Mapping Blindspots in Urban Atmospheric Pollution Assessment in the U.S.–Mexico Borderland

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ABSTRACT: Populations living in urban environments along the US-Mexico international border face significant environmental health challenges from atmospheric pollution in the next two decades due to the combined and disproportionate impacts of climate change, population growth, and urbanization in the borderland. Yet the region is underserved by atmospheric sensing and environmental regulatory frameworks that could identify emerging threats to urban populations. The investigative research seeks to identify urban neighborhoods in the borderland that are particularly under-represented by current environmental sensing networks, where large populations will face elevated levels of atmospheric pollution by 2050. Locations and common morphological features of these built environments are analyzed in order to suggest more equitable alternatives to the current spatial distribution of environmental sensors. Using Geographic Information Systems (GIS) software to visualize open-source datasets from regulatory agencies, researchers analyzed hundreds of borderland environmental sensor locations. By categorizing and symbolizing the range of atmospheric scales each sensor is designed to address (from smallest to largest: *microscale*; *middle scale*; *neighborhood scale*; *urban scale*; and *regional scale*), the research reveals the varying levels of resolution afforded to different urban populations in the US, and an asymmetric distribution of fine-scale assessment for large population centers in the borderland. Original "heatmaps" illustrate areas and degrees of investment for environmental sensing, providing evidence of low investment in microscale sensors in high-population border cities and relatively high levels of investment border-wide in regional scale sensors, with particular focus on federal land outside of urban areas. The border is thus relatively "dark" to fine-scale and "population oriented" sensors at the micro-, middle-, neighborhood, and urban scales. These unique transnational airsheds—and the populations living within them—will be better served with more equitable spatial distributions of atmospheric sensors.

KEYWORDS: urban geography, transboundary geography, mapping, computation, environmental justice

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1.0 INTRODUCTION

1.1 Urban Environmental Health Challenges in the U.S.–Mexico Border Region

Significant environmental, climatic, and demographic shifts in the United States over the last several decades have produced new stressors on urbanized environments and urban populations nationwide. The southern border region is particularly challenged by significant rates of climate change, population growth, and urbanization, as well as their combined impacts. Climate change continues to reshape the border landscape and atmosphere, as desertification expands areas of arid soil and exacerbates seasonal dust storms in the region. With an increase in domestic migration to southwestern cities, the population of the borderland has grown faster than the U.S. average over the last decade (SBCC, 2021). Steady population growth at the border over the past 80 years, accelerated by industrialization and bilateral trade agreements, has consistently outpaced national averages in both the U.S. and Mexico (PAHO, 2012). While the population living within 100 kilometers of the international boundary was estimated at 15 million people in 2017, that number is expected to double by the year 2025 (DHHS, 2017). The growing population is significantly altering land use and urban development, making the region one of the most rapidly urbanizing regions in the nation. While many cities throughout the region demonstrate evidence of these shifts, their impacts are concentrated in major and growing metropolitan areas. In 2012, around 84% of the border population was urban (PAHO, 2012). In recent years, the border has been home to two of the ten fastest growing metropolitan areas in the U.S.—Laredo and McAllen in South Texas (DHHS, 2017)—while existing border cities in the region—including the El Paso–Ciudad Juárez metroplex—continue to host large urban populations.

1.2 Unique Vulnerabilities of Urban Populations in the Borderland

While these stressors are particularly heightened in the borderland, their impacts on borderland populations will be further amplified due to existing vulnerabilities within the social and economic context, and the infrastructural capacities of the region. From an economic perspective, the rate of poverty in border communities on the whole is higher than national averages, with the disparity the greatest in Texas border communities (SBBC, 2021), including some of the major and quickly urbanizing areas noted above. Many border counties post unemployment figures significantly higher than national averages. Poor environmental health conditions are pervasive in the region. Border cities register levels of environmental air pollution higher than standard. Especially in self-settled areas lacking infrastructural investment in urban peripheries, residents have lower-than-average access to drinking water and sanitary sewers. These economic and environmental conditions correlate with low levels of public health and health access. The population has evidenced lower life expectancy rates than national averages (PAHO, 2012). The percentage of the population without health insurance in U.S. border states has been lower than for the nation as a whole (PAHO, 2012). Over 70 percent of U.S. border counties are classified as medically underserved, while over 60 percent evidence a shortage of health professionals (Moya et. al., 2020). The borderline itself seems to exacerbate these issues. Populations living near U.S. ports of entry have been found to be exposed to greater environmental health hazards than those in other locations in the same city (Eades, 2018).

1.3 Assessing Environmental Injustice in Border Cities

From the issues described above, it is clear that, while the type of environmental health challenges facing cities near the U.S.–Mexico border might be shared with other cities in the U.S. or Mexico, the urgency of addressing these shared challenges is amplified within the border context. Despite this urgency, the border region continues to suffer from “environmental injustice,” or the “disproportionate negative impacts on socially marginalized people” (Grineski & Juárez-Carillo, 2012). There are many shared environmental injustices in the borderland. There are also threats unique to particular environments. The borderland, spanning the continent, is not a homogeneous entity —it is a vast region with a diverse population and varying social, economic, geographic, and environmental conditions. Assessment strategies must be developed conditional on each border city’s particular context.

Many regulatory frameworks exist to monitor and assess environmental conditions at the border, but changing federal, state, and local priorities can problematize consistent, accurate, and timely assessments (Coronado & Mumme, 2020). To alleviate the continued undue environmental and public health burdens on borderland populations, there is a need to investigate several pressing questions: whether adequate resources are dedicated to environmental assessment, whether these systems are capable of meeting the substantial and diverse needs of urban populations in the borderland, and whether the data and analysis provided is adequate in service of these populations.

2.0 BACKGROUND: ENVIRONMENTAL AIR QUALITY ASSESSMENT IN THE BORDERLAND

2.1 Factors Contributing to Poor Environmental Air Quality in the Borderland

One of the most significant and pervasive environmental health issues in the borderland is poor environmental air quality. Arid terrain throughout the borderland, coupled with mountainous geography and the dynamics of airflow conspire to produce atmospheric "inversions," trapping smog and dust and fostering pervasive atmospheric pollution conditions in many border cities. Some of the largest border metroplexes, including El Paso–Ciudad Juárez, are thus described as "air pollution catchment areas" (Heyman, 2017). With continued pollution generated by industrial processes, idling cross-border traffic, dust transfer from nearby desert landscapes, and other anthropogenic impacts, large populations in this and other border city regions will face elevated levels of atmospheric pollution by 2050.

2.2 Geographic Considerations for Locating Atmospheric Sensors

U.S. federal regulations dictate protocols for the selection of sites to deploy ambient air quality sensors for the national air monitoring network (EPA, 2020), noting a need to balance available resources with a desire for appropriate resolution, or *scale of representativeness* obtained from the sensor. Within a given country, the scales of representativeness are, from smallest to largest: *microscale* (with resolution from a few meters up to 100m), *middle scale* (from 100m to 0.5km resolution), *neighborhood scale* (from 0.5km to 4.0km resolution), *urban scale* (from 4.0 to 50km resolution), and *regional scale* (up to hundreds of km resolution) (CFR, 2021).

Environmental agencies will deploy a given scale of sensor on a given site, depending on many interrelated factors, including: which pollutants they intend to monitor; what scale of transport they are studying; whether they believe the site to be a source of the contaminant; as well as the location upwind, downwind, or on-site of human populations likely to be affected by aerial contaminants. The selection of a sensor at a given scale assumes that the level of a given airborne pollutant within an "air parcel" at that scale is "reasonably homogeneous" (CFR, 2021). Each sensor network tasked to monitor a given phenomenon can thus be evaluated periodically. Anomalous readings within the network are meant to signal a need for additional sensors or increased resolution to locate particular threats, while consistent readings over large areas might signal a redundancy of sensors amidst relatively stable situations, resulting in shuttered stations and lower-resolution output.

2.3 Shortfalls of Atmospheric Monitoring in Vulnerable Urban Neighborhoods

Many urban neighborhoods within the borderland are underserved by existing sensor networks. The limited number of high-quality and high-cost sensors deployed in a metropolitan region, and the limited tasking of national sensors for regional-scale readings often results in the sensors placed far from vulnerable neighborhoods, which may be seen as outliers for statistical averages (Kripa & Mueller, in-press). Sensors that are part of regulatory assessments in general have suffered from *inconsistent maintenance*, thereby negatively impacting the continuity of operations and reliability of steady streams of sensor data. The relatively large *spatial resolution* of most existing sensors may elide distinctions between neighboring urban environments, flattening out the differences in air quality that are otherwise perceptible street by street, or block by block. The *temporal resolution* of available sensor data, often collected and reported every hour or half-hour, may not be capable of detecting and recording significant pollution events or dust events that can enter and leave an airshed more quickly. Lower-cost devices that are affordable for smaller spatial and temporal scales are often of lower quality and may not provide verifiable results vulnerable communities would need to advocate for improved conditions. While these sensors may help a growing number of communities to detect conditions that significantly endanger the health of their residents, data from these low-cost sensors are not accepted as adequate evidence by regulatory agencies empowered to mandate improvements to environmental health (Mueller & Kripa, in-press). Verifiable data produced by existing sensor networks is not always readily available or easily accessible except to experts or owners of proprietary systems.

2.4 Common Morphological Features of Urban Neighborhoods with Poor Atmospheric Air Quality

While border cities are themselves more susceptible to deleterious effects of poor environmental air quality based on their geographic conditions, certain neighborhoods within those cities are even more at risk. Nuances in the local geography, the physical characteristics of the built environment, and microclimatological effects can impact the amount of airborne pollution suspended within the neighborhood, and increase the length of time the population may be exposed. Features influencing the amount of suspended particulate include the condition of buidings and roads. Unpaved roads, for instance, are a large contributor to suspended fine particles, while congested roads contribute to truck exhaust and brake dust. Features impacting exposure time include the position of the neighborhood relative to geographic features like mountains and valleys that may create static airflow conditions, and the density and orientation of the buildings relative to prevailing winds.

3.0 OBJECTIVES

3.1 Identify blindspots in existing atmospheric sensor networks

To begin, the research set out to identify "blindspots" within the current atmospheric sensor network—areas including city regions and metropolitan areas that are under-represented by the current sensor deployment. From this assessment the research seeks to gauge whether individual border cities are adequately served, whether the territory of the borderland is adequately served, and if there are any assessment disparities amongst border cities, or between border cities and other cities outside the borderland. This article will focus mostly on this stage of the research.

3.1 Identify urban neighborhoods in borderland under-represented by atmospheric sensors

The research suggests, as a long-term goal, mapping methods to identify urban neighborhoods in the borderland that are particularly vulnerable to persistent poor environmental air quality yet under-represented by the current deployment of atmospheric sensors.

3.2 Suggest criteria that would support more equitable distribution of sensors

The research suggests, as a second long-term goal, to establish criteria to support the more equitable distribution of sensors, thereby reducing or eliminating the disparities in the amount, quality, and access to data available to previously underserved urban neighborhoods.

4.0 4.0 METHODS

4.1 Geographic Information Systems (GIS)

The author(s) began by compiling locational data and associated data for currently-fielded air quality monitoring stations nationwide. The data was downloaded from publicly available GIS service layers published by the Environmental Protection Agency (EPA, 2020).

4.2 Representing Scale of Sensing

The author(s) then set out to develop mapping techniques to translate the locational data and the range each sensor was capable of sensing. A series of iterative maps was developed as test cases to highlight and document the multiple scales of environmental air quality assessment, developing representational techniques to translate the numeric information (including range and density of sensors) with geographic and jurisdictional features (Figure 1). Using the border sister cities of San Diego–Tijuana as a graphic reference, a series of visualizations were made at increasingly finer scale. Each visualization shows the location of sensors operating at a given scale within the given range. The maximum range of each sensor type is captured in the scale and centering of each of the maps, with the circular extent of the map corresponding to the maximum range. The maps then use the point features of each sensor location to extrapolate the coverage of each station. Using the standard range for the sensor type as an input, a "heat map" layer is added to each collection of sensor points, indicating the anticipated, combined coverage of the collection of sensors.

4.3 Active Sensor Location Mapping

Expanding these strategies to maps at the national scale, a series of nationwide heatmaps of active sensor locations as produced (Figure 2) showing concentrations of different sensor types including: a) regional, b.) urban, c.) neighborhood, d.) middle and e.) micro scale. Dark areas in these maps indicate blindspots in environmental monitoring at each scale.

4.4 Composite Sensor Location Mapping

The individual maps were then composited by weighting the value of individual layer proportionally to the scale of sensing, and superimposing the multiple layers in a single map. Dark areas in this composite map indicate blindspots in overall environmental monitoring nationwide.

5.0 RESULTS

5.1 Visualizing Uneven Investment

From the individual maps of active sensor locations at each scale, we note a relatively low level of investment in microscale sensors nationwide, and a relatively high level of investment in regional scale sensors. With the large investment in sensors that cover a larger area, and the range of the sensors, nationwide coverage at the regional scale is more even than nationwide coverage of other scales, which are more unequally distributed and centered mainly around large metropolitan areas. Outside of urban areas, coverage is apparently most intense on or near federal lands.

5.2 Significant Monitoring Deficits for Populated Areas Along the US–Mexico Border

While sensor distribution is most dense in the urbanized areas of the borderland, the borderland is relatively underserved at most scales of sensing and overall. The land border between the U.S. and Mexico stands in stark contrast to other national borders in the map. There are more deployments of regional scale sensors in coastal areas, especially in large U.S. cities and city regions near large Canadian cities, suggesting investment priorities are focused on assessing and managing transborder flows in those regions more so than their U.S.-Mexico counterparts.
The southern border does appear to be additionally served by regional sensors protecting national parks.

But borderland populations are not as well-served. Border cities are host to fewer sensors than other metropolitan areas in the nation.The border is relatively "dark" to fine-scale and "population oriented" sensors at the micro-, middle-, neighborhood, and urban scales, leaving significant borderland cities and their populations underserved. Even at the higher resolution of state-managed and regionally-managed sensing networks, the U.S.–Mexico border, and the El Paso–Ciudad Juárez border region in particular, is subject to several blindspots.

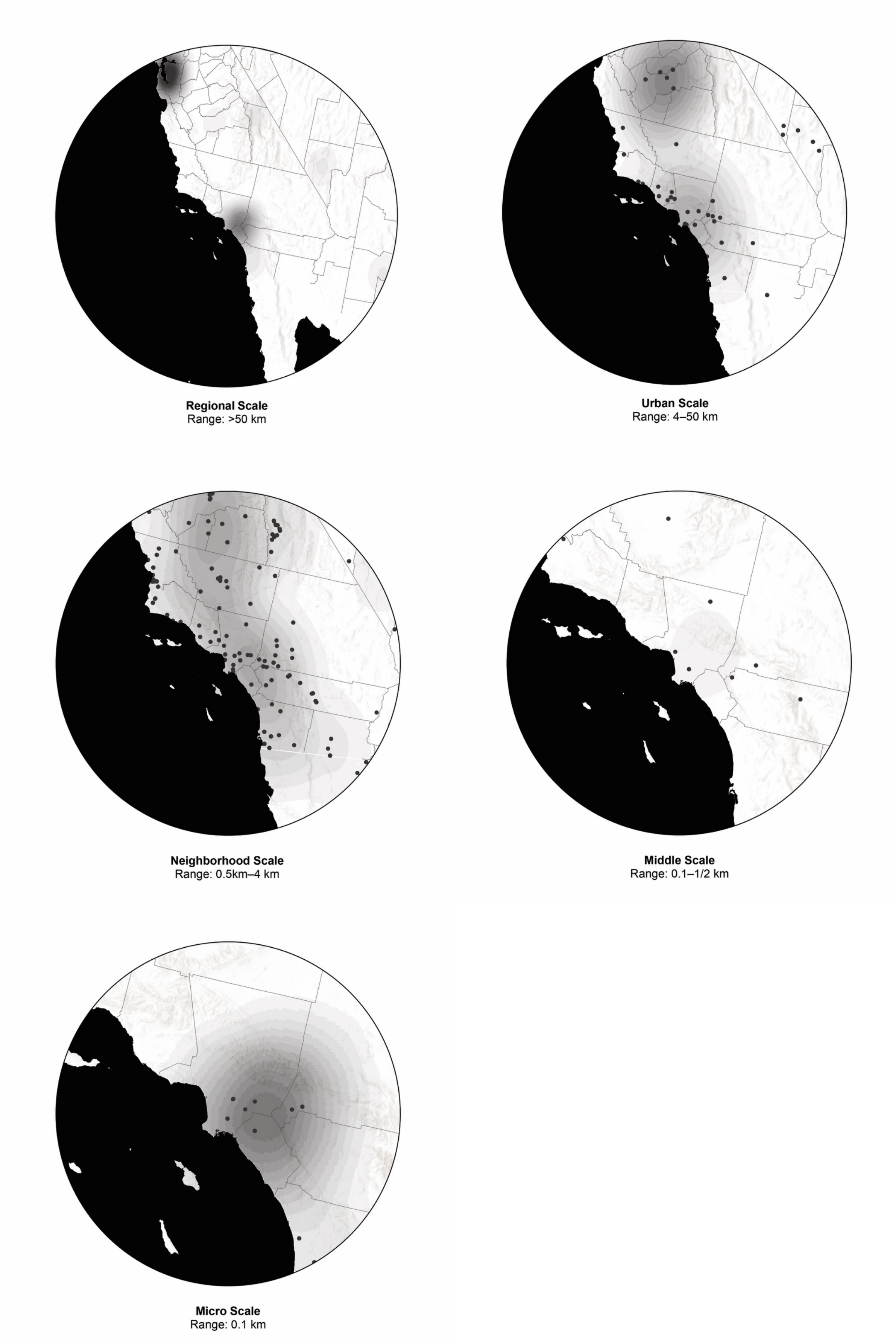

Figure 1: **Atmospheric Sensing: Scales and Subjects**. Federal protocols correlate the sensor type with the people and places it is meant to cover. Population-oriented studies produce large urban- or regional-scale assessments, while source impact and concentration studies produce finer-grain sensor networks.
Data Source: https://gispub.epa.gov/arcgis/rest/services/OAR_OAQPS/AQSmonitor_sites/MapServer
(Map by POST–Project for Operative Spatial Technologies, 2021)

a.) Regional Scale Sensor Distribution

b.) Urban Scale Sensor Distribution

c.) Neighborhood Scale Sensor Distribution

d.) Middle Scale Sensor Distribution

a.) Micro Scale Sensor Distribution

Figure 2: **Atmospheric Sensing Heatmaps by Sensor Type**. Heatmaps showing concentrations of different sensor types including active sensor locations including: a) regional, b.) urban, c.) neighborhood, d.) middle and e.) micro scale. Dark areas indicate blindspots in environmental monitoring at each scale.
Data Source: https://gispub.epa.gov/arcgis/rest/services/OAR_OAQPS/AQSmonitor_sites/MapServer (Map by POST–Project for Operative Spatial Technologies, 2021)

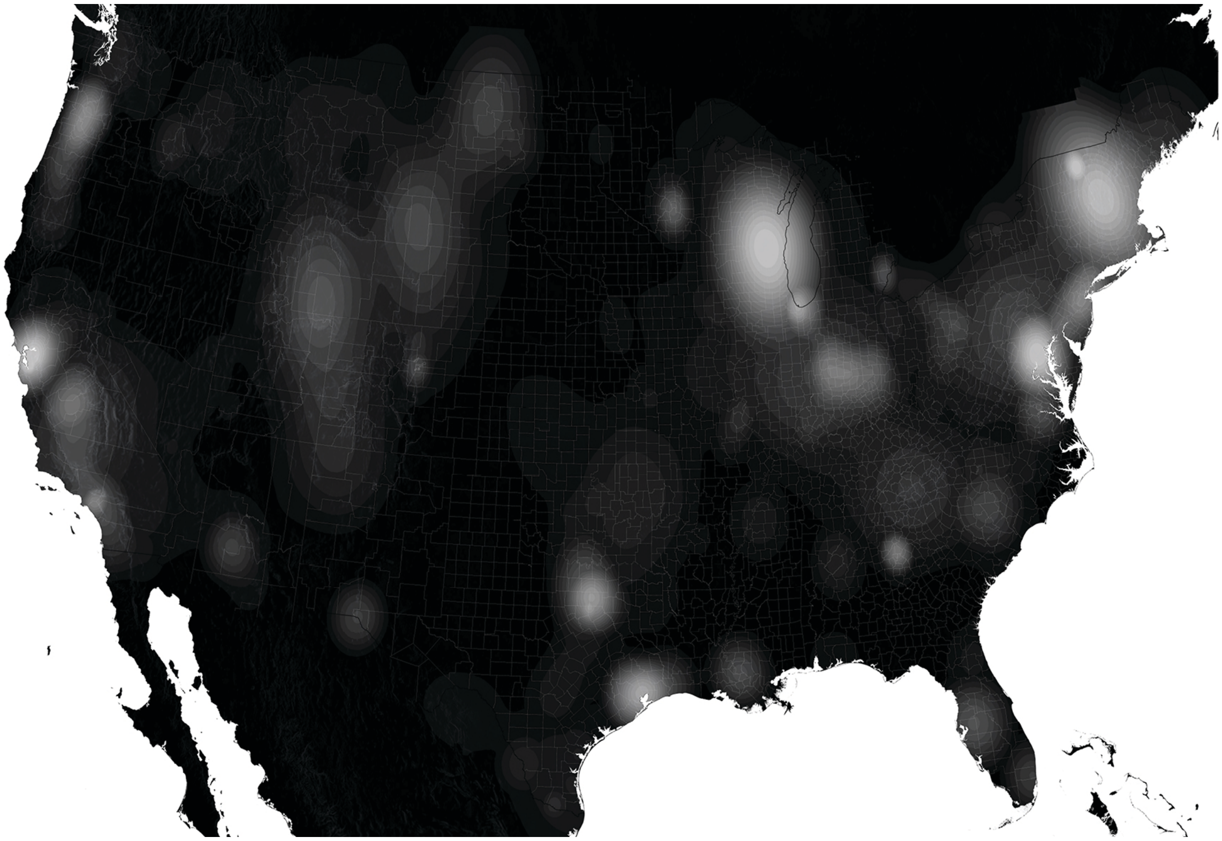

Figure 3: Atmospheric Sensing Heatmap Composite. Composite heatmap showing concentrations of active sensor locations including sensors of all five types. Dark areas suggest blindspots in environmental monitoring.
Data Source: https://gispub.epa.gov/arcgis/rest/services/OAR_OAQPS/AQSmonitor_sites/MapServer
(Map by POST–Project for Operative Spatial Technologies, 2021)

6.0 DISCUSSION

6.1 Indexing Population

Further study correlating the sensor types and locations with the locations and populations of cities in general, and border cities in particular, would prove useful. An index of "sensors per capita" in areas falling under the coverage map of each sensor type would provide insight into the level of assessment each urban area receives.

6.2 Indexing Investment

Further study investigating the investment in new sensors, and disinvestment evidenced by the consolidation or the disactivation of existing sensors would provide insight into the shifting priorities and trends in the provision of environmental air quality monitoring. Additional research in the funding streams and appropriations at federal, state, and local level would also prove instructive in identifying areas that continue to be risk.

6.3 Neighborhood Investigations

While the completed mapping provides an overall assessment and characterization of sensor coverage in the borderland, its quantitative methods can be further refined and its study area narrowed for applications at a smaller scale in the border cities and neighborhoods themselves. Continued investigation will further develop and refine the tools, visualizations, and methods, to identify underserved neighborhoods and communities with urgent needs for improved sensing.

6.3 Binational Collaboration

Currently there are few sensing networks collaborating across the international divide. Collaborative border regions are few and far between, with only five transborder air quality monitoring areas border-wide established in the past decade (see Eades, 2018). Instead, border air quality monitoring is enacted through a collection of state agencies operating mostly independently within their respective boundaries.[1] The most recent binational initiatives include the maintenance of "air-monitoring networks with real-time access to air quality data in all binational airsheds" as a top priority (Eades, 2018), but sustained binational efforts thus far have been few, and binational participation is low.[2] Previous work by the author(s) has resulted in the installation of temporary low-cost monitoring across the international divide, and more work can be done to make this or similar initiatives more permanent.

CONCLUSION

Need for Improved Representation

In light of the current deficiencies in air quality monitoring evidenced by the maps, the demand for an extensive, actionable accounting of air quality in border regions is greater than ever. As some of the most highly polluted environments overlooked by environmental air quality sensors, transnational airsheds—and populations affected by them—demand new forms of representation.

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ENDNOTES

[1] Combination of TCEQ, NM Environment Department, Arizona Department of Environmental Quality, The California Air Resources Board, the Imperial County Air Pollution Control District, and the San Diego County Air Pollution Control District. (see Eades, 2018)

[2] In a comprehensive EPA report on binational air quality, only five stations (San Diego, Imperial Valley, Nogales, Ciudad Juarez/El Paso, Lower Rio Grande Valley) contributed data. Only the Ciudad Juarez/El Paso system included sensors on the MX side, due to "quality assurance issues" with Mexican monitoring systems and the "complexity of maintaining a binational network." (See EPA, 2011)