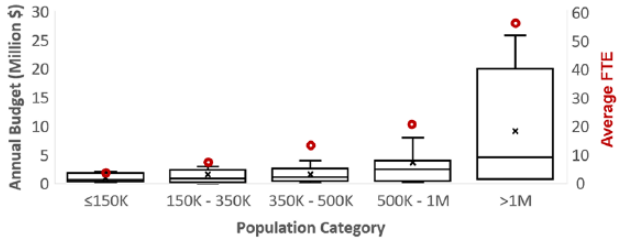

Figure 7. Average budget and employment per population category.

organization had a different governance body than those listed, and results included the following: a hearing board, deputy commissioner, county manager, and some authorities are a part of a larger public health department and thus report to a health commissioner.

Budget and employment. Survey results regarding annual budget and employment suggest significant variation in the size and scope of local air quality authorities (Table 3). According to responses, annual budgets of authorities range from $30 000 to nearly $26 million, with an average of just more than $3.1 million. Annual revenues range from $10 000 to nearly $26 million, averaging just more than $3 million (current dollars). The minimum annual budget and revenue values came from 2 different respondents, one of which did not provide a value for the other variable, thus explaining the discrepancy between these values.

Similar variation is observable in the number employed at authorities, which ranges from approximately one-third of a full-time employee's time to a staff of 800. That said, the authority with full-time equivalent (FTE) of 800 was found to be an outlier in the data, as the next highest employment rate is 146.

Analyzing the average annual budget and employment based on the population covered by respondent authorities exposes some interesting trends. The box and whisker plots in Figure 7 represent the distribution of the annual budget per population category, with the average displayed by an "x." The red circles represent the average employment (FTE) per population category. Not surprisingly, the average budget and FTE increase as the population covered by the authorities increase—on average, as the populations covered by the authorities increase, authorities have greater staff and thus higher budgets. However, the variation of annual budget also increases significantly as the population covered rises. This suggests that most of the authorities that cover smaller populations consistently have a lower budget, but as the population increases, while some authorities have an expansive budget, others still work on a small budget.

For regions with a population greater than 1 million, the annual budget ranges from just more than $800 000 to nearly $26 million, with an average of roughly $9 million. Average employment in authorities covering populations greater than 1 million, excluding the outlier of 800 FTE, is 58 full-time employees.

Analyzing employment based on the authority type shows that, on average, city, county, and regional authorities employ a similar number of staff: 20, 24, and 23 FTE, respectively. The small circles on the figure represent outliers in the employment data; however, the FTE of 800, which is from a Regional authority, has been removed from the data as it overtly skews the analysis.

Revenue sources. On average, authorities generate revenue from 4 sources. Approximately 75% of respondents indicated they receive revenue from permit fees and 75% also receive revenue from state funds. Federal funds constitute the third most common source of revenue followed by "other" sources. Other sources described include emission and inspection fees, annual registration fees, and pass-through grants. To get an understanding of which sources contribute the most to the revenue stream, we tallied the number of responses in which each source was marked as the highest percentage of total revenue for each authority. The results indicate that permit fees tend to serve as the greatest revenue source, followed by state funds. That said, the extent to which these sources contribute to the revenue stream varies greatly. On average, permit fees make up 37% of the revenue stream, but ranges from 3% to all of the revenue stream. Similarly, state funds contribute on average 28% of the revenue stream, and range from 1% to 95%.

The sources and distribution of revenue varies when considering the administrative structure of the local authority, specifically whether they are city, county, and regional authorities (Figure 8). Of the 3 authority types, city authorities rely the most on revenue from permit fees, as some authorities receive 100% of their revenue from this source. While not all city authorities receive revenue from permit fees, of those that do, the fees contribute on average 56% of the total revenue stream. Similarly, federal and state funds contribute on average 41% and 54%, respectively, to the revenue stream of city authorities. County and regional authorities receive revenue from a greater number of sources, thus relying less heavily on select sources. Not surprisingly, county funds make up a greater share of the revenue stream of county authorities than city or regional authorities.

Table 3. Budget and employment of local air quality authorities.

	ANNUAL BUDGET	ANNUAL REVENUE	FULL-TIME EQUIVALENT EMPLOYMENT
Minimum	$30 000	$10 000	0.35
Maximum	$25 800 000	$25 800 000	800
Average	$3 158 687	$3 066 687	35.9
Median	$1 400 000	$1 200 000	13.5

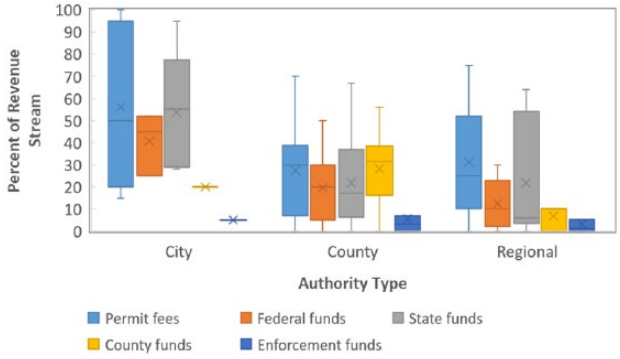

Figure 8. Distribution of revenue sources based on authority type.

Figure 9. Number of program divisions based on authority type.

Divisions. The survey results indicate that authorities have between 2 and 9 program divisions with an average of 5. The majority of respondents indicate that the primary authority divisions include monitoring, compliance, and enforcement. Analysis of the number of program divisions based on authority type indicates that city and county authorities both have, on average, 5 program divisions (Figure 9). Regional authorities tend to have a higher number of program divisions, with an average of 7.

In addition to selecting authority divisions, we asked respondents to write in the percentage of total staff that work within each division. According to responses, the compliance division tends to be the largest in terms of employment, with an average of 28% of employees (Table 4). The permitting, monitoring, and administration divisions follow in terms of average staff size.

Regulatory and non-regulatory mechanisms employed

To get an understanding of how local authorities address air quality challenges (ie, the practice of local air pollution control), we started by asking respondents to select if regulatory and/or non-regulatory mechanisms are employed by the authority. A series of additional follow-up questions propagated depending on which type of mechanisms respondents selected. Nearly 70% of authorities employ both regulatory and non-regulatory mechanisms. Less than 2% of respondents employ only non-regulatory mechanisms and 29% only employ regulatory mechanisms. All respondents who marked "other" also had both regulatory and non-regulatory mechanisms. Other mechanisms identified include reviewing subdivision plans to verify all modes of transportation are adequately addressed for that specific area, use air alerts that can restrict industry and wood stove use activity, and write articles for the local papers about air quality issues.

Regulatory. More than 80% of respondents who noted they employ regulatory mechanisms indicated that regulations are primarily employed to address air pollution generated from industrial and business sources. Approximately 31% of respondent authorities regulate residential emissions, 12% regulate automobile emissions while roughly 18% regulate emissions from other entities that reportedly include emissions from construction, earth moving, open burning, and agricultural operations.

Nearly 65% of authorities use inspections, permits, issuance of violation, and penalties (all 4 options listed in the survey). Roughly 93% of respondents indicate regulations are enforced through inspections, 82% enforce through permitting, 78% issue violations, and around 69% serve penalties. Nearly, 10% of respondents noted other enforcement strategies including registration, and the state serves as the entity responsible for enforcing air quality regulations. For respondents who indicated enforcement by means of inspections, we followed with a question regarding frequency of inspections. Responses indicate that authorities generally perform inspections on a regular, recurring basis. Frequency ranged from annual inspections, every 2 to 4 years, and every 3 to 5 years. Some authorities noted inspections are only performed when a complaint is issued, whereas few other respondents stated that inspections are

Table 4. Percentage of staff in each major division.

DIVISION	PERCENTAGE OF STAFF WORKING IN EACH DIVISION, AVERAGE (MINIMUM, MAXIMUM)
Compliance	28 (5, 80)
Permitting	26 (8.5, 70)
Monitoring	21 (5, 40)
Administrative	17 (2, 43)
Engineering	16 (8.5, 34)
Other	15 (5, 36.6)
Enforcement	15 (2, 50)
Planning	14 (10, 35)
Education and Outreach	10 (1, 35)
Executive Office	8 (1, 20)

dependent on the type and rate of emissions. For respondents who indicated enforcement by means of penalties, we also asked a subsequent question pertaining to the penalty fees. Responses included the following: "up to $1,500," "up to $25,000 per day," and "$100 to $10,000 per violation."

Participants of the first survey phase were asked if the regulations employed are more stringent than those of the federal mandates. Of the 14 respondents, 11 responded affirmatively. Respondents were also invited to provide further information and select responses are presented herein. One respondent stated that they have stricter rules for industry inside the authority's geographic region. In addition, they stated "[w]e also have two zones for wood stove installation and removal in the county that are more stringent than the Clean Air Act." Similarly, a different respondent noted "our woodstove program requires older stoves to be removed or upgraded upon real estate transactions. Our program also has a minimum parcel size requirement to install a stove."

A respondent from an air quality authority of a major city noted vehicle controls that exceed federal and state standards regarding particulate matter (PM) emissions:

> We regulate vehicle controls on the city fleet and any other vehicle that has a license from the city. For example, sightseeing buses must put on a control such as a diesel particulate filter to reduce PM emissions. We also regulate cooking and restaurant PM by requiring controls such as an electrostatic precipitator.

Another respondent similarly noted enforcement of regulations more stringent than the federal mandates by means of permits stating: "For example, our regulations extend to permit holders like coffee roasters that are not explicitly qualified through the Clean Air Act." Regarding addressing non-attainment, one respondent stated: "Due to our extreme non-attainment designation, many of our requirements are more stringent than federal or state requirements." Another respondent indicated that their authority does not have local regulations that are specific to the local community, rather they rely on and enforce the state regulations. Therefore, if the state does not implement additional regulations, the local air quality will not improve.

Non-regulatory. The survey results indicate that the majority of non-regulatory mechanisms employed by authorities (68% of respondents) are aimed at reducing emissions from the industrial sector, but only slightly fewer respondents indicate a focus on business and mobile emissions. Approximately 30% of respondents indicated other focuses of non-regulatory mechanisms, to which written explanations included "non-specific regional air quality status and trends," "grants to replace old school buses," and "incentives for early introduction of reductions."

Nearly 90% of respondents indicate that the non-regulatory mechanisms employed are designed to provide education and outreach services. Less than half of respondents indicate that the non-regulatory mechanisms employed in their authority aim to address citizen complaints, and decreasing percentages of respondent authorities employ policy advocacy, offer economic incentives, or perform specialized studies. Other non-regulatory mechanisms identified include small business assistance, commute trip reduction program for employees, and grants to retrofit busses and fire trucks.

Nearly all respondents (96%) indicated that particulate matter and ozone are the 2 primary pollutants of concern to which non-regulatory mechanisms are designed to address. Between 56% and 65% of authorities also focus non-regulatory mechanisms on the remaining 4 criteria pollutants (carbon monoxide, lead, nitrogen dioxide, and sulfur dioxide) and toxic pollutants. "Other" pollutants of concern identified include greenhouse gases, odors (nuisance), and hydrogen sulfide.

Perceived effectiveness

Measurement of program effectiveness. Effectiveness is an ambiguous concept, and thus, we sought to understand how local authorities measure the effectiveness of their programs by asking each respondent to explain in an open-ended question. Common measures of effectiveness described by respondents included the following: monitoring of air quality trends, timeliness of processing permits and responding to complaints, attainment status in relation to federal standards, community and/or customer feedback (often based on surveys), as well as compliance of regulated facilities and/or ambient air pollution levels with federal standards. One respondent indicated they "conduct surveys and research to estimate the impacts on emission-generating activities, emissions rates, emissions, and ambient air quality when possible." Results of these investigations are published on the authority's website for public review. Another

respondent indicated that program effectiveness is measured as part of a larger "Healthy Community" initiative, in which they track chronic disease measures such as rates of obesity, diabetes, chronic heart disease, chronic obstructive pulmonary disease (COPD), and asthma. Another identified the "number of outreach activities, number of permits issued, and the number of policies implemented" as the primary measures of program effectiveness.

Perceived current and future effectiveness. Based on responses of the Likert-type-scale regarding how respondents view the effectiveness of their authorities, it appears that, in general, authority representatives are confident that their program has improved and will continue to improve local air quality into the future. The average response pertaining to whether authorities have already improved local air quality is 4.52. One respondent ranked this question with a 1 (strongly disagree); however, both the median and mode of responses is 5, indicating that respondents are confident their authority has effectively improved local quality. Regarding the question about whether the authority will improve air quality by 2025, the average of responses is 4.31. Again, the minimum response was 1 (from the same authority who ranked the previous question with a 1), although the mode and median were again 5, indicating that respondents are confident their programs will have a positive impact on local air quality into the future.

Respondents were less confident in their authority's ability to effectively mitigate disproportionate exposure to historically marginalized populations. Responses to this question ranged from 2 to 5 with a mode of 3, median of 3, and an average of 3.49. This indicates that respondents feel more neutral (neither agree nor disagree) about whether their programs address the disproportionate exposure of air pollution to marginalized populations. One respondent explained that the state generally does not take into account marginalized populations when evaluating facility citing and, therefore, although the local authority could implement regional regulations, politically there is no support.

Program improvement. Respondents indicated multiple ways in which their air quality authorities could be improved. Several respondents noted increased funding as a primary means to improve their authority. Stated examples of how this funding would benefit the authority include increases in the number of staff, enhanced education and outreach programs, better monitoring and inspection equipment, and more grant funding available for residents and businesses. Another improvement method involved increasing authority flexibility and the capacity to update regulations. One authority noted improvement could be made with greater influence on neighboring (particularly upwind) jurisdictions, whereas another mentioned establishing a regional working group between states. A proposal made by a city air quality program representative included increasing participation with or even nesting the local authority under a regional authority such as a council of governments (COG) or metropolitan planning organization (MPO). Multiple respondents noted increased control of mobile sources as a means to improve local air quality management. One respondent in particular noted "local control of 'federal' sources like locomotives and heavy-duty trucks." Respondents also noted increasing community and stakeholder engagement would improve authority effectiveness. One respondent specifically stated that "more could be done working with universities, industry, and other federal-local organizations like the National Estuary Programs to reduce dry and wet deposition through voluntary programs and monitoring efforts." In addition, one respondent wrote "figure out how to scale 'highly impacted community' work to more action in more places" as a means to improve the local air quality authority.

Discussion

The results of the survey suggest a number of key findings about common characteristics of local air quality authorities—namely, authority origins, structure, and enforcement—as well as perceived effectiveness. We focus on those specific results that can help us to address our third research question—using the experience of existing air quality authorities to enhance and improve local air quality management in the United States.

Origins and structure

We have learned that while stationary sources have traditionally driven air quality management, with increased access to high-resolution data regarding the distribution and effects of air pollution, other drivers such as community concerns, state policies, and transportation are playing a greater role in the initiation of local authorities. This is supported by the fact that since 2000, 4 local authorities have been created, all of which are city authorities (as opposed to county or regional authorities). This suggests that municipalities are reacting to localized air quality concerns unique to metropolitan areas. Increasingly, communities as well as state and local regulators recognize a gap in the ability of state and federal regulations to address localized air pollution challenges in municipal regions and thus support the formation of local air quality management agencies. The results of this study suggest that the design of such agencies takes into consideration the following factors: pollutants of concern and sources of the emissions of those pollutants; mechanisms that can be employed to reduce emissions from said sources; vulnerable populations and strategies to lessen exposure to pollution by those populations; geographic conditions, land use, and cultural customs that influence air quality; and the political climate as it relates to environmental management. Each of these factors plays a significant role in the ability to effectively manage local air quality.

Our findings further suggest that the structure of existing local air quality agencies largely varies by several factors relevant to their institutional design. First, the authority type, whether within a city, county, or regional organizations, drives source of revenues which the respondents stated were essential for operations. Regional entities are also more likely to have complex organizational structure, which tend to include executive leadership, board of directors, and advisory councils. Surprisingly, even with a potentially greater complexity in terms of institutional designs, we did not observe a larger number of employees for regional authorities. While all metropolitan regions in the United States have formal city and county designations, only some have regional authority types with regulatory power, including places like Portland, OR (eg, Metro), Minneapolis, MN (eg, Metro Council), and those with metropolitan planning organizations. Barring such existing regional organizations, creating a regional air quality agency would likely require a new form of government, which can be politically cumbersome and challenging.

City authorities appear to be less complex than regional authorities in terms of the organizational structure, but rely more heavily on fewer revenue sources. Based on the survey results, city authorities receive revenue from 3 primary sources—permit fees, state funds, and federal funds—with a heavier reliance on permit fees than either county or regional authorities. This heavy reliance on permit fees is of concern because permit fees are based on industrial emissions that may decrease due to emission-reduction technologies and globalization. Instead, funding should come through a variety of sources and not rely heavily on any particular revenue source.

Enforcement

Our survey results suggest that most existing authorities employ both regulatory and non-regulatory mechanisms with the primary aim of reducing air pollution from industrial sources. The dual-enforcement approach aligns with the initial drivers of most local authorities—address emissions from stationary sources. Many existing non-regulatory programs rely on information campaigns, and although they may offer opportunities for improving industrial processes, they may not reach the broader public. Strengthening regulatory approaches, however, may be the immediate approach to improving local air quality, which the respondents indicate requires political receptivity.

Some of the qualitative responses to the survey suggest that passing air quality legislation at the local level may be more likely due to the ability to work with special interest groups—both citizen groups as well as industrial lobbyists—that may be more cumbersome at the state and federal levels. Increasing community concern about environmental quality combined with high-resolution data are driving local agencies to better safeguard communities from pollution. That said, one of the primary challenges of local air quality management is determining the governing organization responsible for the design and enforcement of the program and subsequently the collection and funds to operate the program. Existing local air quality authorities are housed within a municipal or county government or as a joint venture between city and county managers. Revenues to support local air quality agencies will largely depend on this organizational structure and agreements made with state and federal environmental protection agencies.

Perceived effectiveness

The results suggest that local air quality authorities are generally perceived to have positively impacted local air quality since program inception, although the measure of effectiveness varies greatly among authorities. It is worth noting that this perceived effectiveness is the judgment of those responsible for the management of air quality rather than those who suffer its effects or those who are regulated. Some respondents characterize program effectiveness in terms of the granular data collected, perhaps because those regions with local air quality authorities are able to describe intra-urban variation at unprecedented scales. Others examine effectiveness through the reduction in total pollution concentrations over time. The idea that monitoring will provide benchmarks for progress is compelling in its own right, though when coupled with specific regulatory or non-regulatory approaches, respondents describe quantifiable benefits. Several authorities measure effectiveness based on the capabilities and processes executed by the authority (ie, processing of permits), and less so on the air quality itself. This approach presumes that more authority activity results in improved air quality, which remains to be determined. Ultimately, effectiveness will, in our opinion, depend on the number of people who are no longer breathing dirty air. Exposure assessments, however, are extremely difficult to develop, and the emerging field of exposure studies holds promise for creating measures of effectiveness that serve the penultimate purpose of a local air quality authority.

Respondents also indicated a general optimism that local authorities will continue to improve local air quality into the future. Apparent in responses, and not surprising, is that improvements to program effectiveness could be realized with increased resources in the form of funding, staff, and technology. Alternative strategies to increase the impact of local air quality management are to better integrate air quality initiatives with local transportation and/or land use policies, currently a highly underexplored area of research or practice. Better integration can aid in the execution of the authority mission without necessitating additional resources.

Conclusions

Local air quality management has a relatively short and complex history when compared with other natural resources

policies. This study may shed light on reasons for this short period. First, the Clean Air Act is a complex policy containing dozens of specific rules for varying pollutants (eg, hazardous and criteria), which can hamstring local agencies in effectively integrating regulatory avenues. As a result, State agencies often take the lead and aim to provide technical support to local agencies. With states that have a singular (or few) large urban areas (eg, New York City; Chicago, Illinois; Albuquerque, New Mexico; and Portland, Oregon), the spatially explicit management may pose serious challenges because one size fits all policies may not be effective. Other areas that contain dozens of urban areas, though all diverse in terms of land use and levels of pollution generation, can pose other challenges in terms of ensuring adequate support for interpreting and applying federal clean air regulations.

Alternatively, the limited history of local air quality management may also coincide with the recognition about the disproportionate exposure across an urban area, which new technological, monitoring, and field campaigns bring to light. As the severity of air pollution impacts are increasingly known, communities and policymakers are taking a renewed interest, which is emerging in the form of air quality regulation at the state and federal levels. However, a gap exists between state and federal regulations and healthy air quality in many localized areas. As a result, many communities and local officials are seeking alternative ways to manage local air pollution, and one such strategy under investigation is the establishment of a local air quality authority. Our findings of an assessment of the 117 existing local air quality authorities in the United States indicate that there is no one size fits all approaches to local air quality management. Rather, the effective design of a local agency must consider regional geographical, cultural, and political factors. That said, the results of this study provide a backdrop that can be used to improve and enhance local air quality management.

Although our focus was on the mechanisms employed by individual local agencies, we note that our approach did not address several complementary aspects, which both limit its application, and need to be addressed in future research. First is the bias introduced by creating a 2-part sample selection process. After a survey, we selected a subset of those participants as a second part of the survey, using a convenience sampling method. By only engaging with those who agreed to respond, we have unintentionally biased our sample to respondents who may have or see a particular interest in our work, and/or have the time and responses to participate. Future work will need to be more systematic in reaching out to those underrepresented local air quality agencies, perhaps including those who are smaller and/or had regional authority. Doing so will ensure that descriptions of possible structures and governance systems are more inclusive of the diverse ways in which local air quality is (and can be) managed.

Second, the perceptions of effectiveness are from the perspective of those who are managing the programs, which may further bias these results. Since one of the explicit goals of local air quality management is to reduce exposure of harmful air pollutants to human populations, community perspectives would provide a complementary, and, arguably, more accurate description of potential exposure. A community-based perspective of program effectiveness can also provide insights about the extent to which programs are addressing issues of environmental justice. Well recognized in the United States is the disproportionate exposure of communities of color and lower income residents to harmful air pollutants, as first described by Dumping on Dixie,[28] From the Ground Up,[29] and other seminal texts. These descriptions from communities who have local knowledge about and experience with the quality of local pollutants, can complement the administrative perspectives by providing greater nuances in our understanding of management strategies. Indeed, several projects, many sponsored by the US Environmental Protection Agency and the National Institutes for Health are attempting to do just this (see, for example, Air Pollution Monitoring for Community Grants[30] and Using of Community Based Mapping and Monitoring to Reduce Air Pollutant Exposure[31]).

Future work can also better situate the US characteristics within the international context. As mentioned in the introduction, Europe has taken many large strides in developing management system for addressing local air quality. Although much of this work stemmed from the rapid rise of the industrial revolution in places like England, an emerging body of recent work highlights the structures and governance systems that can be illustrative for applying to the US context.[11,13] The European model, both at the EU level and select countries such as those of the United Kingdom, affirm local authority as superior when it comes to air quality control because of the ability of local agencies to draw on local knowledge and resources to appropriately target and address air quality challenges.[10,12] Future research comparing the United States and European local air quality standards, particularly with respect to the role of land use and transportation planning, political histories, and other factors that contribute to the unique characteristics of local air quality authorities (ie, regulation of wood stoves, vehicle retrofit, education, and outreach), would address questions currently unanswered by this study and would help provide additional research directions to advance air quality management.

In addition, complementary assessments could further examine concepts of effectiveness regarding air quality management in the US context. Perceived effectiveness is a challenging concept to define and quantify and future research should aim to better define metrics regarding authority effectiveness. In addition, future research could evaluate the perceived effectiveness of local programs by the general public. To what extent do local communities know about, use, and benefit from these local air quality agencies? Can local air quality agencies reduce the disproportionate exposure to historically marginalized communities? What mechanisms offer the greatest potential for community groups to engage with local air

quality issues? In addition, further assessment could investigate if and how air quality management is considered in other local agencies such as those who perform transportation and land use planning. Future research can address these questions and fill an essential gap of knowledge by examining community perceptions, actions, and understandings of local air quality management. As such, although air quality has historically been administered at State and Federal scales worldwide, local efforts at rescaling environmental policies can help to address the major challenges facing communities.

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Author Contributions

KS was directly responsible for conducting the survey and developing the manuscript. VS provided the conceptual framing, oversight of the survey and manuscript, and contributed to the writing.

Ethical Approval

All procedures performed in studies involving human participants were in accordance with the ethical standards of the institutional and/or national research committee and with the 1964 Helsinki Declaration and its later amendments or comparable ethical standards.

Supplemental Material

Supplemental material for this article is available online.

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