Title of Manuscript: Rapidly Developing a Community and Evidence Based Heat Action Plan

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Abstract

Extreme heat contributes to 8,000 to 12,000 excess U.S. deaths per year. Partly due to increasing summer temperatures and a renewed focus on environmental justice, local governments started new initiatives to manage and adapt to extreme heat. For example, Miami-Dade County, Florida, U.S., appointed Jane Gilbert as the world's first Chief Heat Officer. This manuscript summarizes Miami-Dade County's preliminary efforts to build local evidence, engage the community, and rapidly respond to extreme heat. The manuscript's goal is to expedite the translation of existing tools into mainstream extreme heat, health, and equity planning. The study generated local evidence to identify the places and periods of time with elevated heat related illness using a statistical vulnerability and time series analysis, respectively. The places with the highest severe heat-related illness rates had hotter land surface temperatures and/or higher proportions of people who were outdoor workers, indigenous, living in poverty or mobile homes, and households with children. "Everyday" summer conditions instead of rare heatwaves increase the risk of a heat related death. The Chief Heat Officer convened workshops that engaged 298 unique community members on six cross-sectoral heat topics. Key recommendations included: increasing multi-sectoral heat monitoring and risk communication, building more affordable housing, preserving and expanding greenspace, and creating heat resilience hubs. The activities culminated in a Heat Action Plan, which was completed in less than two years from the receipt of project funding.

Capsule

This manuscript summarizes the world's first Chief Heat Officer's efforts to build local evidence, engage the community, and rapidly respond to extreme heat.

Significance Statement

Extreme heat is a contributing factor to more U.S. deaths per year than any other weather hazard. This manuscript summarizes the world's first Chief Heat Officer's efforts to build local heat and health evidence. The places with the highest heat-related illness rates had hotter surface temperatures and/or higher proportions of people who were outdoor workers, indigenous, living in poverty or mobile homes. On hot and humid days, 7.8% (603 deaths) of the summer deaths per year were associated with the concurrent and preceding day's heat exposures. In response, Miami-Dade County is targeting heat interventions, lowering heat advisory thresholds, and considering new heat safety laws.

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Introduction

Over 2002 to 2020, an increasing proportion of jurisdictions considered extreme heat in their planning activities (Bernard and McGeehin 2002; Meerow and Keith 2022). In Miami-Dade County, Florida U.S. (M-DC), community based organization's (Miami Climate Alliance, Catalyst Miami, and others) conducted a survey to reveal the most pressing issues facing residents. The top two concerns were housing affordability and coping with extreme heat – rather than sea level rise. Extreme heat planning is most commonly described in municipal or county sustainability, climate action or resilience, emergency response, comprehensive, or hazard mitigation plans (Meerow and Keith 2022). The Adrienne Arsht-Rockefeller Foundation Resilience Center awarded M-DC a challenge grant to rapidly respond to extreme heat under the Resilient305 Strategy framework. In May 2021, Mayor Daniella Levine Cava appointed Jane Gilbert to serve as the Chief Heat Officer (CHO) to develop and oversee the implementation of a cross departmental and community-wide plan to address the increasing health and economic impacts of extreme heat. The CHO works within the M-DC Office of Resilience ensuring an integrated approach with the County's Sea Level Rise and Climate Action Strategies. As of 2023, three U.S. (M-DC; Los Angeles, California; Phoenix, Arizona) and five global jurisdictions (Santiago De Chile; Freetown, South Africa; Athens, Greece; Melbourne, Australia, and North Dhaka, Bangladesh) host Chief Heat Officers. This manuscript shares M-DC activities to rapidly respond to extreme heat. Specifically, it describes building an evidence base for heat risk and coordinated and inclusive planning process that culminated in an extreme heat action plan: i) vulnerability assessment, ii) heat attributable mortality analysis, iii) Climate and Heat Health Task Force community-based workshops (Meerow and Woodruff 2020).

Spatial heat vulnerability assessments provide insight into key risk groups and help jurisdictions prioritize areas for heat adaptations (e.g., San Francisco Department of Public Health Climate and Health Program 2023; New York City 2023). While they are considered a valuable resource, extreme heat vulnerability maps were only available for 26% of U.S. jurisdictions (Meerow and Keith 2022). The present study used a spatial regression to create separate heat related emergency department (ED) and hospitalization vulnerability maps. Beneficially, this technique derives the relative importance of risk factors and increases alignment between risk factors and adverse health outcomes (Harlan et al. 2013; Bao et al. 2015; Mallen et al. 2019; Conlon et al. 2020). In the Southeastern U.S., outdoor

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workers, people living in rural areas, manufactured homes, and/or poor households report higher heat related illness (HRI) rates (Crider et al. 2014; Kovach et al. 2015; Jung et al. 2021).

The heat attributable mortality analysis examines whether "everyday" summer heat exposures and/or rare heat waves were more consequential for human health in M-DC. This critical knowledge points to somewhat different risk groups, sensitive health outcomes, and ultimately adaptations strategies tailored to short term versus persistent heat exposures (Zografos et al. 2016; Bolitho and Miller 2017). For example, older adults, who are more likely to have pre-existing health conditions or access and functional needs, face the largest heatwave risks (Meade et al. 2022). In contrast, the persistent and cumulative effects of persistently high heat exposures may be most consequential for outdoor workers (e.g., Bandala et al. 2022). Across hot and humid Florida, "everyday" summer heat exposures are more consistently linked to adverse health outcomes than heatwaves (e.g., Harduar-Morano 2016; Jung et al. 2021). The present manuscript updates Shindell et al. (2020) estimate of 32-43 local heat exacerbated deaths over 2006-2010.

The manuscript's overall goal was to expedite the translation of existing tools into mainstream extreme heat, health, and equity planning. The research objectives were to develop local evidence on the places and periods with elevated heat related illness. In parallel, the M-DC CHO convened a task force to review the vulnerability assessment, heat mortality analysis, and community workshop feedback before iteratively recommending actions to be incorporated into M-DC's Heat Action Plan (2022).

Methods

Study Location

M-DC summer season is growing longer and heat exposures are becoming more intense due to climate change and urbanization. As of 2021, M-DC hosted an estimated 2,662,777 residents. Over 2017-2021, the median household income was $57,815 and 15.2% residents lived below the poverty line (U.S. Census Bureau 2022). Mirroring the U.S., 16.9% of residents were aged 65 years or older while 20.2% were under the age of 18 years old. A clear majority of residents are Hispanic or Latino (69%), followed by non-Hispanic Black or African American (15%), and non-Hispanic white (13%). Since 1957, M-DC's has a unique governance structure (two-tier federation) which grants the county the ability to enact regulations, plans and resolutions without prior state approval.

Data

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Extreme Heat Related Illness for Vulnerability Study

This study separately analyzed publicly available emergency room and hospitalization rates for 2015-2019 (Florida Department of Health 2022b). The cases recorded a primary or secondary International Classification of Diseases Clinical Modification (10th revision) heat-related illness (T67, X30) billing code. Per Florida Department of Health policies, the health outcomes are only reported at the five-digit postal zip code level. While HRI is likely under-counted, this study presumes cases are under-reported at similar rates throughout the county.

All-Cause Mortality

This study analyzed all-cause mortality (International Classification of Diseases Clinical Modification (10th revision, A00-Y89) for people with a Miami-Dade billing address from 2015-2019 (Florida Department of Health 2022a). This study opted to analyze all-cause versus cause-specific (cardiovascular, respiratory, renal, etc.) mortality due to variability in medical coding and the growing range of health conditions considered heat sensitive. Individual deaths were aggregated into a daily count over the summer (May-September) from 2015-2019.

Heat Exposure for Vulnerability Assessment

The study created a long-term, average, summer season (May to September) land surface temperature (LST) maps over the years 2003-2021. Separate maps correspond to the daytime (1:30 pm) and nighttime (1:30 am) overpasses of the Moderate Resolution Imaging Spectroradiometer (MODIS). The study composited all LST images with less than 50% cloud cover over the summer study period. In spite of their similar names, LST is distinct from surface air temperature measured at 2 m. In general, LST overestimates surface air temperatures but urban morphology, building materials, vegetation, and mechanical heat sources complexly influence the relationship (Venter et al. 2023).

Heat Exposure for Mortality Analysis

The National Oceanic and Atmospheric Administration's National Centers for Environmental Information (2022) provided outdoor weather conditions for the Miami International Airport weather station. The station recorded nearly all hourly (99.95%) outdoor temperature and dew point measured at a 2 m height from 1989-2019. Wet Bulb Globe Temperature (WBGT), which also considers solar radiation and ambient winds, may exhibit stronger associations with outdoor heat related illness

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(NIOSH 2016). The Florida Automated Weather Network provided temperature, humidity, wind speed, and solar radiation for two M-DC stations (Fort Lauderdale, Homestead). The weather information was subsequently converted to Wet Bulb Globe Temperature (WBGT) using Liljegren et al. (2008)'s energy transfer equations.

To align with previously published studies, we created heat wave definitions based on long-term daily temperatures over the period of record. Specifically, heat waves were defined as two or more days above the 98th percentile of maximum daily temperatures (33.9 ℃) (Chen et al. 2017). For reference, the 98th percentile of daily heat indices is slightly below the 2022 regional NOAA National Weather Service heat advisory threshold (42.2 ℃).

Sociodemographics

This study presumes that the ZCTA and five-digit postal zip codes are similar enough to be considered equivalent for this analysis. The study included established heat vulnerability dimensions as well as a broader range of factors that might be proposed by the general public (Table 1). Older adults (age > 65) are physiologically sensitive to heat, more likely suffer from chronic diseases, and take medications that increase heat storage, sensitivity, and/or dehydration (Havenith 2001; Meade et al. 2020). Due to their limited language skills, agency, and small body sizes, young children (age <5) can face elevated heat risks (Olsen et al. 2019). For example, hot and/or humid exposures may account for ~12% of the summer season, childhood emergency department visits (Bernstein et al. 2022). Teenages may be more likely to engage in outdoor athletics and suffer from heat-related illnesses (Kerr et al. 2019; Grundstein et al. 2012).

Table 1. Summary of the heat exposure and sociodemographic considered in the vulnerability analysis. The following variables were excluded from the analysis with a variance inflation factor > 5 (% Black, non-Hispanic, % Female Head of Household, % Limited Language Proficiency, % High School Education or Less). The table also references the data source.

Category	**Description of Data**	**Data Source**
Health Outcome	Heat Related Illness Emergency Department	FDOH
	Heat Related Illness Hospitalizations	FDOH
Exposure	Land Surface Temperature	NASA MODIS 2002-2021
	% Impervious Surface	NLCD (2019)

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	% Outdoor Workers	ACS 2015-2019
	(Agriculture, Forestry, Fish, Mining, Construction)	
Sensitivity	% Older Adults (age > 65)	ACS 2015-2019
	% Living Alone	ACS 2015-2019
	Children 0-5	ACS 2015-2019
	% Living in Poverty	ACS 2015-2019
	Household Income	ACS 2015-2019
	% Hispanic	ACS 2015-2019
	% Indigenous	ACS 2015-2019
	% Total Housing that are Mobile Homes	ACS 2015-2019

Multiple studies found a direct relationship between increased poverty and adverse heat-associated health outcomes (Gronlund, 2014). Poorer residents are less likely to have access to and pay for or maintain air conditioning, access cooling centers, and have health insurance. (Snyder and Baker 2010, Schmeltz et al. 2015; Hayden et al. 2017; Gabbe and Pierce 2020; Zhang et al. 2013). Across the U.S., African Americans have limited access to healthcare and are more likely to face institutional biases and engage in unhealthy behaviors (Peek et al. 2010; Dunkley et al. 2014). Florida's hosts relatively large proportions of Hispanic migrants who were relatively more highly educated, economically secure, and healthier than more recent Latin American migrants (Alarcón et al. 2016).

Indigenous people are more likely to suffer from intergenerational trauma, engage in outdoor occupations, live in rural areas with limited healthcare and social service access, and are less likely to speak English fluently (Hansen 2013; Petitti et al. 2013; Maldonado et al. 2016). In the U.S. American Community Survey, people self-report whether they are "American Indian or Alaska Native", which includes Indigenous people of both North (e.g., Mayan dialects) and South America that maintain a tribal attachment. In Maricopa County, Arizona mobile homes account for a disproportionately high 29% of indoor heat-related deaths but only comprise 5% of the population (Phillips et al. 2021). The reasons for this disparity are complexly related to the characteristics of people who live in a mobile

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home (e.g., fixed income, pre-existing health conditions) and higher heat exposures (Gabbe and Pierce 2020).

High heat exposures increase the risk of outdoor worker illness, injury, and death and reduce economic productivity and cognitive functioning (Wilson and Morely 2003; Spector and Sheffield 2014; Riley et al. 2018; Varghese et al. 2019). The heat related illness rates are derived from the patient's billing zip code and aligns with occupational information from existing datasets. The U.S. Census Bureau American Community Survey reports occupations of many but not all groups (agriculture, construction, forestry, fishing, and mining) who either work outdoors or indoor locations without air conditioning.

Methodology

The methodology section discusses three inter-related approaches to build evidence and listen to community feedback. The heat evidence time period focused on 2015-2019 to avoid the potentially non-representative impact of SARS-CoV-2 (COVID-19) on 2020 data. The section first describes the characteristics of the places (vulnerability assessment) with elevated heat related illness. Separate regressions examined emergency room visits or hospitalizations rates averaged over a five-year period at the five-digit postal zip code level, which was the smallest available geographic resolution. Next, the complementary analysis estimated heat attributable mortality over the entire county. The study aggregated data up to the county level to provide sufficient statistical power. In parallel, the CHO convened community workshops on six cross-sectoral topics. Collectively, the information contributed to the development of the M-DC's Heat Action Plan (2022).

Vulnerability Assessment

The study separately associated vulnerability characteristics against the geographic patterns of heat related ED or hospitalizations. Previous studies suggest ED often reflect exertional and occupational heat exposures while hospitalizations are more likely to reflect older and/or sicker patients (Hess et al. 2014; Florida Department of Health 2015; Bernstein et al. 2022). Standard diagnostics confirm that the regression assumptions were fulfilled. A Global Moran's I verified whether the assumption of independent and identically distributed residuals, which is commonly violated by geographic data.

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The study implemented two procedures to limit "double counting" of risk factors that contain overlapping or redundant information. First, the analysis sequentially removed risk factors with the largest variance inflation factor (VIF) until all candidate variables had a VIF < 5. Specifically, the percentage of households with the following characteristics were excluded: non-Hispanic Black, female head of household, limited language proficiency, and High School education or less. A pre-screening procedure separately associated each heat exposure metric against HRI rates. Daytime land surface temperature (versus night time) exhibited a stronger model fit and were included in subsequent analysis. Second, the study used a variable selection procedure (stepwise backwards and forwards) to select a well-fitted model. While the limitations of this procedure are well documented, it can be appropriate for considering a wider range of vulnerability metrics to respond to public feedback. As a consequence, the statistical p-values should be interpreted more as guideposts than a clear threshold between significant/non-significant results.

Heat Attributable Mortality Analysis

In the time series analysis, a jurisdiction is compared against itself over time and acts as its own control. This procedure controls for slowly changing risk factors (e.g., income) that "cancel out" during the comparison process. The time series analysis used distributed lag non-linear models (DLNM) (Poisson statistical family, log link function) to associate heat indices (concurrent and preceding nine days) and heatwaves against daily all-cause mortality from 2015-2019 (Gasparrini et al. 2010). Beneficially, DLNM jointly identify the "shape" (e.g., linear, curvilinear with threshold) of the exposure-mortality relationship and for the preceding day's exposures (natural cubic beta splines). The DLNM also implicitly controlled for short-term mortality displacement; people would have normally perished shortly after the event due to natural causes, by examining lagged associations (Armstrong 2006). The statistical analysis controlled for: study year and day of the week using indicator variables, study day with natural cubic regression splines, temporal autocorrelation with a one day autoregressive term, and the population at-risk. The observed temporal lag between heat exposure and mortality may be influenced by the human body's heat storage and/or the time between death and finding the decedent (Notley et al. 2018). Excess heat can accumulate in the human body over the order of hours to days and cumulatively increase the risk of adverse health outcomes (Kenny et al. 2017). The second reason for the lag may be that older adults who live alone and succumb to heat can be found multiple days after high heat exposures (Donoghue et al. 1997). To account for this uncertainty, sensitivity testing

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considered temporal lags over the three scenarios: the preceding zero to three, zero to nine, and zero to twenty days.

Adjusting for the population size provides more confidence that the results are not an artifact of more people moving to the study area during the study years with higher heat exposures. The study did not adjust for ozone due to the relatively high percentage (15.2%) of missing regulatory monitor observations (Florida Department of Environmental Protection 2023). Thus, the temperature beta coefficient represents the direct effect of temperature and ozone mediated effect of temperature on all-cause mortality (Reid et al. 2012). The results report the heat index beta coefficient, standard error, 95% confidence intervals, and p-values. Finally, the analysis inferred the heat attributable mortality from the DLNM model and the total number of summer deaths over the study period (39,760; Gasparrini and Leone 2014). Monte Carlo simulation estimates the 95% confidence intervals for the estimated fraction and number of deaths attributable to heat.

Climate and Heat Health Taskforce and Public Workshops

In November 2021, the CHO launched the Climate and Heat Health Task Force in partnership with The Miami Foundation to guide the development of the Extreme Heat Action Plan. The 15-member task force was co-chaired by the CHO and Dr. Cheryl Holder, physician, professor and community advocate. The task force included two community members from our most vulnerable communities with lived experience of extreme heat who were selected out of 53 applications. The community representatives were provided a modest stipend for their time. Ms. Gilbert and Dr. Holder then appointed key stakeholders from the National Weather Service, State Health Department, municipal partners, County, university, private sector and community-based organizations representing outdoor workers, affordable housing, and climate resilience interests.

The CHO and M-DC Office of Resilience convened six public virtual workshops from December 7th, 2021 to March 29th, 2022. The online workshops were synchronously facilitated at 10:30 am Eastern Time (America/New York). The goals of these workshops were to broaden awareness of the health and economic impacts of extreme heat, to gather insights and recommendations for heat preparedness, response and mitigation, and engage diverse stakeholders to be involved in and support the implementation of the plan. The six workshops addressed: i) outreach & education, ii) data and research, iii) emergency preparedness and response, iv) workers exposed to heat, v) housing, and vi)

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streets and trees. During each workshop, the CHO subject matter experts led a brief presentation on the state of the current initiatives within the county and/or national/international best practices. The majority of the workshop was spent in smaller, facilitated, break-out groups that posed questions to gather further feedback and ways the stakeholders involved could address those concerns. During the last portion of the workshop, the small group facilitators reported recurring or key themes to the larger group of participants, which provided initial themes for the qualitative analysis. The presentations, recordings, list of attendees and notes from facilitated break out groups can be found on The Miami Foundations' (2024) webpage on Extreme Heat. The workshops were recorded and transcribed. Two coders iteratively refined each workshop's themes, generated interconnections, and developed cross-linkages to the planning literature, and Heat Action Plan.

Results

Vulnerability Assessment

The study results suggest somewhat different combinations of risk factors were related to emergency department visits versus hospitalizations across M-DC over 2015-2019. In general, the results align with other regional heat vulnerability studies and Florida life expectancy studies (e.g. Melix et al. 2020). The geographic pattern of HRI ED was strongly related to land surface temperature and the proportion of outdoor workers. A one degree (℃) increase in average summer, daytime, land surface temperature translated into 0.74 HRI ED calls per 100,000 people. HRI ED were also consistently higher in zip codes with proportionately more children, perhaps reflecting the greater likelihood of children to participate in outdoor exertional or recreational activities. Consistently, zip codes with a higher proportion of Indigenous residents also experienced higher average HRI ED rates. However, this effect was imprecisely estimated, as reflected by the wide beta coefficient 95% confidence intervals. Consistent with local political and migration histories, neighborhoods with higher proportions of Hispanics reported lower HRI ED rates.

Table 2. The results of the classified HRI ED statistical vulnerability analysis. The analysis considered 79 zip code tabulation areas and the model accounted (adjusted R^2) for 65% of the HRI ED variability. Table 1 summarizes the analysis data sources.

Risk Factor	Beta Coefficient	95% CI	p-value
Daytime Surface Temperature ℃	0.74	0.46 : 1.01	<0.001
Outdoor Workers %	0.57	0.38 : 0.76	<0.001

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Age Less than 18 %	0.43	0.25 : 0.61	<0.001
Indigenous %	13.47	3.98 : 22.97	0.01
Hispanic %	-0.06	-0.1 : -0.02	0.01
Living Alone %	0.17	0.01 : 0.32	0.03
Mobile Homes %	0.30	-0.01 : 0.6	0.06

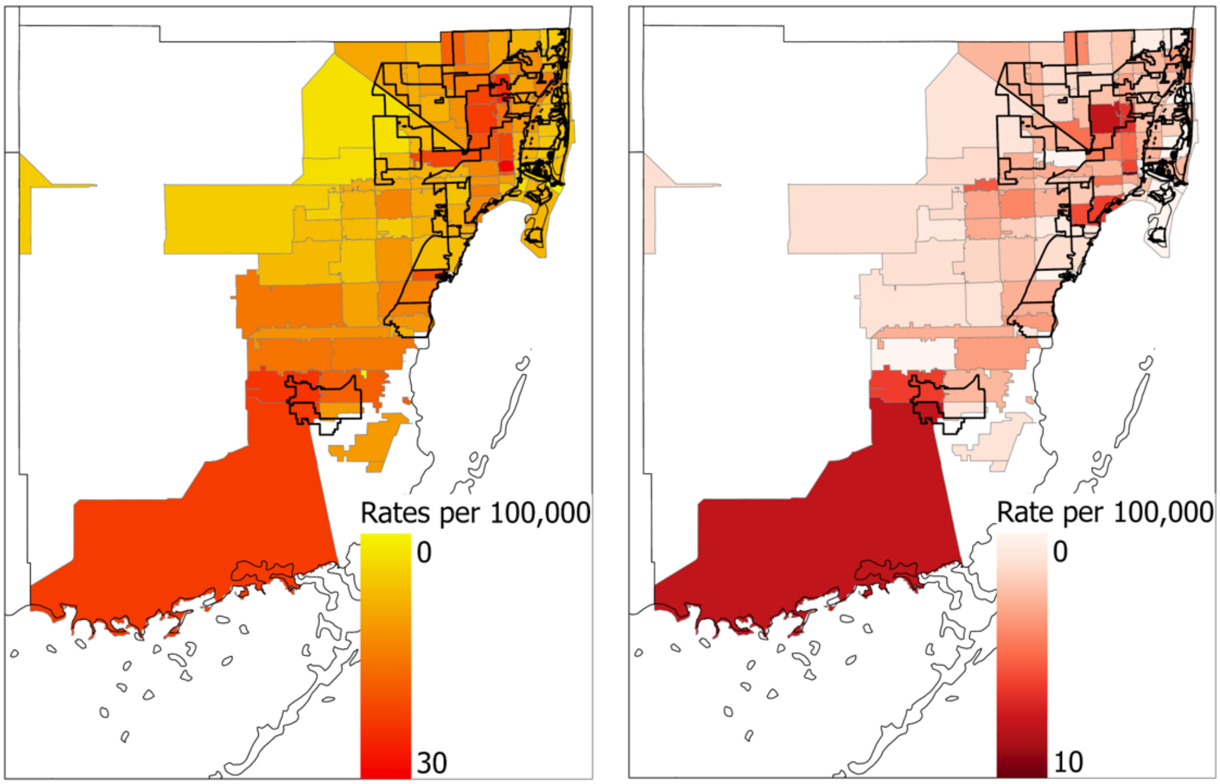

Figure 1. Maps of the rates of classified HRI ED (1a) or hospitalization (1b) rates reported to the Florida Department of Health over 2015-2019 across the study area. The grey polygons correspond to U.S. Census zip code tabulation areas while the black polygons are specific M-DC municipalities. The highest HRI ED and hospitalization rates were reported in the southern portions of the county (Florida City and Homestead), and surrounding the Miami International Airport (Hialeah, Little Havana, Fontainebleau). In addition, high HRI hospitalization rates were reported in western Miami-Dade County and South Miami.

While the geography of HRI ED was multifactorial, the HRI hospitalization rate was only related to socioeconomic position as reflected by higher percentages of people living in poverty and/or living in manufactured/mobile homes. Each percentage increase in the proportion of economically impoverished translated into 0.14 HRI hospitalizations per 100,000 people.

Table 3. The results of the classified HRI hospitalizations vulnerability analysis. The analysis considered 79 zip code tabulation areas and the model accounted (adjusted R^2) for 44% of the HRI hospitalizations variability. The Florida

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Department of Health and U.S. Census Bureau respectively shared HRI hospitalizations and sociodemographic information.

Risk Factor	Beta Coefficient	95% CI	p-value
% Living in Poverty	0.14	0.1 : 0.18	<0.001
% Mobile Homes	0.19	0.07 : 0.31	<0.001

Heat Attributable Mortality Analysis

The maximum daily heat index (combined effect from nine days prior to the concurrent day) linearly increased all-cause mortality risk in the study area from 2015-2019. The cumulative lagged mortality and heat association became significant by the sixth to ninth day preceding death (Figure 2). In other words, multiday periods of elevated temperatures were most consequential for health. The analysis controlled for temporal cycles, trends, the previous day's morality count (statistically significant), and the size of the population at-risk. Over the study period, there were 42 heatwave days (8.4 per year). In contrast to daily heat index, these relatively rare events were unrelated to mortality. Neither average or minimum daily heat indices nor WBGT were consistently related to daily deaths. The DLNM estimated that 7.8% (95% confidence interval: 1.4-13.5%) of summer deaths on days with average heat indices over 30 ℃ may be exacerbated by extreme heat. This translates to 603 excess deaths per year (95% confidence interval: 138-1063 deaths per year). Since the DLNM comprehensively considers lagged exposures, it estimates larger excess mortality than series studies that only consider concurrent exposures (Shindell et al. 2020).

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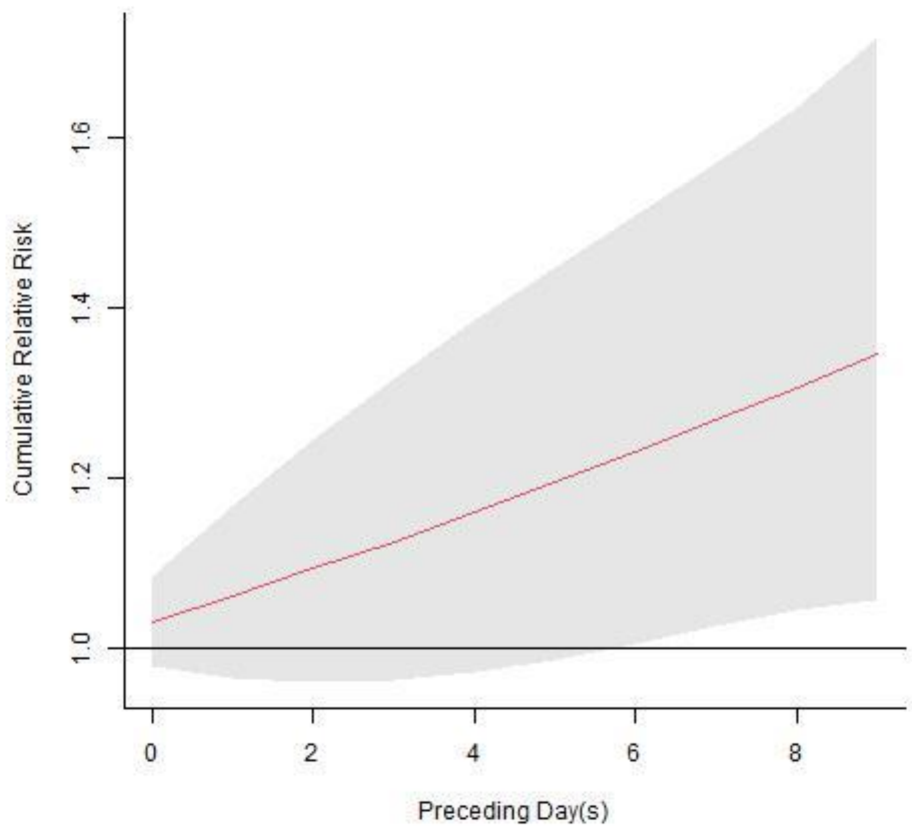

Figure 2. Cumulative relative risk of an excess death due to heat indices greater than or equal as opposed to below 30 °C in the preceding zero to nine days. The figure plots the point estimate (red line) and 95% confidence intervals. The Florida Department of Health shared the mortality data while NOAA's National Weather Service provided heat exposure information.

Workshop Results

The six public workshops engaged 298 individuals (50-70 participants/workshop) and covered six thematic areas (Supplemental Material). The Climate and Heat Health task force assisted in the promotion of the workshops and participants represented a diverse mix of County and municipal staff, university researchers, community-based organizations and active/concerned residents.

The Outreach and Education workshop first asked participants for high-quality examples of heat outreach and communication strategies. A participant referenced New York City Mayor's Office's (2023) Be a Buddy Campaign. This program works with community-based organizations to provide

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services to at-risk individuals during emergencies such as heatwaves. The workshop participant articulated different mediums and messengers to communicate with at-risk groups such as race/ethnic communities (mass media, radio, community newspapers, social media), pregnant people (existing Florida Health Department programs), and outdoor enthusiasts (heat warning signage or risk flags). Participants recommended partnering with existing community-based organizations and integrating heat education into existing programs (e.g., cardiopulmonary resuscitation).

The data and research workshop discussed partnerships to improve underreporting of heat related illness, heat advisories, and short-term research priorities. In order to detect a higher proportion of cases, the participants proposed heat related illness training for a wide range of healthcare workers. Specifically, health care providers should ask patients about housing and air conditioning access and potentially refer patients to social service providers. Multiple participants suggested increasing multi-sectoral collaboration on heat monitoring and awareness involving broadcast meteorologists, the private sector working on low cost sensor networks, and local government programs (resilience hubs, public transportation, school districts), and faith based organizations.

The emergency preparedness and response workshops focused on heat prevention recommendations and knowledge of heat related illness from key heat risk groups. Participants emphasized the importance of pre-event planning such as knowledge of the closest cooling refuge and training existing 311 municipal service request dispatchers to respond to extreme heat. Community-based organizations stated that communities of color are aware of extreme heat and health risks. This is consistent with the Miami Climate Alliance (2023) survey highlighting affordable housing and extreme heat as top community priorities.

Occupational heat and health discussions focused on raising employer and worker heat knowledge, piloting programs to incentivize employer heat prevention, and existing county and state heat and health legislation. Participants recommended funding a widespread mass media heat awareness campaign, encouraging businesses to write emergency heat action plans, and creating free employee heat safety training. Respondents also suggested that M-DC could create an anonymous helpline for workers to report heat safety violations. During the 2022 legislative session, Florida Senators introduced a bipartisan bill (SB 732) to mandate the right to cool drinking water, shade, and mandatory breaks during high heat exposures. The bill did not make it out of committee for a full vote.

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The housing workshop discussed accelerating measures to reduce the energy burden for single and multifamily building. Discussions recognized existing barriers toward partnering, mandating, and incentivizing private electrical companies and/or landlords to fund energy efficiency retrofits. Related strategies included expanding funding and broadening eligibility for existing programs (e.g., Weatherization Assistance Program) or disseminating low-cost but high efficacy energy efficiency packages to renters. Multiple participants highlighted the insecurities created by the high cost of housing.

The streets and trees workshop focused M-DC engagement, policies, and actions to cool vulnerable neighborhoods. Respondents highlighted a range of considerations and potential trade-offs when promoting tree species such as native vegetation, fruiting trees to improve food security, or risk to power transmission lines. In addition to green infrastructure, potential investments included white roofs, cool and/or pervious pavements, and shading. Key partnerships to build upon include school districts, healthcare facilities, and land use developers.

This section briefly describes how the heat evidence and community workshops were developed into M-DC's Heat Action Plan (2022). The CHO's team compiled, reviewed, and grouped the workshop participant's feedback into potential goals and associated action items. The vulnerability assessment, time series results, and community workshop summaries were formally presented to the Climate and Heat Health Task Force. The task force completed an initial survey to prioritize actions recommended through the public forums. The CHO's team and task force iteratively discussed and refined the priorities while considering the level of impact, feasibility, and cost-effectiveness of proposed actions.Priority action items were more extensively developed by M-DC staff and organized under the following three resilience-building goals to: i) inform, prepare and protect people, ii) cool our homes and emergency facilities, iii) cool our neighborhoods. These three goals aim to move Miami-Dade County's people, places and organizations toward a more resilient, healthy, inclusive and equitable future. Each action described the background and intentions of the action, who would be involved and the timeline for implementation.

Discussion

Key M-DC Heat Action Plan strategies included building the comprehensive heat watch/warning system, a communications campaign, and leveraging tree-planting resources. Issuing a heat watch

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triggers coordinated preparations by emergency management, homeless trust, parks, and libraries. A heat advisory activates communications about the opening of cooling sites (at park community centers and libraries) and outreach to the unsheltered populations with including distributions of bottled water and cooling gaiters. A heat warning uses stronger language encouraging cancelling or rescheduling outdoor activities and offers extended hours at cooling sites. The 2023 heat safety communications campaign targeted neighborhoods identified in the vulnerability assessment and key risk groups (e.g., outdoor workers).

The multi-media campaign engaged both conventional advertising (e.g., radio advertising, bus panels and shelters), digital resources (e.g., search engine marketing, social media, YouTube), and community based outreach through a series of trainings and presentations. The 2023 summer radio, social media, and advertising campaign reached at least 3 million M-DC residents and visitors in three languages (English, Spanish, and Haitian Creole). M-DC developed a companion ESRI StoryMap to the Heat Action Plan that received over 3,700 unique page views (10 per day) from May 2022 to April 2023. To meet the goal of cooling homes affordably, 1,700 efficient AC units were installed in public housing. To meet the goal to cool our neighborhoods, M-DC planted 16,000 trees and gave away an additional 10,000 trees targeting low-income and low tree canopy neighborhoods. Additionally, Parks, Recreation and Outdoor Spaces was awarded $10 million USD grant to increase tree canopy in disadvantaged neighborhoods and engage residents through strategic tree planting.

This section contextualizes the study findings with a discussion of existing and planned M-DC Heat Action responses. A growing list of institutions (e.g., Heat Health Information Networks [Global, South Asia], World Meteorological Organization (2021), Adrienne Arsht-Rockefeller Foundation Heat Action Platform (2023), American Planning Association (Meerow and Keith 2021)) provide guidance on effectively adapting to extreme heat. The corresponding heat guidance documents all emphasize heat vulnerability, heat forecasting and services, and partnerships and capacity building. While the evaluation type, approach, and quality vary, there is some evidence that a suite of interventions implemented outlined in heat adaptation plans save lives (Dywer et al. 2022)

This manuscript found some evidence that "everyday" summer heat exposures proportionately increased the risk of heat related deaths in the study area. This led to the heat education campaign's focus on the entire May-October "Heat Season" instead of rare heat waves to take preventative measures for themselves, their loved ones, employees and people they serve. Through multiple

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channels including radio, television, outdoor ads and billboards, and social media, the multilingual campaign reached over 3.5 million people through multiple touchpoints. Consistent with previous studies, severe HRI was not influenced by relatively rare heatwaves in the study area (e.g., Vaidyanathan et al. 2019).

Hondula et al. (2022) found south Florida issued heat advisories less frequently than expected based on average heat indices. The lower heat advisory thresholds may be further compounded by warmer microclimates. A 2023 study found average maximum surface (0.5 to 2m) heat indices could be ~6 ℃ hire than the airport weather station (Clement et al. 2023). In 2023, the CHO worked with the National Oceanic and Atmospheric Administration National Weather Service to lower the heat watch (daily maximum heat index of 42.2 ℃ to 40.6 ℃) and warning thresholds (44.4 ℃ to 43.3 ℃). Heat advisories trigger a series of societal heat adaptations such as heat safety messaging, opening cooling centers, and heat resilience hubs. In New York City, New York, U.S., lowering heat advisory thresholds and the corresponding social programs decreased average heat related illness in older adults (Benmarhnia et al. 2019).

Relatedly, the data and research workshop discussed healthcare strategies to document a higher proportion of HRI cases. In Pakistan, multi-pronged heat training and education strategy doubled the proportion of heat emergencies, exhaustion, and stroke emergency physician diagnosis (Ullah Khan et al. 2023). In September of 2022, the Florida Clinicians for Climate Action (a key CHO partner) partnered with Baptist Health and M_DC in the creation of a continuing education series for healthcare professionals and then targeted outreach about the workshops and information resources to healthcare providers serving the residents living in zipcodes with the highest HRI rates. Maricopa County, Arizona U.S., developed a workflow to more expansively monitor heat related mortality by combining state level vital mortality information with notes about the decedent's living situation (Iverson et al. 2020).

The ED vulnerability results may point to a broader suite of policy actions to support at-risk groups and manage heat exposures. While land surface and air temperatures are not equivalent, neighborhoods with elevated outdoor land surface temperatures reported higher severe HRI rates. A key M-DC Extreme Heat Action Plan goal is cooling neighborhoods by: increasing tree canopy coverage to 30% particularly in neighborhoods with the highest HRI; cooling bus stops, pedestrian walkways, and schools; and piloting cool infrastructure materials such as pavements.

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Geographic areas with higher proportions of outdoor workers and/or Indigenous people reported higher rates of HRI. To respond to this challenge, M-DC Extreme Heat Action Plan created separate actions to support outdoor workers and employers and workplace protections for outdoor workers. Households with children (age < 18 years old) and specific racial and ethnic groups faced disparate health risks. Young children may be particularly susceptible to extreme heat due to their limited language skills, agency, and small body sizes (Olsen et al. 2019; Bernstein et al. 2022). Children participating in recreational sports may also face elevated risks (Nelson et al. 2010; Fuhrmann et al. 2015). There was also some evidence that Indigenous communities reported elevated HRI, possibly because they were more likely to engage in outdoor livelihood strategies (Petitti et al. 2013).

In general, heat hospitalizations were more likely to reflect older adults and/or people with pre-existing, and/or unmanaged health conditions (Hess et al. 2014; Florida Department of Health 2015; Bernstein et al. 2022). This report suggests limited financial resources are most strongly related to elevated HRI illness rates. Poor households receiving federal energy assistance spend the same proportion of their income on electricity (~16%) as food or transportation (Snyder and Baker 2010). The proportion of mobile home residents may capture a different dimension of housing poverty or serve as a proxy for fixed or unstable incomes (Aman and Yarnal 2010; Phillips et al. 2021).

The advantages of this manuscript's approach was greater collaboration and engagement with community based organizations, the healthcare sector, and universities. This section briefly summarizes the study's limitations and trade-offs. The vulnerability assessment aligned HRI at the five digit postal zip code with sociodemographic information from zip code tabulation areas. While this slight spatial mismatch is most consequential in rural areas, it adds additional uncertainty to the HRI results (Grubesic 2008). The vulnerability assessment presumed that HRI rates are under-reported at similar rates throughout the county. However, HRI rates may be under-reported in areas with lower rates of health insurance coverage and/or undocumented people (e.g., Jung et al. 2021). Thus, the magnitude of the HRI disparity may be larger than documented by existing health records. Future research can map how a comprehensive suite of programs/interventions can reduce HRI vulnerability (e.g., Keith et al. 2022). The precision of the heat attributable mortality analysis estimates and ability to statistically control for ambient ozone levels would be improved by a longer study period. The community workshops were held online during normal business hours due to ongoing COVID-19

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transmission. This modality is well suited for gathering community suggestions and ideas but may reduce deliberations compared to face-to-face meetings (Friess and Eilders 2015; Bobbio 2018). Relatedly, inequitable access to video conference and high-speed internet may further constrain equitable participation (Van Dijk 2017).

One recommendation for other jurisdictions engaging with extreme heat would be to work with government division leaders to clarify work plans and performance benchmarks for the Heat Action Plan programs and activities relying on their leadership. Relevantly, it may be difficult to replicate this effort in smaller jurisdictions with fewer financial, technical resources, and academic partners (Trego et al. 2023). While the field is rapidly evolving, jurisdictions with less capacity can consider using a modified Delphi method. This iterative, consensus building methodology, allows community experts to anonymously prioritize heat programs and interventions (e.g., Adler and Ziglio 1996; Shortridge et al. 2022). Alternatively, the Centers for Disease Control and Prevention (2022) or Adrienne Arsht-Rockefeller Foundation Resilience Center (2023) Heat Action Platform provide frameworks for selecting and/or implementing or evaluating heat adaptations. In the U.S., the National Integrated Heat Health Information System will establish two Centers of Excellence to work with small and medium jurisdictions, but the need for technical cooperation will likely exceed current levels of financial support.

Conclusions

The manuscript's goal is to expedite the adoption of public health and geographic tools into heat, health, and equity planning. The places with the highest severe heat-related illness rates had hotter land surface temperatures, and higher proportions of people who were outdoor workers, indigenous, living in poverty or mobile homes. M-DC is targeting interventions such as green infrastructure to the 15 census places with disproportionately high heat related illness rates. The time series analysis estimated that daily average heat indices contribute to ~7.8% of summer deaths on days with heat indices at or above 30 ℃. Feedback from the Climate and Heat Health Taskforce workshops was integrated into the larger M-DC Extreme Heat Action Plan (2022) whose goals are to: i) inform, prepare and protect people, ii) cool our homes and emergency facilities, iii) cool our neighborhoods.

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Availability

The mortality information can be requested from the Florida Department of Health Office of Vital Statistics. The remaining study data sources are openly available at locations cited in the reference section.

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