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REUSE ARTICLE

TOPICAL COLLECTION ON POTABLE REUSE

Mapping potable reuse survey data using spatial statistics to inform tailored education and outreach

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Abstract

This research describes geospatial analyses of water-related knowledge and opinion data on potable water reuse collected through a large-scale public survey of water utility customers in Albuquerque, New Mexico. We identify key geographic areas, or statistically significant "hotspots," of public distrust in the local water utility provider, public willingness (or lack thereof) to accept potable water reuse, and lack of knowledge or misconceptions about water-related issues and climate change. By combining public survey data, geographic information system software, and spatial statistics for hotspot analyses, we introduce a tailored outreach method to identify geographic locations for targeted outreach and education on water-related issues. This new approach to analyzing survey data is a promising dimension of water management, and the method could be important for tackling other resource management issues in additional cities or regions as well.

KEYWORDS

community attitudes, education and outreach, GIS, hotspot analysis, public survey, water recycling

1 | INTRODUCTION

1.1 | Background

Communities in the southwestern United States are already experiencing the impacts of climate change. In the coming years, increased variability in annual precipitation is expected to lead to less reliable drinking water supplies, among other potential impacts such as increased threat of wildfire, loss of habitat for various species, and decreased agricultural productivity (An, Gan, & Cho, 2015; Brookshire, Gupta, & Matthews, 2013; Kumar, 2016). A critical planning challenge will be ensuring sustainable and reliable water supplies for municipalities, agriculture, and industry.

To meet this challenge, communities can work to reduce water demand through conservation programs or attempt to find "new," currently unexploited water sources (Grant et al., 2012; Hurlimann, Dolnicar, & Meyer, 2009). Reducing water use through conservation is often a cost-effective first step that communities in water-scarce regions can take. For example, Albuquerque, New Mexico, reduced its water usage by almost half over the course of 15 years through incentive-based voluntary programs (Scruggs & Thomson, 2017). Regarding new water sources, many options—such as interbasin water transfers, seawater or brackish groundwater desalination, and rainwater capture—are limited by sustainability or reliability issues (Scruggs & Thomson, 2017). An option with fewer limitations is potable water reuse, which involves augmenting traditional water supplies with highly purified wastewater. Two main types of potable reuse exist. The first is indirect potable reuse (IPR), which directs highly purified wastewater to an environmental buffer (e.g., an aquifer or reservoir) where it is held for a specified amount of time before being withdrawn, treated at the drinking water treatment plant, and distributed to the community. The second is direct potable reuse (DPR), which directs the highly purified wastewater either straight to the distribution system or blends it with traditional water sources for treatment at the drinking water treatment plant prior to distribution for use (Leverenz, Tchobanoglous, & Asano, 2011; Tchobanoglous, Leverenz, Nellor, & Crook, 2011).

Technologies exist to safely implement IPR and DPR (Tchobanoglous et al., 2011; Van Rensburg, 2016). IPR has been implemented by numerous communities across the US and around the world over the past several decades, and DPR facilities exist in Windhoek, Namibia, and several communities in Texas (Scruggs & Thomson, 2017; Tchobanoglous et al., 2011; Van Rensburg, 2016). However, potable reuse may not be the best fit for every community (Scruggs et al., 2020; Scruggs & Thomson, 2017), and public opposition has resulted in tabling or cancelling several recent projects (Hurlimann & Dolnicar, 2010; Tennyson, Millan, & Metz, 2015). Based on focus group and survey data, researchers have suggested that the reasons for opposition are related to numerous factors, such as the history of the water to be reused and a natural aversion to drinking water that was once in the sewer; lack of trust in the entities promoting the reuse project and/or the technologies used to purify the reuse water; lack of transparency by the entities promoting the reuse project; insufficient public dialogue and input; lack of education on fundamental water cycle, water resources, and water reuse concepts; the timing of the proposed reuse project with local drought; attitudes toward the environment; and the cost of the water reuse project (Dolnicar, Hurlimann, & Grün, 2011; Ingram, Young, Millan, Chang, & Tabucchi, 2006; Macpherson & Snyder, 2013; Ormerod & Scott, 2012; Po, Nancarrow, & Kaercher, 2003; Stenekes, Colebatch, Waite, & Ashbolt, 2006; Tennyson et al., 2015). Some studies have included an investigation into demographic features of those who are opposed to (or accepting of) water reuse presumably with the idea that these groups could be targeted for (or excluded from) needed education about water reuse (Dolnicar et al., 2011; Garcia-Cuerva, Berglund, & Binder, 2016; Ishii, Boyer, Cornwell, & Via, 2015; Millan, Tennyson, & Snyder, 2015; Miller & Buys, 2008; Po et al., 2005). While information about the reasons for opposition and the demographic groups that oppose potable reuse may be generally useful, also needed is a method to identify *where* misperceptions, information deficits, and lack of trust related to water resources and water reuse exist within a community. With locational information, water planners could tailor their education, outreach, and trust-building programs to the segments of the population that need particular kinds of information or outreach to allow residents to make informed decisions about water resources and reuse. Such an approach would enable targeted public engagement and input on future water resource options, rather than trying to force-fit predetermined solutions to a given community (Stenekes et al., 2006). After all, members of the public are the ultimate consumers of the resource (US Environmental Protection Agency, 2017).

1.2 | Expanding previous work with the use of mapping tools

The Albuquerque Bernalillo County Water Utility Authority (ABCWUA) is the sole provider of water to over 600,000 Albuquerque and Bernalillo County residents in New Mexico, United States, and it has included IPR and DPR as possible elements of the future water source portfolio to meet projected demands (Albuquerque Bernalillo County Water Utility Authority, 2016; see Figure 1). In 2017, authors of the present study collaborated with the ABCWUA in conducting a survey of ABCWUA residential account holders to fill knowledge gaps regarding perceptions of potable reuse and understanding of water resource-related issues in an arid inland community (Distler & Scruggs, 2020a; Distler, Scruggs, & Rumsey, 2020). While residential account holders are not perfectly representative of our population of interest (Albuquerque water users) because they are likely homeowners (i.e., renters might be excluded), previous University of New Mexico research

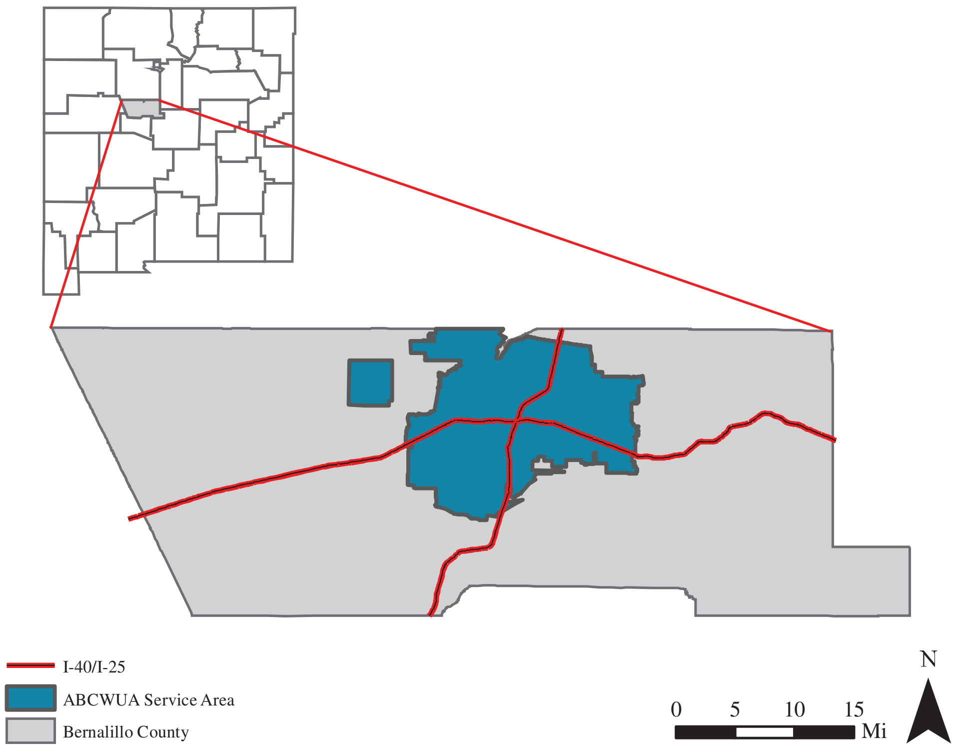

FIGURE 1 The Albuquerque Bernalillo County Water Utility Authority (ABCWUA) service area (highlighted in blue) falls within Bernalillo County and is located in the central portion of the state of New Mexico

on the same population of interest found this approach to result in the most representative sample (Distler & Scruggs, 2020a). The survey was designed with extensive community input using eight focus groups and 12 debriefing sessions that were conducted throughout Albuquerque over 4 months in 2016. Following Dillman, Smyth, and Christian (2014), the final survey was sent by mail to a random sample of 4,000 ABCWUA account holders using a system of five contacts that were distributed over a period of 9 weeks in the spring of 2017. Recipients had the option of either completing and returning the survey packet by mail or doing it online. The survey closed to responses in late summer of 2017 and the response rate was 46% (n = 1,831). Of note, the survey design and administration processes were conducted in English only, possibly limiting accessibility of the survey to the area's non-English-speaking residents. Also, self-selection bias, where only those who had a preexisting interest in local water-related issues chose to participate, could have been an issue for both the focus groups and the survey. Additional limitations specific to the survey research and detailed methods for survey design, administration, and data analysis are further elaborated by Distler and Scruggs (2020a) and Distler et al. (2020).

The previous research with this data set used ordered logistic regression models to demonstrate that demographic data can be used to predict the probability of respondents' willingness to accept potable reuse. Next, chi-square tests of independence were employed to further examine the relationships between the less-accepting demographic groups and their levels of trust in institutions, prior awareness of potable reuse, and knowledge of water scarcity in the region. The previous work proposed that water utilities and planners could use such an approach to initiate inclusive public dialogue and design of education and outreach programming that is specific to the needs and concerns of the community (Distler et al., 2020; Distler & Scruggs, 2020a). While this approach has some value, it is not user-friendly because utilities and planners must determine how to locate and/or access the demographic groups with information needs and where relationship building should occur. The present study adds a valuable final step to the previously proposed approach by using geographic information systems (GIS) to map the locations where knowledge gaps, misperceptions, unwillingness to accept potable reuse, and lack of trust exist in the community.

GIS has evolved from a limited set of tools to a distinct field of study, with applications in numerous areas from design and planning (Drummond & French, 2008) to science-based policing (Fitterer, Nelson, & Nathoo, 2015; Herchenrader & Myhill-Jones, 2015) to public health education and research (Grubesic, Miller, & Murray, 2014; MacQuillan, Curtis, Baker, Paul, & Back, 2017). The ability of modern GIS software to process large amounts of data in short time frames has allowed for broad and novel applications of traditional analysis techniques. In the context of the present study, the addition of mapping allows for a tailored approach to more easily identify geographic locations for targeted outreach and education on specific water-related issues. While the approach is demonstrated in the context of water resources and reuse in Albuquerque, New Mexico, it could be used for any resource-related topic in any community.

1.3 | Objectives of this research

A knowledge gap exists regarding how survey data can be used more effectively for a tailored outreach approach to water resources planning in water-scare regions. Previous research has investigated how demographics are related to acceptance of potable water reuse, but it has not addressed how to connect with people in certain demographic groups who lack information or knowledge about water resources or trust in water-related entities. This research tests whether a geospatial analysis of survey data can identify patterns in public opinion and misconceptions and tie them to geographic regions in the City of Albuquerque and Bernalillo County. Using this approach, the aim is to provide recommendations to entities interested in developing targeted public education and outreach programs and provide a framework for utilities to begin building trust and knowledge within their communities. To be clear, the approach described here is not stand-alone, but rather would supplement and be informed by prior quantitative and qualitative findings that were produced from surveys and focus groups with the study population. This new approach to analyzing survey data is a promising dimension of water management, and the method could be important for tackling other resource management issues in additional cities or regions as well.

2 | METHODS

The authors used a combination of conventional cartographic techniques and spatial statistics to illustrate the results of different methods that could be used to graphically display survey results. The first method involved simple choropleth mapping of survey responses in particular categories to certain questions in each geographical unit of analysis, while accounting for the total number of responses to those questions in each unit (geographical units of analysis are discussed in Section 2.3). This form of mapping allows for easy visualization of responses and response patterns across mapped questions. The second method involved a spatial statistic known as the local Getis-Ord Gi*, which is discussed in the next section.

2.1 | Local Getis-Ord Gi*

The local Getis-Ord Gi* is essentially a z-score that is calculated based on the values of both the selected geographical unit of analysis and the units around it. In the present study, the "value" for each geographical unit of analysis is the number of responses in a particular category to a certain question divided by the total number of responses in all categories to that question. This analysis technique produces graphical output displaying statistically significant hotspots, that is, areas with a high frequency or count of some variable surrounded by other areas that also have a high count. The same analysis technique is also used to display statistically significant cold spots, that is, areas with a low count surrounded by other areas that also have a low count (Allen, 2016; Mitchel, 2005).

The Getis-Ord Gi* has traditionally been used within set geographic areas to analyze frequencies or counts, such as occurrences of crime, 911 calls, or motor vehicle accidents, and to track and identify trends or threats to public safety (Fitterer et al., 2015; Gudes, Varhol, Sun, & Meuleners, 2017; Herchenrader & Myhill-Jones, 2015). In the present study, the authors used the Getis-Ord Gi* to analyze specific types of survey responses and the frequency of their occurrence to better understand if certain locations (neighborhoods or ABCWUA distribution zones) within the study area had lower levels of water knowledge, awareness of scarcity, acceptance of potable reuse, or trust in the local water utility.

2.2 | Survey questions for inclusion in analysis

We identified seven questions from the 2017 ABCWUA customer survey described in Section 1.2 (Distler & Scruggs, 2020a) for analysis of geospatial patterns. The seven questions were selected as the focus of this study because they: (a) provided data on public opinions, attitudes, and/or misconceptions related to water reuse and scarcity, local water resources, or trust in the local water utility and elected officials, and (b) represented issues that have the potential to be well addressed through targeted public education, outreach, and dialogue. However, any of the survey questions could have been included. The full survey instrument is available in the open access peer-reviewed publications associated with this research (Distler & Scruggs, 2020a, 2020b). The seven survey questions and associated response categories included for analysis in this study are shown in Table 1.

TABLE 1 Survey questions included in the current study

Topic	Actual survey question	Response categories	Survey question number
Water scarcity	In your opinion, do you think water is a limited resource in Albuquerque?	Yes, No, or I don't know	2
Water sources	From what source or sources does the Albuquerque Bernalillo County Water Utility Authority (ABCWUA) get the water it serves to customers?	River, Groundwater aquifer (e.g., well water), I don't know, and Other (multiple selections allowed)	3
Climate change	Do you believe that the impact of climate change on the water cycle will make it more difficult for the ABCWUA to meet our community's water supply needs in the next 10 to 40 years?	Yes, No, or I don't know	4
Bottled water	Do you believe that bottled water is safer (higher quality) than Albuquerque tap water?	Yes, No, or I don't know	5
Acceptance of direct potable reuse (DPR)	(This question refers to the DPR water reuse scenario.) How willing would you be to drink the city tap water [i.e., DPR water] in Community A?	Refuse to drink, Prefer to avoid, Neutral, Generally OK, or Very willing to drink	10
Acceptance of indirect potable reuse (IPR)	(This question refers to the IPR water reuse scenario.) How willing would you be to drink the city tap water [i.e., IPR water] in Community B?	Refuse to drink, Prefer to avoid, Neutral, Generally OK, or Very willing to drink	13
Trust in local entities	(This question asked about several entities, but we limited our focus here to the ABCWUA and elected local officials.) Please indicate how much you would trust each of the following entities to provide you with accurate information on water reuse and the safety of drinking water reuse.	Mostly distrust, Somewhat distrust, Neutral, Somewhat trust, or Mostly trust	17

2.3 | Preparing the data for GIS analysis

In preparation for GIS analysis, the individual survey responses ($n = 1{,}831$), along with the associated customer addresses, were geocoded using ESRI/ArcMap worldwide geocoding service and transformed into individual point data. Following the geocoding process, a small graphical offset was applied to the customer address data to maintain survey respondent anonymity. The distribution of survey respondents is shown in Figure 2.

After the survey responses were in a format compatible with ESRI's ArcMap 10.8, specific response options to the survey questions introduced above were queried. Response options that represented key misconceptions and issues in the reuse literature were chosen. For example, consider a hotspot analysis on customer perception of water scarcity using survey question 2: “In your opinion, do you think water is a limited resource in Albuquerque?” which had the response choices of “Yes,” “No,” and “I don't know.” Water is a limited resource in Albuquerque, and the following definition query (i.e., rule-based selection) was used to select only the points that represented respondents who chose “No” or “I do not know”:

`"SCARCITY_3" = 'N' OR "SCARCITY_3" = "DK,"` where `"SCARCITY_3"` refers to the attribute field (i.e., a variable with different response options) that contains the individual answers to survey question 2, and `"N"` and `"DK"` are coded responses for “No” and “I don't know.”

After the selection of queried survey responses, an average nearest neighbor (ANN) analysis was performed on the new collection of point data (i.e., the selected survey responses for each question in the analysis) to determine if the data were “dispersed,” “clustered,” or “random.” ANN makes use of the observed distance, $\bar{D}_O$, between an individual point feature and its nearest neighboring feature, the Expected Distance, $\bar{D}_E$, to create

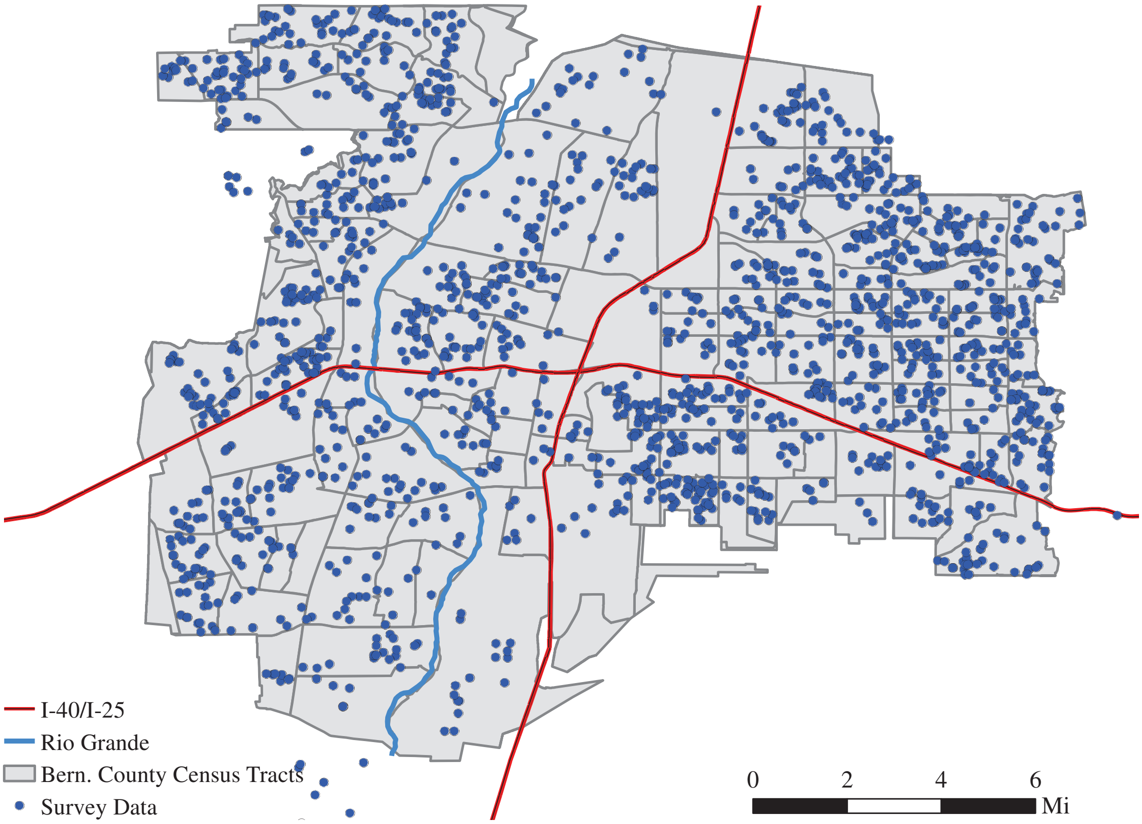

FIGURE 2 Distribution of survey respondents (with graphical offset) to show spread and coverage of survey responses within the Albuquerque Bernalillo County Water Utility Authority (ABCWUA) service area

a nearest-neighbor ratio or index. Starting with the null hypothesis, H_0, that point dispersion is random, ANN uses the $\bar{D}_O$ and $\bar{D}_E$ and a user-defined area (in our case, the area in m^2 of the ABCWUA service area) to calculate the standard error (SE). From here, an ANN ratio can be generated to determine the statistical significance of the clustering, dispersion, or random nature of any point data (Allen, 2016; Mitchel, 2005). The full mathematical breakdown of the ANN analysis can be found in the supplementary materials, Appendix A. Using ArcMap 10.8, a complete ANN analysis was performed for the point data in preparation for hotspot analysis. The results of this analysis, including graphical output detailing the ANN, z-score, *p*-value, as well as a determination of whether the data is "clustered," "random," or "dispersed," is included in the supplementary materials, Appendix B.

To conduct these analyses, a suitable scale must be selected that has both (a) sufficient data within each geographic unit (i.e., the units should not be too small), and (b) meaning on an actionable scale to allow for effective outreach or educational programming (i.e., the units should not be too large). In determining a reasonable geographical unit for hotspot analysis, the GIS literature suggests that the decision on whether to use zip codes, census tracts, or creation of a raster fishnet would be an arbitrary one, with varying tradeoffs (Allen, 2016; Wang & Varady, 2005). In balancing the considerations of sufficient data and actionable scale, the authors decided to conduct analyses at the census tract level. The use of census tracts allows for the potential added benefit of being able to compare survey data to demographic data collected by the census or American Community Survey. Therefore, a new shapefile was created by "clipping" the Bernalillo County census tract layer to contain only the tracts falling within the ABCWUA service area, as shown in Figure 2.

Before the statistical analysis, it was required to spatially join the survey responses to the ABCWUA census tracts and create a new field within the attribute table of this shapefile containing the total number of survey responses within each individual census tract. Next, a shapefile for each survey question was created containing the count of the queried survey responses by census tract. The final step before analysis was to create an additional field in the attribute table of the shapefiles for each question that contained the number of queried survey responses divided by the total number of survey responses for each census tract. This new field, which the authors called the "response ratio," was used as the count input for the Getis-Ord Gi* hotspot analysis. The final census tract shapefile containing the response ratio was then used as the Input Feature, or layer source, for the hotspot analysis.

An assumption of the analysis is the null hypothesis, which states that there is no spatial-autocorrelation (i.e., clustering) between points, or, in other words, there is no pattern to how the responses will be distributed across the city. The Getis-Ord Gi* hotspot analysis produces graphical output displaying hotspots, cold spots, and areas of no significance as well as calculating a z-score and *p*-value for each polygon in the analysis (Allen, 2016; Getis & Keith Ord, 1992; Mitchel, 2005; Ord & Getis, 1995). Results are then displayed as hotspots and cold spots. Hotpots are comprised of areas with positive z-scores and ordered by corresponding significance levels based on *p*-value, while cold spots are those areas with negative z-scores ordered by significance level. In short, the analysis indicates how common a particular survey response option is within each census tract and how these responses cluster; it does not account for the location and frequency of the other possible survey response options for that question. For example, a hotspot for "Distrust" indicates a high level of responses selecting "Distrust" as an option in that census tract, as well as those census tracts surrounding it, compared with the dispersion of "Distrust" data on the entire map. For clarity, the cold spots are not discussed in this study, as the research is focused primarily on the hotspots, or areas with statistically significant response ratios. A full mathematical explanation of the Getis-Ord Gi* equation can be found in the supplementary materials, Appendix C.

2.4 | Geographic features and distribution zones used in analysis

Three geographic features within the ABCWUA service area were used to facilitate analysis and interpretation of the results: the Rio Grande, the river that flows north to south; Interstate 25 (I-25), which runs north and south; and Interstate 40 (I-40), which runs east and west. I-25 and I-40 approximate the dividing lines for the city of Albuquerque's four intercardinal quadrants: NE, SE, SW, and NW. Smaller areas of note within the quadrants are the ABCWUA distribution zones, which divide the ABCWUA service area into 20 zones. The distribution zones are used to distribute a blend of treated surface water and disinfected groundwater across the service area. The proportions of surface water and groundwater distributed to each zone vary, as do the characteristics of each source. Thus, the water delivered to the various distribution zones varies in quality; for example, concentration of water contaminants such as arsenic can be higher in some distribution zones than in others. The ABCWUA monitors and produces publicly available water quality reports for each distribution zone, and has done past outreach based on distribution zone. In Albuquerque's case, using the distribution zones to facilitate discussion of the findings accounts for the fact that customers within each zone can experience unique problems or concerns, and it would allow ABCWUA to conduct outreach that addresses the specific concerns of the customers in a zone. Other utilities might have different issues and concerns and will want to use geographic boundaries that best address their situation and needs. The distribution zones, which are shown in Figure 3, are used in addition to the city quadrants to discuss the results of the graphical analyses presented in Section 3. All distribution zones are referred to by number except distribution zone 99, which is also known as the northwest service area.

2.5 | Method limitations

The authors acknowledge several limitations associated with the methods of this study. As mentioned in Section 2.3, a different geographical unit of analysis besides census tracts could have been used in this study, with implications for the visualization and relevance of the results. As discussed in the literature and ESRI's guidance for hotspot analysis, the selection of a boundary unit is arbitrary (Allen, 2016; ESRI, n.d.; Wang & Varady, 2005). The authors' decision to use census tracts as the input features was done to meet the requirement for a minimum number of input features for the hotspot analysis results to be reliable (ESRI, n.d.). The use of census tracts also left open the possibility of using the demographic data collected for census tracts, which could provide valuable insights for developing a successful engagement, education, and outreach strategy. The use of this hotspot analysis approach may prove challenging for small or rural utilities when determining the proper geographic boundaries if the required number of input features cannot be met.

Lastly, the method described in this paper analyzes certain responses to each identified survey question separately. For this reason, the number of responses, *n*, analyzed for each question is different. When prioritizing education and outreach needs, a utility could start with the topics that had a higher number of responses indicating lack of knowledge or misconceptions, perhaps devoting a greater amount of resources or time to those topics. Our approach of analyzing survey questions individually may not capture interactions between related topics or misconceptions. However, many of those interactions were explored in the statistical

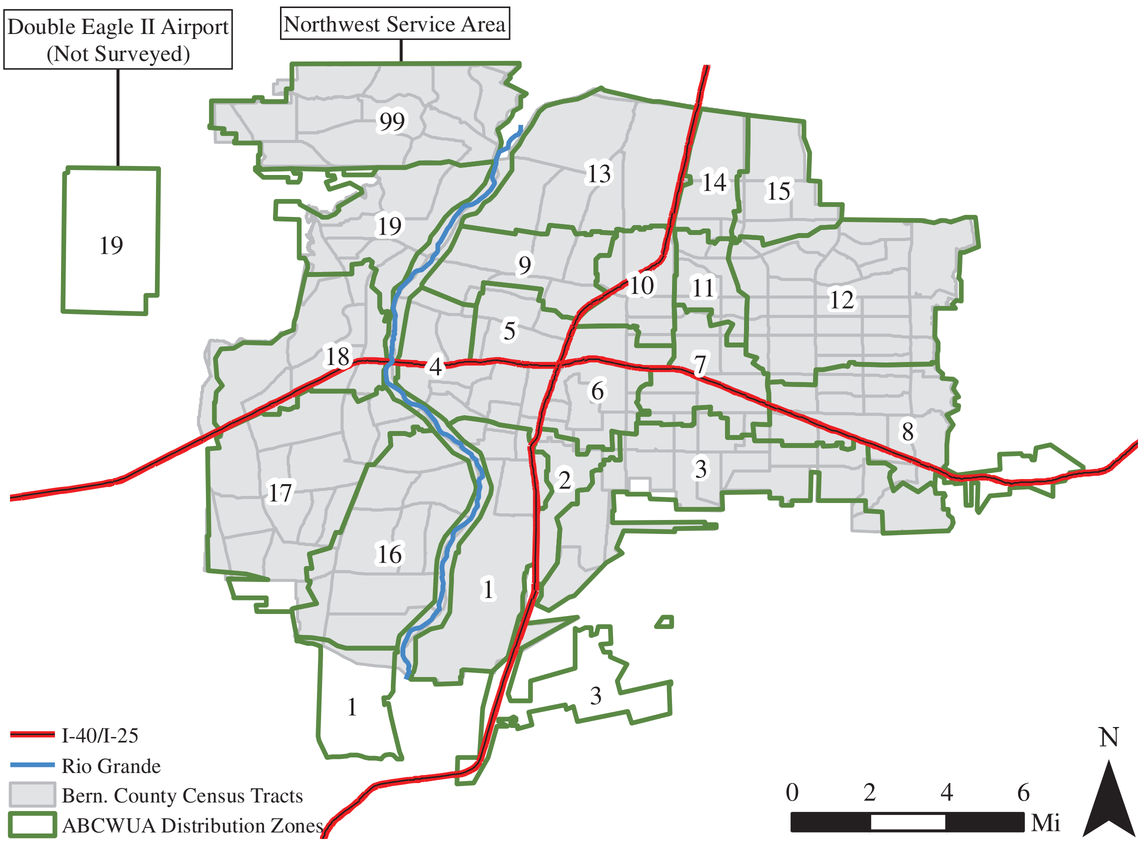

FIGURE 3 Albuquerque Bernalillo County Water Utility Authority (ABCWUA) distribution zones overlaid on service area census tracts

analyses performed by Distler and Scruggs (2020a) and Distler et al. (2020).

3 | RESULTS

For the survey question about whether or not water is a scarce resource in Albuquerque (question 2), approximately 17% ($n = 312$ of 1,831 survey respondents) answered that water is either not a scarce resource or that they were uncertain about whether or not it was. The results of the hotspot analysis for this survey question are shown in Figure 4a. The map shows that the most significant hot spots for "No" or "I don't know" responses were found among ABCWUA's customers in the SW quadrant of the city, within parts of distribution zones 1 and 17. Less significant hotspots were also found in these two zones, and additional hotspots at the 95% and 90% confidence levels ($p = .05$ and $p = .10$, respectively) were also seen in distribution zones 16 and 19. Choropleth mapping of the fraction of "No" and "I don't know" responses per census tract (Figure 4b) indicated that the areas with the highest values (0.401–0.601) fell within distribution zones 1, 3, 17, and 19. Of note, however, a high value area was observed in distribution zone 3 of the choropleth map, but not in the hotspot analysis map likely because of the lack of surrounding, statistically significant census tracts.

For the survey question about knowledge of the area's water sources (question #3), of interest were responses that did not correctly identify both groundwater and surface water as the sources for ABCWUA drinking water. More than half ($n = 918$) of survey respondents did not correctly identify the sources of ABCWUA drinking water. As displayed in Figure 5a, the single hotspot at the 99% confidence level ($p = .01$) straddled distribution zones 16 and 17, while hotspots at the 95% and 90% confidence levels were seen in distribution zones 1, 4, 16, 17, and 18, and the NW service area. Choropleth mapping of the fraction of incorrect responses per census tract (Figure 5b) revealed a distribution of values over 0.601 occurring within all distribution zones except for 2 and 15. In the choropleth map, numerous high values recorded throughout the service area did not register as hotspots due to the lack of immediately adjacent, statistically significant census tracts.

Regarding the survey question that asked if respondents believed climate change would impact the

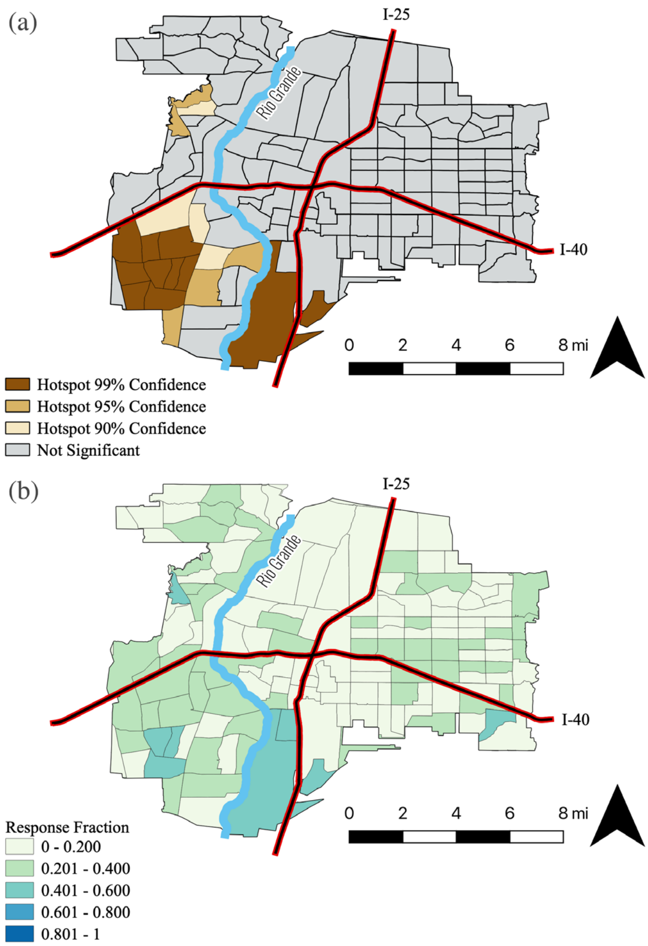

FIGURE 4 Hotspot analyses (a) and choropleth mapping (b) for survey question 2 on whether or not water is a scarce resource (n = 312)

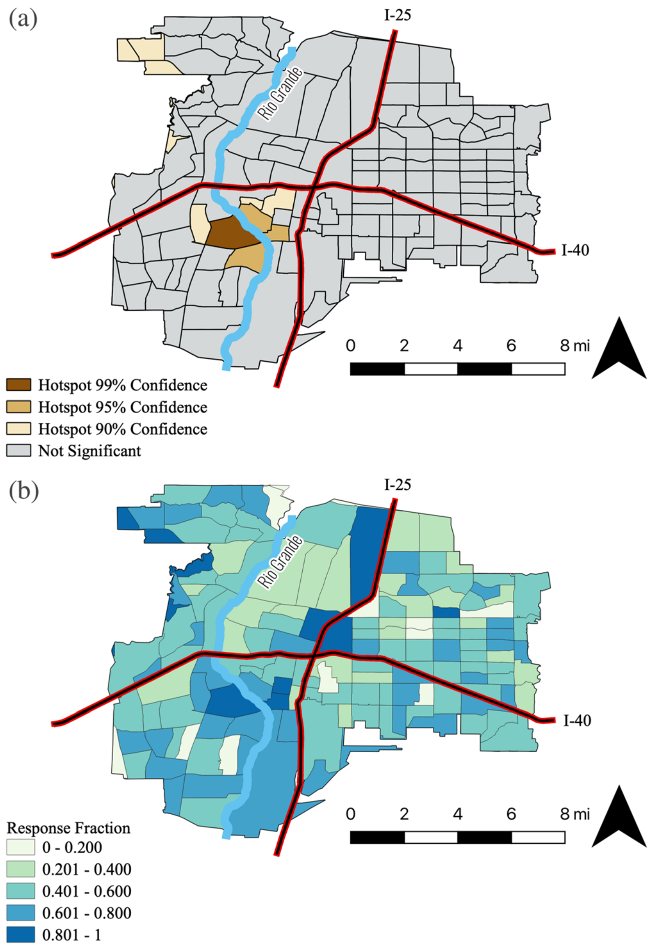

FIGURE 5 Hotspot analyses (a) and choropleth mapping (b) for survey question 3 on knowledge of water sources (n = 918)

ABCWUA's ability to provide for future water needs (question 4), the "No" responses were of interest (n = 264). As displayed in Figure 6a, hotspots at the 95% and 90% confidence levels existed within distribution zones 8, 12, and 15, and the NW service area. Choropleth mapping of the fraction of "No" responses per census tract (Figure 6b) revealed that the tracts with the highest values (0.601–0.801) fell within distribution zones 5 and 6. Also of note, a relatively high concentration of tracts with values between 0.201 and 0.401 were observed in the NE quadrant of the ABCWUA service area. Thus, several high values in the choropleth map were not captured as hotspots in the hotspot analysis.

For the survey question on bottled water (question 5), of interest were responses indicating that bottled water is safer than Albuquerque tap water, and over one-third of all survey respondents (n = 700) believed this to be true. As shown in Figure 7a, hotspots at the 95% and 90% confidence levels were observed within distribution zones 3, 8, 10, 13, 14, 17, and 18. The choropleth mapping of the fraction of responses in each census tract indicating that bottled water is safer (Figure 7b) shows that the tracts with the highest values (0.601 and higher) fall within distribution zones 1, 2, 3, 4, 7, 8, 10, 12, 13, 16, 17, and 18, and the NW service area. Again, numerous high values in the choropleth map, especially in the SW quadrant, are not captured in the hotspot analysis.

Hotspot results from the survey question asking about acceptance of DPR (question 10) can be found in Figure 8. The analysis indicated that of those surveyed, approximately 28% (n = 502) were not accepting of DPR. As shown in Figure 8a, hotspots at the 99% confidence level were observed in distribution zones 10, 13, and 14, with distribution zone 14 also containing a hotspot at the 95% confidence level. Hotspots at the 90% confidence level occurred within distribution zones 9, 10, 13, 18, and 19, and the NW service area. Choropleth mapping of the unaccepting fraction per census tract (Figure 8b) shows that the highest values (0.601 and higher) occur within distribution zones 5, 6, 9, 10, and 13, and the NW service

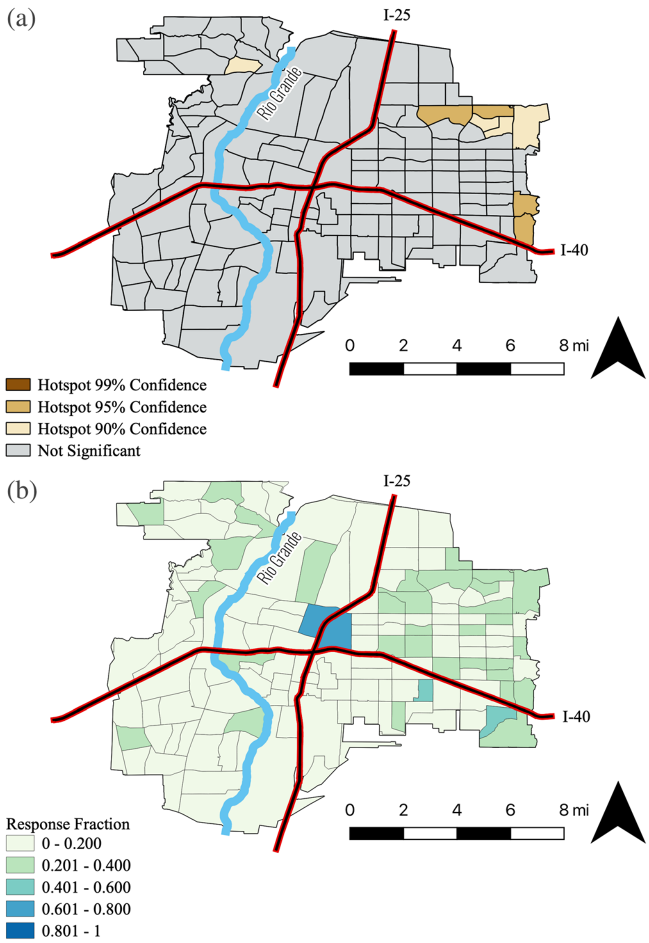

FIGURE 6 Hotspot analyses (a) and choropleth mapping (b) for survey question 4 on whether climate change will impact future water supply needs ($n = 264$)

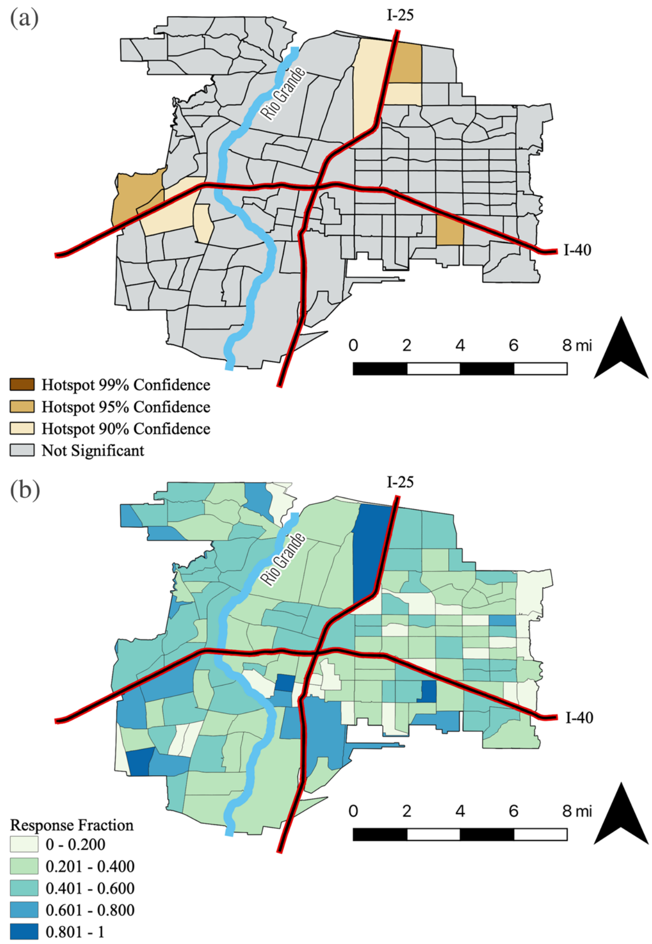

FIGURE 7 Hotspot analyses (a) and choropleth mapping (b) for survey question 5 on bottled water ($n = 700$)

area. In this case, the hotspot analysis reasonably captures the high values in the choropleth analysis.

For the survey question that asked about respondents' acceptance of IPR (question 13), approximately 17% ($n = 319$) indicated that they did not accept IPR. Hotspots for lack of acceptance of IPR were similar in location and significance to those for DPR. Hotspots at the 99% confidence level (Figure 9a) occurred within distribution zones 9, 10, and 13. Distribution zone 14 contained hotspots at the 95% confidence level, and distribution zones 17, 18, and 19, and the NW service area contained hotspots at the 90% confidence level. Choropleth mapping of the fraction of unaccepting responses per census tract (Figure 9b) revealed two census tracts with high values (0.801 or higher; this map contained no values in the 0.601–0.801 range). These tracts fell within distribution zones 6, 10, and 13. Similar to DPR, the hotspot analysis reasonably captures the high values identified in the choropleth map.

Regarding the survey question asking about trust in various entities (question 17), the authors were interested in responses about trust in both local elected officials and the ABCWUA. These two items were thought to be important for analysis because the survey results indicated that local elected officials were the least trusted of all entities included in the question, and the ABCWUA was only moderately trusted. Specifically, 51% of respondents ($n = 937$) indicated distrust in local elected officials (Figure 10), and 17% ($n = 307$) indicated distrust in the ABCWUA (Figure 11). Trust in these entities is important because local elected officials and the water utility are typically responsible for conducting education and outreach related to water projects such as IPR or DPR. Figure 10a shows the hotspot analysis for distrust in local elected officials. This hotspot analysis does not match patterns seen in any of the previous figures, suggesting that trust in local officials may not be associated with geographic location at all; a majority of people distrust the local government. In the analysis for distrust of local officials, the few hotspots were only significant at the 90% confidence level, indicating that distrust of local elected officials was present among many census tracts within the entire ABCWUA service area. This suggests

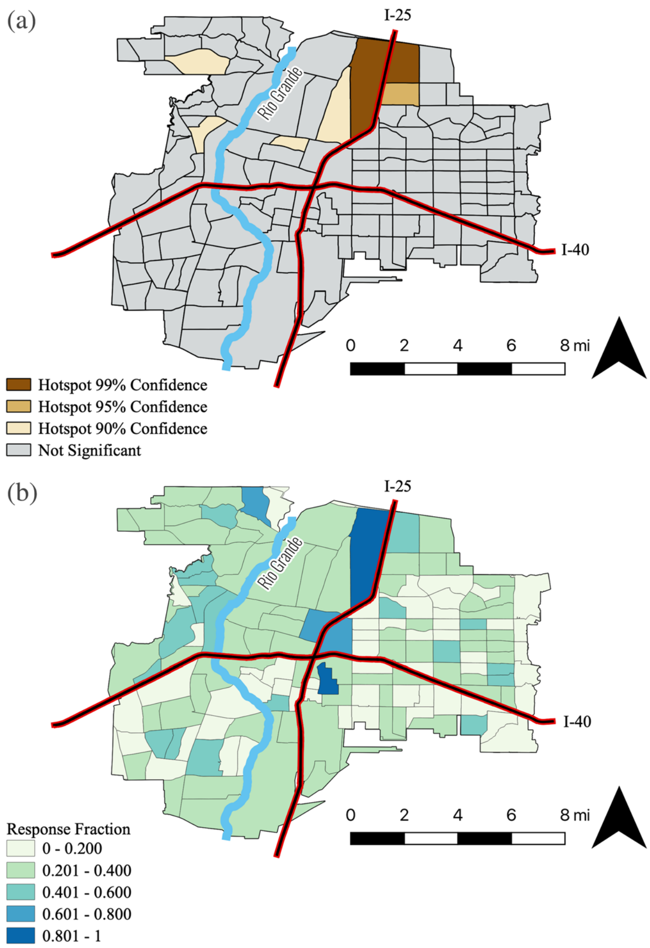

FIGURE 8 Hotspot analyses (a) and choropleth mapping (b) for survey question 10 on acceptance of direct potable reuse ($n = 502$)

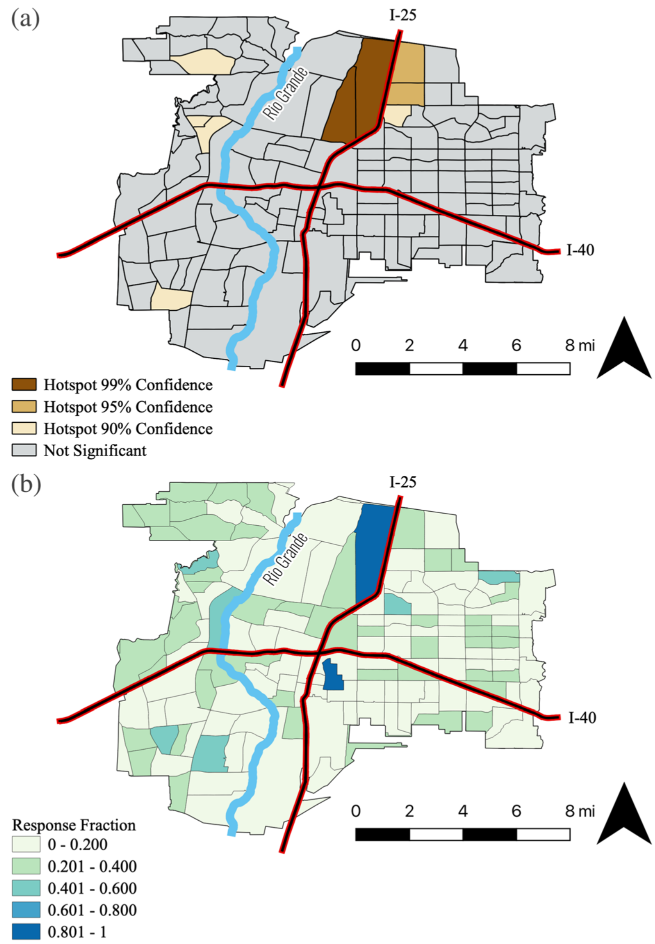

FIGURE 9 Hotspot analyses (a) and choropleth mapping (b) for survey question 13 on acceptance of indirect potable reuse ($n = 319$)

that there is no underlying pattern of distribution for the survey responses. The choropleth mapping (Figure 10b) shows no discernable pattern to the distribution of survey responses, but rather a fairly high level of distrust in elected officials across the ABCWUA service area.

Figure 11a shows the hotspot analysis for distrust in the ABCWUA. Hotspots at the 95% and 90% confidence levels occurred within distribution zones 2, 3, 5, 6, 7, 9, and 10. The choropleth mapping (Figure 11b) revealed, again, a dispersed distribution across all quadrants of the service area with no discernable pattern, but at a lower level of distrust as compared with that for elected officials. The fraction of respondents indicating distrust in the ABCWUA was consistently below a value of 0.601.

4 | DISCUSSION AND CONCLUSIONS

Mapping the responses to seven questions from a survey of water utility customers provides an example of how water planners and utility managers can incorporate the graphical display of data as a value added to traditional analysis of survey data. With additional interpretation, the approach allows for creation of a tailored education and outreach program by identifying specific geographic locations where certain educational information is needed, misperceptions exist, or trust in various entities is lacking.

The results of this collection of hotspot analyses and choropleth maps for perceptions and knowledge related to water resources, scarcity, reuse, climate change, and bottled water safety showed overlapping needs in various census tracts for certain types of education and outreach. The present study assumes that utilities have limited resources to plan and conduct customer outreach and education. Therefore, the authors suggest primary use of the hotspot analyses to focus on areas in most need of education and outreach, while using the choropleth maps for a complementary and broader view of what knowledge and attitudes related to the survey topics look like in the overall service area. Choropleth mapping of the

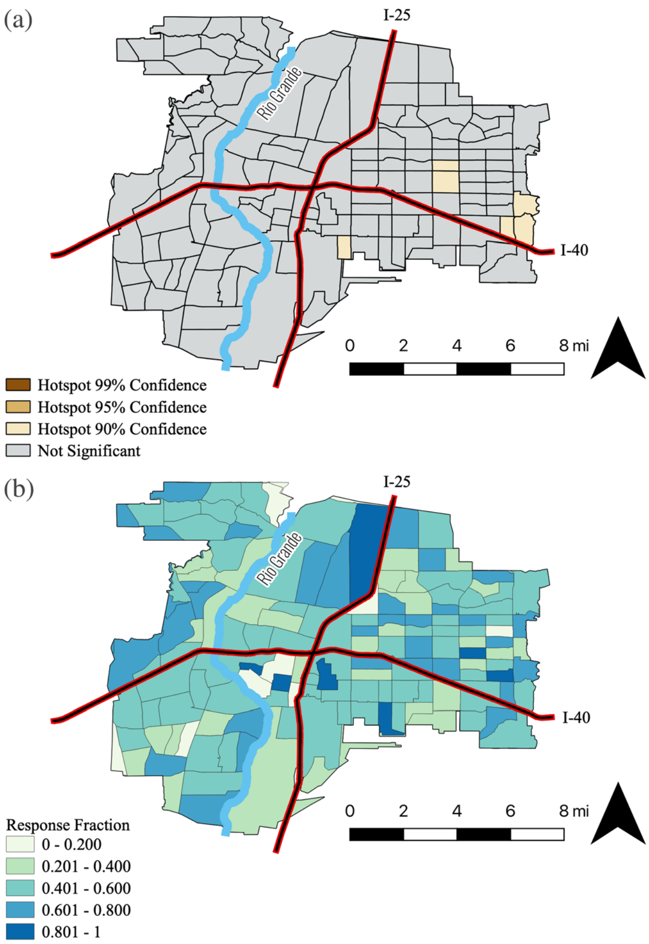

FIGURE 10 Hotspot analyses (a) and choropleth mapping (b) for survey question 17 on trust in local elected officials (n = 937)

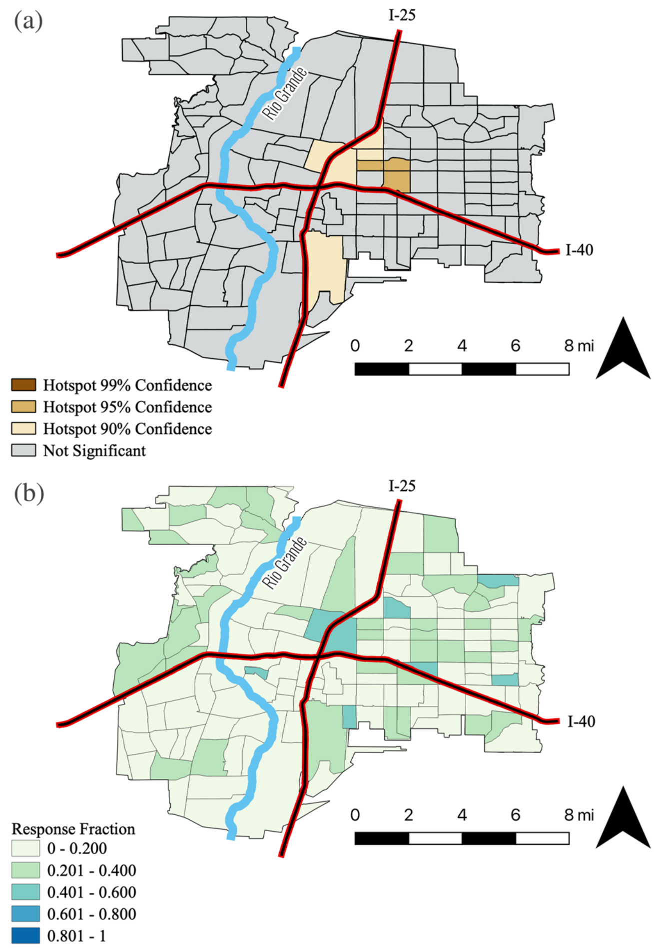

FIGURE 11 Hotspot analyses (a) and choropleth mapping (b) for survey question 17 on trust in Albuquerque Bernalillo County Water Utility Authority (ABCWUA) (n = 307)

response ratio also can help identify isolated areas of high response that are not accounted for using the Getis-Ord Gi* hotspot analysis, since the latter identifies only those areas of high response ratio that are also surrounded by other areas with a high response ratio. An upside to using distribution zones to analyze the results is that the zones provide a convenient way to think about community education and outreach. However, a downside is that the zones are large enough that they sometimes only capture a small segment of a census tract that was identified as a hot spot. Therefore, additional interpretation and comparison of the hotspot results are needed to narrow down the number of distribution zones in which certain kinds of education and outreach should occur.

An examination of distribution zones containing the most significant hotspots in Figures 4–11 reveals interesting patterns for related survey topics. The hotspot maps for the survey questions about basic knowledge of local water resources (question 2 about water scarcity and question 3 about water sources) show common significant knowledge gaps occur in distribution zones 1, 16, and 17 (see Figures 4 and 5). The hotspot maps for the survey questions related to perception of water quality (question 5 about bottled water, and questions 10 and 13 about acceptability of DPR and IPR, respectively) show common significant outreach needs in distribution zones 10, 13, and 14 (see Figures 7–9). The map indicating hotspots of belief that climate change will not impact future water supplies, along with the associated choropleth map (see Figure 6), suggest that education and outreach related to climate change is most needed in distribution zones 8 and 12. Figure 12 highlights the ABCWUA distribution zones recommended for specific kinds of education and outreach based on these additional interpretations of mapping results. Billing inserts could be used to provide educational information and to announce community meetings about specific topics in locations within each distribution zone. In the past, the ABCWUA has used water bill credits as an incentive for customer participation in meetings, and that strategy could be useful here, too, to ensure ample community involvement.

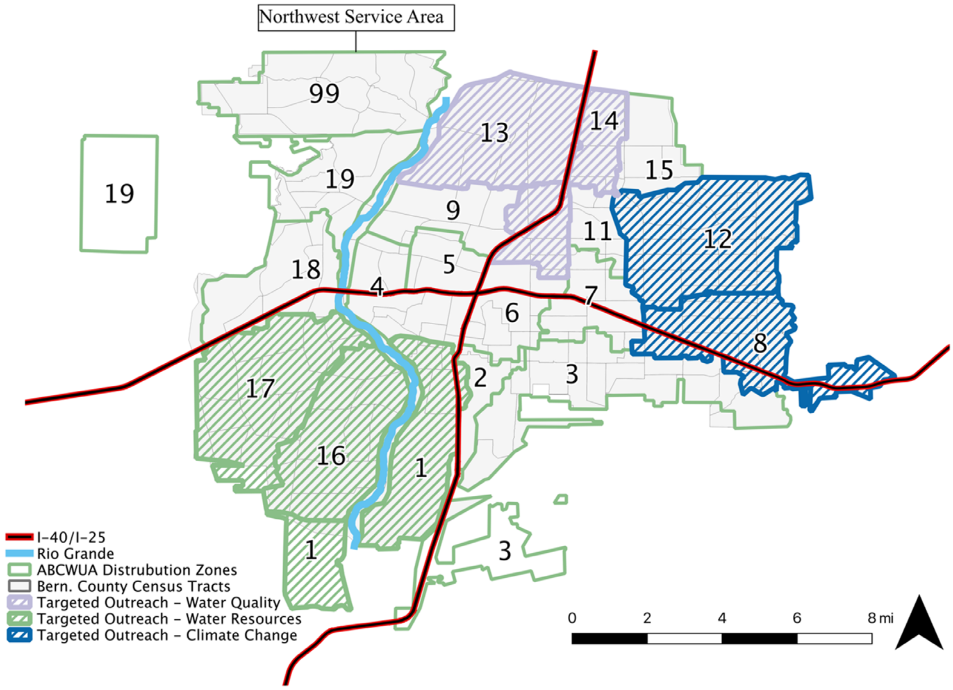

FIGURE 12 Albuquerque Bernalillo County Water Utility Authority (ABCWUA) distribution zones with highlighted targeted outreach areas for the following topics: water quality, water resources, and climate change

The maps on distrust of local elected officials and the ABCWUA (Figures 10 and 11, respectively) suggest that trust building is needed throughout the service area, particularly for elected officials, but for ABCWUA to some extent as well. While hotspot analysis displayed some scattered hotspots, mostly at the lowest confidence level, the choropleth maps show that distrust is fairly widespread, especially for the elected officials. This suggests not only that the ABCWUA should include trust building as a component of any education and outreach activities it conducts, but also that it should consider those other than elected officials when recruiting messengers to provide public information about water issues. The previous survey identified categories of people and entities (e.g., academic researchers, public health professionals, and environmental nonprofit organizations) that ABCWUA customers trusted to provide them with information about water-related issues (Distler & Scruggs, 2020a). This information provides the ABCWUA with guidance for initiating or fostering collaborations with local and grassroots individuals and/or entities to help with education and outreach efforts. The ABCWUA and its collaborators should emphasize transparency of all information and processes in building or fostering relationships with the community, and utility staff should participate in the outreach events to maximize public trust.

These findings illustrate how mapping allows for more effective use and visualization of survey data. For example, the previous statistical modeling of the survey data indicated that water-related knowledge gaps and lack of reuse acceptance were more prevalent among Spanish, Hispanic, and Latino respondents (Distler et al., 2020; Distler & Scruggs, 2020a). Because of this modeling result, the area's South Valley, which has a large Spanish, Hispanic, and Latino population, may have seemed like a reasonable place for the ABCWUA to focus its education and outreach efforts. However, the valley is largely located within distribution zones 1 and 16, which contained hotspots related only to knowledge about water sources and scarcity, and not for the other topics studied.

In this way, mapping provides a powerful addition to survey data analysis and has the potential to make education and outreach programming more targeted and effective. Of course, additional considerations are important when using these types of study results to engage with the community and design education and outreach programming. For example, in the census tracts where hotspots were observed, does English tend to be a second language, possibly making responding to a written survey in English more challenging and subject to misinterpretation? In this situation, language preferences should be accounted for in design of community engagement activities. Or, in areas where bottled water is preferred, have there been disruptions to water service, such as broken mains and aesthetically displeasing tap water? Here, localized experience with water quality must be understood. Investigation into census data and utility records can add additional context that might be important when preparing to engage with residents of the different distribution zones. Preliminary discussions with community groups can also help improve understanding of local institutional and cultural knowledge, allowing a utility to better conduct its outreach and target specific misconceptions or areas of distrust.

To ensure the future reliability and sustainability of water supplies in water-scarce regions, it is critical that water planners considering potable reuse or other alternative water sources take the initiative to understand knowledge, perceptions, and trust in the community in advance of a water shortage crisis. With a thorough understanding of these issues, planners can provide tailored education about local water resources and water supply options. Dispelling misconceptions and providing education on needed topics is a first step toward allowing the community to make informed decisions about its future water supply options. Understanding the community's knowledge, perceptions, and trust related to water issues and entities is also a useful starting point for planners to build trust with community members and initiate a public dialogue to understand community values related to water resources.

The techniques described above illustrate the value that mapping can add to analysis of survey data to reduce uncertainty and guesswork about where certain attitudes, misconceptions, or feelings of distrust are more prevalent in a community. Since mapping helps to pinpoint the areas with the most need for education and outreach, its addition to analysis of survey data may be especially useful to utilities that have limited resources to plan and conduct customer outreach and education.

More broadly, this article illustrates how survey data can be viewed and analyzed geospatially by taking advantage of the ever-growing presence of GIS within municipal and private utilities. The approach allows researchers and utility managers the ability to visualize the statistical significance of public opinions and perceptions with direct applications for community outreach and public education. While the example presented in this article deals with survey data associated with a metropolitan water utility, the methods of survey implementation plus geospatial analysis can be employed and tailored by any utility or organization that seeks to better understand its customer base. For example, a gas or electric utility could survey its customer base about adoption of new green technologies or rate increases. Using the geospatial output, the utility could target areas for outreach and customer education about why upgrades and/or changes are needed or to understand the degree to which knowledge gaps or misconceptions exist on certain topics. Using this method of hotspot analysis to identify and prioritize areas for targeted outreach may be especially beneficial to utilities or municipal entities serving a total number of customers similar to or greater than the number served by the ABCWUA, because the process simplifies analysis of a large amount of data. Smaller communities may also benefit even if they have only basic GIS capabilities available in-house, as the process is straightforward and uses built-in tools provided in ESRI's ArcMap 10.8. In either case, it is critical to ensure that the requirement for a minimum number of input features per geographic unit is met, as detailed in ESRI's online guide for best practices for hotspot analysis (ESRI, n.d.). Otherwise, the results are unreliable; this issue could limit the approach's usefulness in rural and small communities. As a final consideration, by doing the up-front work to enable a tailored outreach and education program, any utility or organization utilizing the approach stands to benefit financially from focused use of resources.

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DATA AVAILABILITY STATEMENT

Except for the locational information, all data associated with this study can be found in a separate open access publication (Distler & Scruggs, 2020b).

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SUPPORTING INFORMATION

Additional supporting information may be found online in the Supporting Information section at the end of this article.

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