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Strategic locating of refuges for extreme heat events (or heat waves)

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ABSTRACT

Public cooling centers are a recommended component of heat management plans aimed at reducing morbidity and mortality during extreme heat events. Access to air conditioned space is known to reduce health risks associated with heat exposure, it is not known if these facilities are well positioned to serve those who are vulnerable to heat. Other public air-conditioned spaces such as indoor shopping malls, libraries, and movie theaters are also recommended. Placement of official cooling centers near these types of facilities provides redundant coverage. As a constrained resource, these facilities could be better located in areas where other heat relief options are limited. We explored the distribution of two public cooling center networks (Los Angeles County, CA and Maricopa County, AZ) and found that significant fractions of the networks were located in areas with abundant, publically available, air-conditioned spaces Instead of allowing the networks to develop in an ad hoc nature, location analysis should be used to site a potentially life-saving resource more effectively. Using a new iterative method of the maximal covering location problem, we identified potential facilities that improve access for those who are more susceptible to heat without access to potential alternatives and identified locations for network expansion.

1. Introduction

With increasing evidence of climate change, cities are developing response and management plans to mitigate potential impacts (Rockefeller Foundation, 2016). In addition to the direct impacts to infrastructure (Neumann et al., 2015), there is also a significant concern for how climate change and the increasing frequency, intensity and duration of extreme weather events will affect people (Epstein, 2005; Haines et al., 2006; Huang et al., 2011; McMichael and Lindgren, 2011). Hurricanes, tornadoes, and coastal storms are widely recognized for their destructive potential but there is also a growing concern for the impact that rising average temperatures and future heatwaves will have on public health (Luber and McGeehin, 2008). Health impacts resulting from heat exposure can range from mild discomfort and fatigue to death (Stafoggia et al., 2006). In addition to known heat-related clinical syndromes, environmental heat stress is also known to exacerbate existing medical conditions leading to increases in hospitalizations and mortality (Schwartz, 2005; Stafoggia et al., 2006) (Schwartz, 2005; Stafoggia et al., 2006). Extreme heat events, in particular, are associated with higher risks of negative heat-health outcomes. Though there is no universal definition of an extreme heat event, they can be generally described as "periods of summertime weather that are substantially hotter and/or more humid than typical for a given location at that time of year" (U.S. EPA, 2006). Heat management plans and programs are being implemented in many cities

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across the United States to reduce public health risks. Of particular concern is the US Southwest, where heat forecasts are particularly severe and populations are growing quickly (Bartos and Chester, 2014). There is indirect evidence that heat-health warning systems which couple early warnings with emergency response measures reduce heat related mortality but there have been concerns as to whether they are adequately reaching those who are at the greatest risk of negative health outcomes (Bassil and Cole, 2010; Ebi et al., 2004; Widerynski et al., 2017). While the characteristics of vulnerable groups vary between locals, groups at higher risk often include the elderly, those living in poverty and those with preexisting medical conditions (Li et al., 2015).

The most important physical resource in reducing heat-health consequences is cooled space (Kovats and Hajat, 2008). Air-conditioning has been shown to be an important protective factor and the prevalence of in-home units has increased but there are many places (e.g. older neighborhoods and temperate climate cities) where it is still uncommon in residential buildings (Braga et al., 2001; Curriero et al., 2002; Kaiser et al., 2001; O'Neill et al., 2005). In response to known disparities in access to in-home air-conditioning (Fraser et al., 2016), cities across the United States have developed networks of public cooling centers to provide heat refuges (Berisha et al., 2017; Nayak et al., 2017; Widerynski et al., 2017).These facilities help the public to escape the heat. Cooling centers are often sited at public libraries, senior citizen centers, and community based organizations (Fraser et al., 2016). However, while these centers can help reduce health risks, there is no evidence that quantitative methods have been used to site these facilities. Everyone is vulnerable to heat but there are particular population subsets that are more likely to experience negative health outcomes when exposed to extreme temperatures (Eisenman et al., 2016; Harlan et al., 2013; O'Neill et al., 2005; Reid et al., 2009; Weisskopf et al., 2002). The strategic placement of these facilities should consider underlying characteristics (age, ethnicity, economic status, etc.) of nearby communities that contribute to higher risks of heat-health incidents.

Official cooling centers are meant to serve as the air-conditioning alternative for those who may not have access to or are unable to use in-home air-conditioning. There are, however, questions regarding their utilization and overall effectiveness of these centers. A recent report from the U.S. Center for Disease Control and Prevention (CDC) summarizes existing peer-reviewed and grey literature assessing cooling centers and the related behavior of vulnerable populations during periods of extreme heat (Widerynski et al., 2017). The highlighted studies focused primarily on cooling center networks and citizens in U.S. and Canadian cities. The implementation and use of cooling centers as part of "heat health warning systems" differ by location (one of the purposes of the CDC report is to provide standardized recommendations for implementation) but there were several common threads that emerged within the literature. First, there is a general acknowledgement that public cooling centers are underutilized. Potential barriers to their use identified by various studies include lack of knowledge of cooling centers, lack of transportation, fear or inability to leave home, individuals not self-identifying as heat vulnerable, and a negative stigma associated with cooling centers. It was suggested by several studies that cooling center use is driven by the primary function of the center (e.g. library or senior center) rather than its designation as a cooling center. Lastly, individuals seeking out air-conditioning also use public alternatives instead of official cooling centers such as shopping centers and movie theaters. Seeking out these other public spaces is also recommended the CDC, NOAA, and local public health agencies. To improve the effectiveness of cooling centers in mitigating heat-related death and illness, continued research is needed to address these and other unknown barriers to use. This research sheds light on facility locations relative to where vulnerable populations live within cities and proximity to other alternatives which may contribute to underutilization.

To this end, this paper outlines a method to improve the siting of official cooling center facilities. We employ methods from the field of location science which deals with siting facilities in geographic space to best meet a specified objective(s) (Church and Murray, 2009). To address the siting of public cooling centers we utilize methods associated with a specific class of location science problems known as maximal covering location problems (Church and ReVelle, 1974). The study addresses the following: i) how can disparate and large datasets describing neighborhood level heat vulnerability and residential level access to public air-conditioned space be used to site cooling centers more effectively, ii) how well are the existing cooling center networks positioned to serve vulnerable populations and those without access to alternatives, iii) what geographic areas, and more specifically which facilities, should each county target to expand their network of cooling centers? The research focuses on Los Angeles County, CA and Maricopa County, AZ due to their large existing networks of cooling centers, a public health emphasis on reducing heat morbidity and mortality, and data availability.

2. Methods and materials

To address the research questions, a location analysis mathematical method is employed. In general, location analysis problems use linear and non-linear programing to site facilities in order to optimize some objective. Various models have been utilized to strategically locate both private and public facilities including warehouses, airline hubs, restaurants, schools, fire stations, and emergency medical services. In the private sector the location of a facility influences the firm's ability to compete in the market place and in the public sector, facility location influences the efficiency with which public services are provided (Current et al., 2001). The selection of a particular model for application depends on the context of the specific location analysis problem considered (see (Church and Murray, 2009; Owen and Daskin, 1998; ReVelle and Eiselt, 2005) for detailed descriptions of location analysis problem classes and implementation).

To select an appropriate model for locating cooling centers, the context of their use was considered. Cooling centers are meant to be utilized during periods of extreme heat because exposure to extreme heat is a known health hazard. There are a number of exposure pathways, but one that is critical to understand when siting cooling centers is mobility-based exposure. For those who utilize active modes of transportation, such as walking, accessing a cooling center requires exposure to a hazard that cooling centers are meant to protect against. It is well documented in the literature that the elderly and those living in poverty are among the most vulnerable populations to heat and are also among the groups with the greatest lack of access to an automobile (U.S. DOT FHWA,

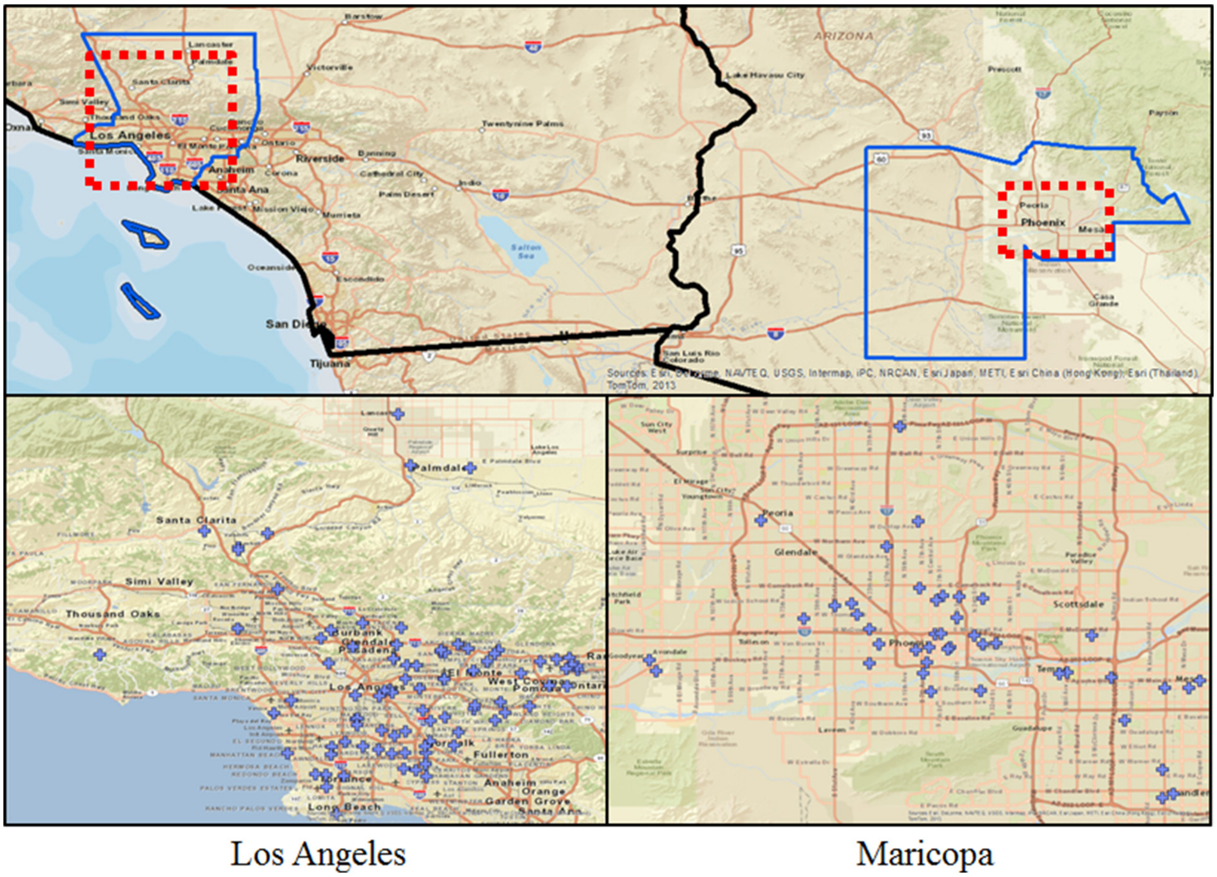

Fig. 1. Los Angeles and Maricopa health 2015 cooling centers. The map shows the cooling centers are primarily found in the urbanized areas Los Angeles and Maricopa counties (blue) (Los Angeles County, 2015; Maricopa Association of Governments, n.d.). (For interpretation of the references to color in this figure legend, the reader is referred to the web version of this article.)

2011). As a public service, the siting of cooling centers should consider the mobility constraints of those they are intended to serve. The Occupational Safety and Health Administration recommends limiting work to 15 min during periods of extreme temperatures (heat index > 115 °F) to avoid negative health outcomes (USDOL, 2014). For the same reasons we contend that walking longer than 15 min should also be avoided during heatwaves. Among the classes of location analysis problems, covering models consider thresholds (either distance or time) to be critical to the potential utilization of the facility. With potential constraints (such as facility costs and/or labor costs) on the number of public cooling centers, the facilities should be positioned in a way that would provide potential service to the greatest number of vulnerable people. Taking these concerns into account, the location analysis method that best fits with siting public cooling centers is the maximal covering location problem (MCLP) (Church and ReVelle, 1974). MCLPs have also been used to site other threshold-dependent public services such as fire stations and emergency medical services (Eaton et al., 1985; Schilling et al., 1980).

2.1. Study location - Los Angeles and Maricopa counties

Located in the American Southwest, Los Angeles and Maricopa counties each experience periods of potentially dangerous temperatures throughout the summer months (NOAA, 2018). The heat season has been typically defined as the summer months (June through August) in Los Angeles while Maricopa experiences a longer season stretching from May through October (Maricopa County Department of Public Health, 2018). In recent years, the county public health departments have promoted a network of cooling centers (Fig. 1) to the community to help mitigate the negative health consequences associated with high summer temperatures. The cooling center networks are largely comprised of volunteer locations. Additionally, the locations of these centers tend to change annually with facilities opting in and out of the program (MCDPH, 2015). Due to the ad-hoc nature of the network, the facilities are scattered across the county (Fig. 1) and it is unclear if the current sites are capable of serving the most vulnerable peoples. While the Los Angeles network is relatively dispersed across the urbanized portion of county, the Maricopa network is heavily concentrated in and around the downtown area of Phoenix, AZ. Faced with growing populations (Arizona Office of Economic Opportunity, 2015; California Department of Finance, 2016), a future that is projected to be increasingly hotter (Bartos and Chester, 2014), and potential resource constraints that could limit the size of the networks, these facilities should be located strategically to allow them to serve the greatest number of heat-vulnerable people.

Due to high summer temperatures, Maricopa County has been a focus of a significant amount of research related to public health, extreme heat, and social heat vulnerability (Golden et al., 2008; Harlan et al., 2013, 2006; Petitti et al., 2013; Reid et al., 2009; Ruddell et al., 2009; Yip et al., 2008). Although temperatures may seem moderate by comparison, high summer and fall temperatures are also a public health issue in Los Angeles County (LADPH, 2014; Reid et al., 2009; Sheridan, Allen, Lee, & Kalkstein, 2012). These and other studies note that specific individual and community characteristics are known to increase the risks of negative heat health outcomes and find that vulnerability to heat varies from neighborhood to neighborhood. These characteristics include, but are not limited to, age, race, economic status, mental and physical health, access to air-conditioning, homelessness, and factors known to impact urban heat island. It has been recommended that public health interventions to mitigate the risks associated with heat exposure, including the provision of cooling centers, target areas where the these characteristics accumulate increasing the likely hood of negative heat-health impacts relative to other areas.

The 2015 public cooling center networks in Los Angeles and Maricopa counties featured 94 and 46 facilities respectively. These locations were identified from lists provided by public health organizations within each county made available in the spring of 2015 (Los Angeles County, 2015; Maricopa Association of Governments, n.d.). MCLP principles and methods were used to evaluate these locations for their potential to serve heat vulnerable population, identity where these facilities could have been placed that would have served a greatest share of the vulnerable population, and where new facilities could be located. To better inform the placement of these facilities, socio-economic characteristics that are correlated with heat morbidity and mortality are combined with residential household information and the location of other publically available air-conditioned spaces. In order to use MCLP a new method, Random Thiessen Aggregation (RTA), was developed to create a problem that was computationally feasible and produced a robust solution. The analysis was completed with ArcGIS 10.3 using GIS functionality largely associated with the *Network Analyst* extension.

2.2. Data

A critical issue for using any location analysis model is obtaining and deriving the data needed to use the framework. The geospatial components are categorized by their respective role in the MCLP model.

2.2.1. Demand locations

Demand locations were considered to be all residential parcels with structures in Los Angeles County (2.1 million) and Maricopa County (1.1 million). These data were developed from county assessor databases (MCAO, 2010). The database details the location of each parcel, type of residential building, and total number of dwelling units. Residential parcels were weighted based on total number of dwelling units in order to capture individual households Additionally, an index describing parcel access to nearby public cooling resources is included as an additional demand node attribute (Fraser et al., 2016).

2.2.2. Candidate sites

Public cooling centers in Los Angeles and Maricopa have previously been sited at a number of different types of facilities including libraries, senior centers, community centers, and humanitarian and religious organizations. All existing libraries, senior centers, community centers, and humanitarian and religious organizations within the county were considered candidate facilities (≈5200 in Los Angeles and ≈2300 locations in Maricopa). The addresses of these facilities, with the exception of religious facilities, were geocoded from directory searches and the assessor database. Religious facilities were identified with the county assessor databases using property use codes. Given the size of each candidate set, the feasibility of individual sites to function as cooling centers (i.e. building conditions, capacity, and willingness to participate) was not established. Some have suggested that public schools could serve as cooling centers (Bradford et al., 2015) but schools have increasingly moved toward closed campus policies for student safety and have been excluded as candidates in this analysis (Perumean-Chaney and Sutton, 2013).

2.2.3. Network dataset

To utilize ArcMap's location analysis models a network dataset is needed. A line shapefile representing the United States street network was used to generate the network dataset for both counties (ESRI (2007). North American Detailed Streets. (Environmental Systems Research Institute & TomTom, Eds.). Redlands, 2007). This dataset is used to determine the distance and walking time between any cooling center candidate sites and individual residential parcels. The assessment assumed pedestrian paths follow the existing street network and all existing roadways, with the exception of freeways and highways, were considered to be pedestrian accessible.

2.2.4. Heat vulnerability indices

To identify neighborhoods where residents may be particularly vulnerable to heat, morbidity and mortality data were used to identify social and economic characteristics associated with negative health outcomes in Los Angeles and Maricopa. Following the work of Eisenman et al. (2016), heat vulnerability scores are developed for each census tract. The variables used are identified in Table 1.

2.3. Random Thiessen aggregation

Location models are difficult to solve and their computational complexity is a key reason why widespread interest in the field did

Table 1
Heat vulnerability index variables.

County	Census variables for estimating heat vulnerability indices
Los Angeles	Percent of households with no vehicles available, percent of renting households, percent where income was below poverty level, percent uninsured and percent foreign born.
Maricopa	Percent of Hispanic/Latino households, percent foreign born, percent uninsured, percent income below the poverty level, percent construction workers, and percent female householder (no husband present)

not begin until after the development of computers (Church and Murray, 2009). Realistically scaled problems, such as siting cooling centers, can have hundreds of thousands of constraints and variables and standard optimization methods can consume an unreasonable amount of computer resources and time (Current et al., 2001). Given the complexity of the location analysis problem a new heuristic method was developed using GIS processes. The stepwise procedure reduces the number of constrains and variables to simplify and is described below and partially illustrated in Fig. 2.

Step 1: Population information from the 2010 U.S. Census was used to generate random points within each census tract for every 100 residents (rounded down). This procedure produces approximately 98,000 and 34,000 points throughout Los Angeles and Maricopa County respectively. This step is identical to the procedure employed by (Bradford et al., 2015) in a similar study for siting cooling centers in Pittsburgh, PA. Subsequent steps improve upon their method by assigning vulnerability and cooling resource access characteristics of nearby households to each random point.
Step 2: Thiessen polygons were then generated from the set of random points within each census tract. Thiessen polygons define areas around individual points such that any location inside the polygon is closer to that point than any other point within the set. This subdivided the census tracts in each county into irregularly shaped polygons.
Step 3: Individual residential parcels were then spatially aggregated to the Thiessen polygons. Each polygon was assigned characteristics of the residential parcels that fall within its boundaries including the total number of households and the mean accessibility index score.
Step 4: Centroids were then generated for each polygon and assigned a weight. These centroids were used as representative demand locations and assigned a weight (W_i) based on the total number of households within each, the average cooling resource

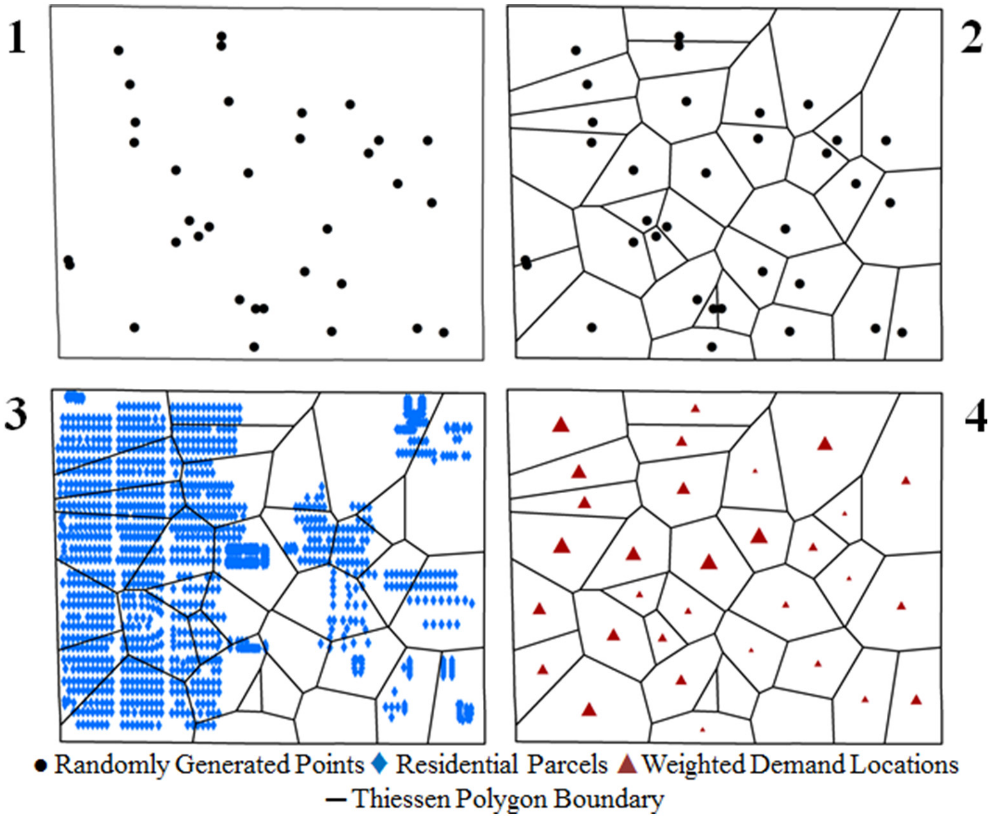

Fig. 2. Random Thiessen method step 1 – Generate random points, step 2 – Generate Thiessen polygons, step 3 – aggregate residential parcels to Thiessen polygons, step 4 – Generate Thiessen centroids and assign weights.

accessibility index of households within, and a measure of socio-economic heat vulnerability based on the following:

$$W_i = HH_i * SV_i * CRA_i^{-1}$$

where:

HH_i = Total number of households in i
SV_i = The socio-economic vulnerability of households in i to heat
CRA_i = Average cooling resource accessibility measurement for households in i.

Step 5: Due to the aggregation method, a number of Thiessen polygons did not contain any households. Centroids with a weighted demand of zero were removed to further reduce the number of demand locations. Collectively, steps 1–5 reduced the total number of demand locations by 97%.

Step 6: The *Location Allocation* tool in ArcMap's *Network Analyst* package was used to determine a maximal coverage solution for the specified number of facilities in each county. The coverage distance set at 0.75 miles and defined by a 15 minute exposure time limit and average walking speed for adults (3 mi/h) (Bohannon and Andrews, 2011).

2.4. Method limitations and iteration approach

The stepwise procedure produced a solution set that maximizes coverage for a new set of facilities. However, the procedure contributes to solution uncertainty for several reasons. First, there are known issues with aggregating data to larger geographic scales. This is known as the modifiable areal unit problem (Dark and Bram, 2007). In this case, CRA_i values may not be representative of the population under examination especially in areas where there is significant variance. Additionally, the procedure artificially groups households together furthering exacerbating this issue because demand weights were directly related to how parcel level data were aggregated in steps 1–3. Secondly, centroid locations may not be a good representation of an average demand for the households within each polygon because residential parcels and households may cluster rather than be uniformly distributed. This effect can be seen on the right side of the census tract illustrated in Fig. 2 where residential parcels are not uniformly distributed. Lastly, because ArcMap's *location-allocation* tool relies on its own heuristic we can only say that any solution derived from it is simply a good solution rather than one that is optimal. While it is unlikely that any two iterations would identify the same set of facilities, a total of 50 iterations were performed to test the stability of the method in identifying a common set of facilities. Solutions for each of the iterations were compared and used to identify sets of facilities that were chosen in most iterations (≥90%), sometimes (10–90%), rarely (≤10%), and those not chosen at all.

3. Results

3.1. Evaluation of random Thiessen aggregation

Selecting a set of locations for a network of cooling centers when the potential candidate sites number in the thousands is a difficult task. The RTA method developed here simplifies this task for decision makers. Despite the large number of candidate sites, only a small subset (~5%) of the candidate sites in either Los Angeles or Maricopa were ever selected as cooling center locations during the iterative process. In effect, using an iterative approach with the RTA method reduced the candidate site set by 95%. In Los Angeles, 223 of the 5200 candidate sites were chosen at least once. Within this set, the method also allows us to place some measure of confidence on how well these locations would serve vulnerable populations with limited access to cooling alternatives. Of these facilities, 36% were selected in 5 iterations or less and 25 facilities were selected only once suggesting they may perform sub optimally. Conversely, 24 facilities were selected in every iteration suggesting that they are in ideal locations to serve as cooling centers. Similarly, in Maricopa, 117 of the 2300 candidates were selected as facility locations at least once, 41% were selected in 5 iterations or less, while 12 were selected in every iteration.

The 2015 cooling center networks included 94 facilities in Los Angeles and 46 facilities in Maricopa. By rank ordering the candidate sites based on their selection frequency we can see how well the method preforms in identifying the facility locations of equivalent cooling center networks. Looking at the top 94 and 46 facilities based on selection frequency, 66% of the sites in Los Angeles and 56% in Maricopa were selected in at least 90% of the iterations. Beyond these top facilities, there was a rapid decay in how frequently the facilities were chosen (Fig. 3). Despite this decay, each facility among the top set of facilities in either county was selected in at least 50% of the iterations. While it is not possible to describe this set as an optimal solution, the frequency with which these sets of facilities were selected across the iterations implies that these facilities are likely positioned to serve both vulnerable communities and those without access to cooling alternatives. In both counties, there is a weak but positive correlation between the frequency with which facilities were chosen and the average weighted demand they covered. This means that facilities selected with higher frequency would likely serve larger and more vulnerable populations with limited access to public alternatives. However, additional consideration should be given to those facilities outside the top facilities sets where the average weighted demand served significantly exceeds those among the top facilities. In these instances the relatively low frequency that these facilities were chosen might be due issues associated with aggregation.

3.2. Evaluation of 2015 cooling center networks and network optimization

There were notable differences in coverage provided by the 2015 County Cooling Center networks across the two counties

Fig. 3. Rank ordered facility selection frequency (blue) and average weighted demand covered (orange). (For interpretation of the references to color in this figure legend, the reader is referred to the web version of this article.)

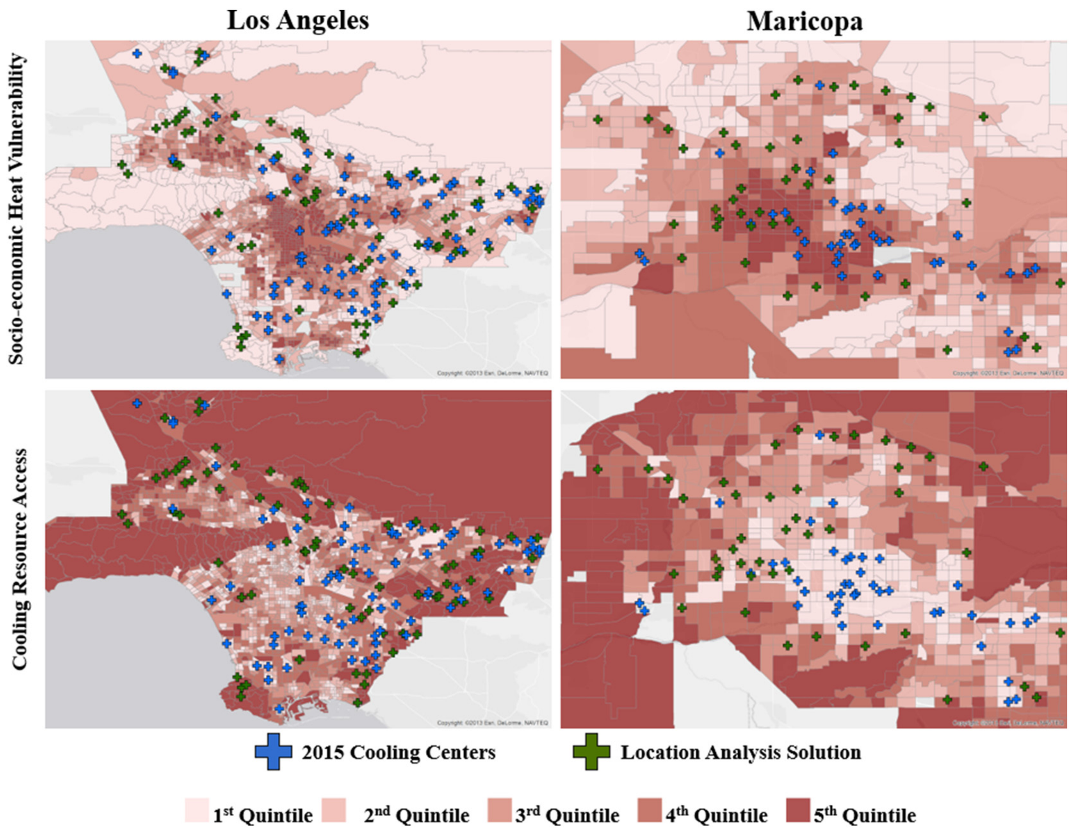

Fig. 4. Optimized location of cooling center facilities.

(Fig. 4). At first inspection, the Los Angeles network appeared far more dispersed potentially providing better coverage while the Maricopa network was more concentrated around the urban core (24 of 46 facilities were within 5 miles of downtown Phoenix). Conversely, the Maricopa network was better positioned to serve vulnerable populations with 25 of the 46 facilities found in census tracts in the upper quintile for heat vulnerability. In Los Angeles, only nine of the 94 facilities were found in the most vulnerable census tracts. In both counties, the ad hoc nature of the networks resulted in a significant number of facilities in areas where vulnerability to heat was relatively low. Due to the known transportation barrier associated with cooling center use, this suggests that the networks facilities were not optimally located to serve the most vulnerable.

Assessments of heat coping behavior have found that individuals seek out public air-conditioned space and that there is a preference for the primary function of any public air-conditioned facilities. While cooling centers are meant as a place of refuge, locating facilities in areas where residents have access to public air-conditioned alternatives may be an inefficient use of resources allotted to establishing cooling center networks. In 2015, many of the facilities in both counties were found in areas where residents have significant access to other air-conditioned public spaces (Fig. 4). In Los Angeles and Maricopa respectively, 46% and 75% of the facilities were located in census tracts with the highest access to other public air-conditioned spaces.

The solution set produced by the optimization model reflects a network design that considered both the heat vulnerability of the population and additional air-conditioned resources that may be used by individuals to mitigate heat exposure (Fig. 4). The sites selected result from the interplay between urban form (density and land use), geometry of the street network, the clustering of vulnerable populations, and a weighting scheme that establishes the relative value of other public air-conditioned spaces. In Los Angeles, the number of facilities found in the most vulnerable quintile decreased from nine to one and from 25 to 17 in Maricopa. In Los Angeles, the areas where heat-vulnerable populations live can generally be described by high building density, heterogeneous land use (residential and commercial), and a finely gridded street network (short block lengths). As a result, a large fraction of the heat-vulnerable population in Los Angeles has relatively high access to other public air-conditioned spaces. In Maricopa, the urban area is generally less dense, more homogenous, with a coarsely gridded street network (long block lengths). There are large concentrations of heat vulnerable populations found in the inner suburbs where there is a scarcity of public air-conditioning alternatives. The results show that the weighting scheme employed emphasizes areas with limited or no access to alternatives. In Los Angeles, 75% of the facilities selected were located in census tracts with the lowest access to cooling resource alternatives and only three were found in census tracts that already have the greatest access to existing alternatives. In Maricopa, 60% of facilities selected were located in census tracts with the lowest access and no facilities were found in tracts with the greatest access to existing resources.

3.3. Siting new cooling center facilities

While re-siting the entire cooling center network would improve coverage compared to the 2015 networks, closing the existing facilities, or removing them from a list of designated cooling centers, would not be recommended. These facilities are likely familiar to existing users and closing them would remove a resource they may have come to rely on. Alternatively, the methods can be used to identify a set of facilities to target for network expansion that complement existing facilities. Using the same procedure but fixing the existing cooling center locations, an additional 50 iterations were performed to identify 10 facilities to target to expand the networks. Across all iterations in both Los Angeles and Maricopa, the same 10 facilities were selected (Fig. 5). In both counties, these facilities are located in areas with high population density, above average socio-economic heat vulnerability, and limited access to alternatives. Relative to the position of the existing network where facilities are concentrated in urban areas, each of the identified

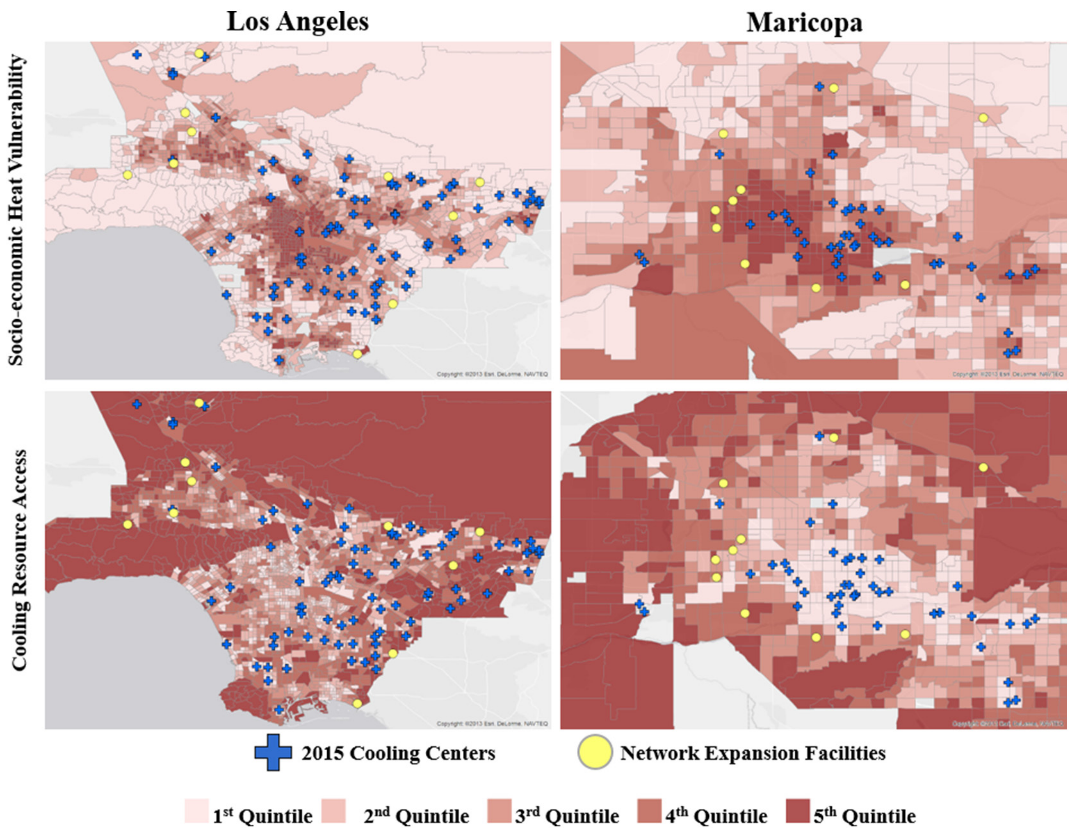

Fig. 5. Target facilities for network expansion.

facilities in both counties are located in suburban community outside of the urban core. This result highlights a significant shortcoming of the current networks. A mixing of commercial and residential land use is characteristic of many urban environments that provide urban residents with access to numerous publicly air-conditioned spaces that could provide heat relief. Conversely, due to the separation of residential and commercial land-uses that is characteristic of suburbs, residents without access to motorized transportation are isolated from necessary goods and services including cooling resources. While alternatives are often limited in suburban communities, many have libraries, community centers, and religious facilities that are well positioned to serve as official cooling centers during periods of extreme heat.

4. Discussion

Location analysis has been used to site many different types of public facilities and the results suggest that these methods could also be employed for improve the reach of cooling center facilities. This type of analysis has been made easier with the advent of GIS. Los Angeles, Maricopa, and any other region looking to establish or expand cooling center networks should make use of these tools. However, the solutions we derive from these methods are dependent on the quality of the input data and assumptions on how facilities are accessed and who uses them. GIS makes it possible to make decisions using precise spatial data but the attributes and weights ascribed to the spatial data are what drive the selection of specific facilities. In this case study, weights were derived from census data, relative heat-health risk estimates, and measurements of access to cooling resource alternatives and each is associated with its own uncertainty. While the census data may suggest a highly vulnerable population inhabits a particular neighborhood, immigration and emigration can change the demographics of a neighborhood quickly. This may be especially true in urban core neighborhoods that have attracted young and relatively affluent millennials who are less vulnerable to heat while displacing lower income minorities who are more vulnerable to heat (Walker, 2016). Similarly, our understanding of the social, economic, and infrastructure factors that contribute to individual heat vulnerability continue to improve. Populations and environments change over time and efforts to locate cooling center locations should use the most up-to-date and state-of-the-art heat vulnerability metrics. Lastly, our understanding of individual behavior during heat waves and the manner in which people engage public cooling resources is limited. The results are based on the assumption that people seek out and use public air-conditioned spaces but Sampson et al. (2013) found that the tendency to engage in cooling behaviors can vary across populations. Additional research is needed to understand adaptive cooling behaviors. Despite this uncertainty, the principles of location analysis would help public health agencies determine facilities that would be better positioned to serve vulnerable populations and those with limited access to cooling alternatives. As new spatial attribute data become available and our understanding of adaptive behavior improves, cooling center networks should be revaluated to insure that they are positioned to serve those who need the services the most.

In both counties, a large fraction (> 70%) of the facilities identified in this analysis as ideal sites for cooling centers are associated with religious institutions. Religious facilities are good candidates for cooling center locations because they are ubiquitous in most U.S. cities and many of them are located in close proximity to or within residential neighborhoods. Additionally, many of these facilities might be available for use on many days outside of periods of worship, unless they are multi-functional and used as community centers, schools, or offices. Faith-based organizations are often a part of community resilience efforts during disaster recovery (Eisenman et al., 2014). However, a previous assessment of cooling centers located at religious facilities found that they have lower relative attendance compared to other facilities types and users are typically congregants (Widerynski et al., 2017). In order for religious facilities, or any other facility, to successfully function as a cooling center efforts need to be made to highlight cooling center services and differentiate them facilities primary purpose.

There are several other issues that public health officials should consider in the siting of cooling center facilities. Despite the large number of candidate sites, there are still areas that could not be covered by any facility as no candidate facilities exist such as homogenous residential developments and rural areas of each county. Alternative interventions may need to be considered for neighborhoods without candidate sites where residents are particularly vulnerable to heat and/or have limited access to other cooling resources. These alternatives could include the construction of new facilities, mobile cooling centers, or providing transportation to existing facilities. This analysis uses residential parcels to describe the location of demand for cooling centers. Homeless and transient individuals have been identified as highly vulnerable subgroups (Ramin and Svoboda, 2009; Uejio et al., 2011) and their demand and need for cooling centers would not be captured using residential parcels or census data. Their whereabouts and movements should also be considered when siting facilities. Additionally, location analysis methods could also consider the daily movements of a population to site cooling center facilities. However, without a fully developed travel demand model detailing the characteristics of the population it would be difficult to define a time-of-day dependent vulnerability measure. Finally, this analysis assumes that vulnerable populations are particularly reliant upon walking. Research into how cooling centers are accessed could provide additional insight for siting these facilities. It is also possible to use location analysis principles to site facilities based on alternative transportation modes as well as multi-modal.

5. Conclusion

Heat related morbidity and mortality is a growing concern for cities if not also a growing problem. If public cooling centers are to have an impact in mitigating these outcomes, it is critical they are located in a manner that makes their services available to those who need heat relief the most. It has been shown that the ad hoc nature of existing networks is likely suboptimal to meet this need. The best outcome would be to insure that a cooling center is located and accessible to every heat vulnerable community but due to resource constraints this is unlikely. With this in mind, the placement of these facilities should consider underlying vulnerability of the population as well as existing resources that may already be used as de facto cooling centers which may be a cause of their known underutilization. However, these facilities are not enough on their own to mitigate regional heat-health challenges and should also be coupled with other elements associated with heat relief programs such as education, warnings, and welfare checks for the most vulnerable.

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