Science of the Total Environment 909 (2024) 168377

Contents lists available at ScienceDirect

Science of the Total Environment

journal homepage: www.elsevier.com/locate/scitotenv

Review

Impact of heat on emergency hospital admissions related to kidney diseases in Texas: Uncovering racial disparities

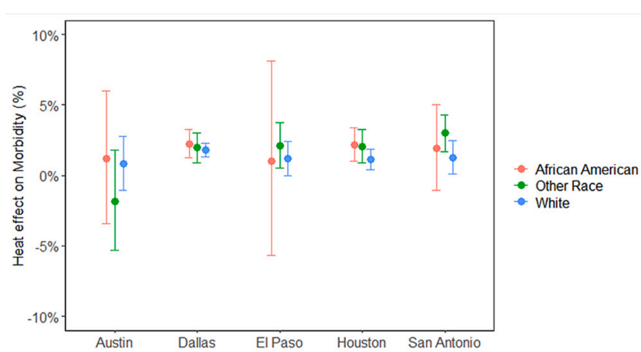
Chunyu Guo [a], Erjia Ge [b], Manzhu Yu [c], Changwei Li [d], Xiangqian Lao [e], Shuang Li [f], Jason Glaser [g], Yongqun He [h], Marina Almeida-Silva [i,j], Sisi Meng [k], Wei-Chung Su [l], Junfeng Zhang [m], Shao Lin [n], Kai Zhang [n,*]

[a] Department of Economics, School of Art and Science, University at Albany, State University of New York, Albany, NY, USA
[b] Division of Epidemiology, Dalla Lana School of Public Health, University of Toronto, Toronto, ON, Canada
[c] Department of Geography, The Pennsylvania State University, University Park, PA, USA
[d] Department of Epidemiology, Tulane University School of Public Health and Tropical Medicine, New Orleans, LA, USA
[e] Department of Biomedical Sciences, City University of Hong Kong, Hong Kong
[f] Department of Sociology, Bridgewater College, Bridgewater, VA, USA
[g] La Isla Network, Washington D.C., USA
[h] Unit for Laboratory Animal Medicine, University of Michigan Medical School, Ann Arbor, MI, USA
[i] H&TRC-Health & Technology Research Center, ESTeSL-Escola Superior de Tecnologia da Saúde, Instituto Politécnico de Lisboa, Lisbon, Portugal
[j] OSEAN-Outermost Regions Sustainable Ecosystem for Entrepreneurship and Innovation, 9000-039 Funchal, Portugal
[k] Pulte Institute for Global Development, Keough School of Global Affairs, University of Notre Dame, Notre Dame, IN, USA
[l] Department of Epidemiology, Human Genetics and Environmental Sciences, School of Public Health, University of Texas Health Science Center at Houston, Houston, USA
[m] Global Health Institute and the Nicholas School of Environment, Duke University, Durham, NC, USA
[n] Department of Environmental Health Sciences, School of Public Health, University at Albany, State University of New York, Rensselaer, NY, USA

HIGHLIGHTS

- High temperature in Texas affects kidney disease-related morbidity.
- Heat effect on kidney disease-related morbidity varies by MSA and age groups.
- Heat effect on morbidity varies by specific types of kidney diseases.
- Minorities face a higher risk of kidney disease-related morbidity due to heat.

GRAPHICAL ABSTRACT



ARTICLE INFO

Editor: Scott Sheridan

ABSTRACT

Background and objective: While impact of heat exposure on human health is well-documented, limited research exists on its effect on kidney disease hospital admissions especially in Texas, a state with diverse demographics

* Corresponding author at: Department of Environmental Health Sciences, School of Public Health, University at Albany, State University of New York, Rensselaer, NY 12144, USA.
E-mail address: kzhang9@albany.edu (K. Zhang).

https://doi.org/10.1016/j.scitotenv.2023.168377
Received 26 August 2023; Received in revised form 25 October 2023; Accepted 4 November 2023
Available online 11 November 2023

Keywords:
Heat
Emergency hospital admission
Kidney disease
High temperature

and a high heat-related death rate. We aimed to explore the link between high temperatures and emergency kidney disease hospital admissions across 12 Texas Metropolitan Statistical Areas (MSAs) from 2004 to 2013, considering causes, age groups, and ethnic populations.

Methods: To investigate the correlation between high temperatures and emergency hospital admissions, we utilized MSA-level hospital admission and weather data. We employed a Generalized Additive Model to calculate the association specific to each MSA, and then performed a random effects meta-analysis to estimate the overall correlation. Analyses were stratified by age groups, admission causes, and racial/ethnic disparities. Sensitivity analysis involved lag modifications and ozone inclusion in the model.

Results: Our analysis found that each 1 °C increase in temperature was associated with a 1.73 % (95 % CI [1.43, 2.03]) increase in hospital admissions related to all types of kidney diseases. Besides, the effect estimates varied across different age groups and specific types of kidney diseases. We observed statistically significant associations between high temperatures and emergency hospital admissions for Acute Kidney Injury (AKI) (3.34 % (95 % CI [2.86, 3.82])), Kidney Stone (1.76 % (95 % CI [0.94, 2.60])), and Urinary Tract Infections (UTI) (1.06 % (95 % CI [0.61, 1.51])). Our research findings indicate disparities in certain Metropolitan Statistical Areas (MSAs). In Austin, Houston, San Antonio, and Dallas metropolitan areas, the estimated effects are more pronounced for African Americans when compared to the White population. Additionally, in Dallas, Houston, El Paso, and San Antonio, the estimated effects are greater for the Hispanic group compared to the Non-Hispanic group.

Conclusions: This study finds a strong link between higher temperatures and kidney disease-related hospital admissions in Texas, especially for AKI. Public health actions are necessary to address these temperature-related health risks, including targeted kidney health initiatives. More research is needed to understand the mechanisms and address health disparities among racial/ethnic groups.

1. Introduction

The growing concern about climate change has brought attention to the negative impact of hot weather on public health. Earlier studies have revealed the damaging effects of exposure to high temperatures on emergency department visits and hospital admissions due to various disease pathways (Guo et al., 2023b; Schramm et al., 2021; Ye et al., 2012). However, the kidney failure has received much less attention, even though kidney diseases can be compromised by high temperature exposure (Borg et al., 2019; Liu et al., 2021; McTavish et al., 2018). High temperatures and heat can lead to dehydration as individuals perspire and lose fluids, potentially resulting in kidney stones, renal colic, and electrolyte imbalances, with severe cases leading to conditions like arrhythmias and acute renal failure (Harlan et al., 2014). Even healthy individuals may experience acute kidney injury due to heat-induced volume depletion. Given the kidneys' vital role in maintaining water and electrolyte balance, understanding the impact of temperature changes on kidney function and hospital admissions is crucial.

Previous studies in various regions and cities have linked high-temperature exposure to kidney disease-related hospital admissions (Fletcher et al., 2012; Hansen et al., 2008; Kim et al., 2018; Knowlton et al., 2009; Malig et al., 2019; Remigio et al., 2019). However, no such research has been conducted in Texas, a state with a hot climate and high summer evaporation rates, posing significant public health challenges (Zhang et al., 2015). Guo et al. (2023b) identified a significant correlation between high temperatures and mortality in Texas, motivating our exploration of the impact of heat on kidney disease-related hospital admissions in the state. Our findings may have implications for regions with climate conditions and socio-economic characteristics similar to those of Texas. For instance, areas with comparable temperature and humidity profiles, such as Florida, Arizona, and California, might encounter similar patterns of heat-related hospital admissions. Furthermore, the research methodology employed in this study has the potential to be replicated in other geographical areas to explore the impact of heat on hospital admissions.

Furthermore, disparities in hospitalization and morbidity related to climate change have been observed, but few studies have explored the health disparities in kidney diseases caused by high temperatures. African American and Latino populations face higher risks and mortality due to elevated temperatures compared to Whites, with foreign-born populations at even greater risk (Berberian et al., 2022; Thongprayoon et al., 2020). Several studies have shown that the impact of high temperature on hospital admission can differ between ethnic groups (Hansen et al., 2013; O'Neill et al., 2005). A study by O'Neill et al. (2005) suggested that the health impacts associated with exposure to heat could vary across different racial groups and this difference may be related to the levels that air conditioners used in these groups or cities/regions. Populations and areas with insufficient healthcare and cooling equipment are particularly vulnerable to health effects from climate change. Studies by Fletcher et al. (2012) and Qu et al. (2022) found differences in the estimated heat effect on renal diseases across racial/ethnical groups in New York state. In Texas, approximately 40 % of the population is Hispanic, and 12 % is Black (Texas Demographic Center, 2020). Studies have uncovered health disparities in Texas, with more Black and Hispanic residents being reported as having poor health compared to White residents (Guo et al., 2023a; Turner et al., 2021). In our paper, we took advantage of the diverse population composition in Texas to explore the disparities of emergency hospital admission related to kidney diseases caused by high temperature.

Our study sought to comprehensively explore the correlation between high temperatures and emergency hospital admissions related to kidney diseases in Texas. By utilizing a consistent statistical approach and a dataset that spans a longer time period and wider geographical region than prior research, we were able to develop a complete understanding of the connection. Additionally, we conducted a thorough analysis to examine how this relationship varies across geographic locations, age groups, and types of kidney diseases. Furthermore, we shed light on healthcare disparities in Texas by examining how the impact of heat on emergency hospital admissions differs among racial and ethnic groups in the five largest Metropolitan Statistical Areas (MSAs), namely Austin-Round Rock, Dallas-Plano-Irving, El Paso, Houston-The Woodlands-Sugar Land, and San Antonio-New Braunfels.

2. Data and methods

2.1. Data

Located in the south-central region of the United States, Texas is the second largest state in terms of both population and area. According to 2010 Census Bureau data, it has 25 Metropolitan Statistical Areas (MSAs), out of which we selected 12 for our analysis based on the consistent availability of data. These 12 MSAs comprise major cities and each has a population of over 200,000 people consistently between 2004 and 2013. The selected MSAs are Austin-Round Rock, Beaumont-Port Arthur, Brownsville-Harlingen, Corpus Christi, Dallas-Plano-Irving, El Paso, Houston-The Woodlands-Sugar Land, Killeen-Temple, Lubbock, McAllen-Edinburg-Mission, San Antonio-New Braunfels, and Waco. Our dataset was limited to the summer seasons in Texas, which extend from May 1st to September 30th.

2.1.1. Emergency hospital admission and population data

Data on emergency hospital admissions for all causes among residents of 12 Texas MSAs were obtained from the Texas Department of State Health Services. We specifically selected cases of emergency hospital admissions due to kidney diseases which are non-previous scheduled. The raw data was then aggregated into daily-MSA level data covering the years 2004–2013. The emergency hospital admission data was categorized by age group (0–18, 18–65, 65–75, 75+), racial/ethnic group and different causes of emergency hospital admissions. Due to the small number of observations of hospital admission related to renal diseases for children under age 5, we use age group 0–18 in our estimation. Besides, literature has indicated an insignificant effect estimates for age group under 5 (Qu et al., 2022). For our type-specific analysis, we obtained Emergency Department visits with a primary diagnosis of acute and chronic kidney diseases using International Classification of Diseases 9 (ICD-9) codes: 580–599 and 788. We focused on five major subtypes of kidney diseases: Acute Kidney Injury (AKI) (code 584), Urinary Tract Infections (UTI) (code 599), kidney stones (code 592), nephritis and nephrosis (codes 580–583, 590, 591), and other lower urinary tract disorders (codes 595–598, 788). We excluded other subtypes of kidney diseases that had fewer than 100 observations at the MSA level. The population dataset for each MSA was obtained from the Texas A&M University Texas Real Estate Research Center.

2.1.2. Weather and air pollution data

We obtained hourly weather data from the Integrated Surface Database (ISD) in the National Climate Data Center (NCDC). The dataset includes hourly temperature and dew point temperature data from multiple monitoring stations for the period of 2004–2013. To aggregate the data into MSA-daily level, we chose weather records from one representative monitoring station in the most populated areas within each MSA following the method in Zanobetti et al. (2012) and aggregated the hourly data into daily data. Subsequently, we aggregated the hourly data into daily mean, minimum, and maximum temperatures, as well as dew point temperature records. For temperature exposure, we used daily mean temperature (Chen et al., 2017).

Considering the strong association between ozone levels and increased temperatures, as well as the potential negative effects on public health (Bloomer et al., 2009; Coates et al., 2016; Norval et al., 2011; Reid et al., 2012; Sheffield et al., 2015), we gathered ozone data from the Texas Air Monitoring Information System Database (Texas Commission on Environmental Quality). We chose a commonly used approach in air pollution epidemiology – a city-wide averaging exposure assessment (Liu et al., 2016; Liu et al., 2014). By averaging the daily measurements from all monitoring stations within each Metropolitan Statistical Area (MSA), we consolidated the hourly monitor-level ozone information into daily-MSA level data.

2.2. Statistical analysis

Upon integrating kidney disease-related emergency hospital admission data with weather, population, and air pollution information, we carried out a two-stage multi-city time series analysis, as outlined by Chen et al. (2017). In the first stage, we estimated the effects of heat on emergency hospital admissions for each MSA using the generalized additive model (GAM). Subsequently, we combined the estimated results from the initial stage by conducting a meta-analysis to examine the relationship between elevated temperatures and emergency hospital admissions.

2.2.1. MSA-specific models

Firstly, we investigated the relationship between temperature and emergency hospital admissions by plotting a generalized additive model (GAM) with a spline function of temperature for each MSA. We considered the average temperature of the same day and one day prior (lag 0–1) as the primary exposure variable to account for acute heat-related effects following the method in Qu et al. (2022). The most pronounced health effects of high temperatures usually occur within the first two days, which is commonly reported in the literature (Zhang et al., 2014). We included days of the week and year to adjust for time trends and seasonality, as well as mean dew point temperature and yearly population, since the impact of heat on health can vary based on population size (Marsha et al., 2018). In order to regulate the relative humidity, we managed the dew point temperature since the relative humidity level can be determined by considering the dew point temperature and temperature. Secondly, we proceeded to estimate the range of potential heat thresholds for MSAs exhibiting a nonlinear relationship between temperature and emergency hospital admissions related to renal diseases. Beyond this range of thresholds, the risk of emergency hospital admission increases linearly with temperature. Finally, we determined the most optimal heat threshold within this range by minimizing the Akaike information criterion (Q-AIC) in regressions using the quasi-Poisson distribution.

Next, we employed generalized additive models (GAM) to model the relationship between daily mean temperature and the average of lagged emergency hospital admission counts related to kidney diseases, following the method described by Zhang et al. (2014). Specifically, the Poisson regression model for each MSA can be expressed as:

$$log[E(Y_t)] = \alpha + \beta\, meTMP_{t,l} + \delta\, DOW_t + s(DOY_t, 71) + s(meDWP_t, 4) + \lambda\, ln(Population_y), \quad (1)$$

where $\mathrm{meTMP}_{t,l} \geq$ threshold.

Y_t is the number of hospital admission related to kidney diseases on day t; $meTMP_{t,l}$ is the mean temperature on lag day l of day t; l is up to 1 for our interests; DOW_t is a set of indicator variables representing the day of the week, and DOY_t represents a set of indicator variables representing the day of the year; $s(DOY_t, 71)$ represents a smooth function (natural cubic spline) of DOY_t with 71 degrees of freedom per year to capture seasonality and long-term trends; $meDWP_t$ represents mean dew point temperature with 4 degrees of freedom to capture the amount of moisture in the air, which is larger than the thresholds determined previously; $ln(Population_t)$ represents the natural logarithm of the population in year y; $\alpha, \beta, \delta, \lambda$ are the estimated parameter in the regression. We incorporated the dew point temperature as a covariate in our analysis to account for relative humidity, as relative humidity can be determined from the dew point temperature and temperature measurements.

2.2.2. Meta-analysis

To obtain a consolidated effect estimate by combining MSA-level estimations, we carried out a multivariate meta-analysis using random effect modeling, following the method outlined by Chen et al. (2017). We assumed that the estimated parameter values adhere to a normal distribution, with the true value as the mean and the variance as the sum of within-MSA variance of estimated results and between-MSA variance of the true value. We calculated the between-MSA variance of the true value using restricted maximum likelihood (REML), under the assumption that each MSA included in the meta-analysis was randomly selected. This procedure was repeated for each age group and specific cause.

Additionally, we estimated race and ethnicity groups at the MSA level for the five largest MSAs, including Austin-Round Rock, Dallas-

Table 1
Summary of mean temperatures, population sizes, daily counts of all-cause emergency hospital admission numbers in 12 major Texas Metropolitan Areas, 2004–2013.

Texas MSA	Daily mean temperature (°C) [1]	Number of daily hospital admission due to kidney diseases	Population size [2]	Non-white race ratio (%)
	Mean (min, max)	Mean (min, max)		
Austin-Round Rock	27.5 (10.6,34.2)	9.8 (0,26)	1,716,289	33
Beaumont-Port Arthur	27.2 (14.2,32.5)	3.3 (0,12)	388,745	15
Brownsville-Harlingen	28.7 (17.8,33.1)	3.2 (0,12)	406,220	89
Corpus Christi	28.3 (17.2,35)	4.5 (0,13)	405,027	60
Dallas-Plano-Irving	28 (9.4,36.7)	45 (2,95)	6,366,542	30
El Paso	26.8 (12.5,34.2)	7.2 (0,20)	804,123	84
Houston-The Woodlands-Sugar	27.9 (14.4,34.7)	41.7 (0,82)	5,920,416	38
Killeen-Temple	27.7 (12.2,35)	2.4 (0,11)	405,300	22
Lubbock	24.7 (5.8,34.7)	3.2 (0,12)	290,805	35
McAllen-Edinburg-Mission	29.6 (18.6,35)	5.7 (0,18)	774,769	91
San Antonio-New Braunfels	28.1 (13.1,35.6)	14.5 (0,38)	2,142,508	56
Waco	27.7 (10.8,35.8)	1.9 (0,11)	252,772	26

[1] Average daily mean temperature throughout the study period, May 1st to September 30th. 2004–2013.
[2] Based on 2010 Census data.

Plano-Irving, El Paso, Houston-The Woodlands-Sugar Land, and San Antonio-New Braunfels. These MSAs possess substantial populations, offering a broader range of racial and ethnic groups, enabling us to conduct more extensive observations and estimations within each group. In contrast, data from other MSAs lacked sufficient sample sizes to achieve similar levels of detail across various racial and ethnic categories.

2.3. Sensitivity analysis

We conducted a sensitivity analysis to examine the influence of adjusting for ozone and modifying the lag ranges on the estimates of heat effects on emergency hospital admissions related to kidney diseases. First, we altered the temperature control lag range to encompass lag0, lag0–1, lag0–2, and lag0–6. Next, we integrated ozone into the model, given its status as a significant air pollutant that shares a strong correlation with increased temperatures and can negatively impact public health.(Bloomer et al., 2009; Coates et al., 2016; Norval et al., 2011; Reid et al., 2012; Sheffield et al., 2015).

3. Results

Table 1 displays weather information, emergency hospital admission numbers related to kidney diseases, and population size for 12 major Texas MSAs during the warm seasons (May to September) from 2004 to 2013. The highest daily mean temperature reached 36.7 °C, while the lowest was 5.8 °C. The average daily mean temperature across the years 2004–2013 was the highest in MSA McAllen-Edinburg-Mission at 29.6 °C and the lowest in MSA Lubbock at 24.7 °C. Moreover, Dallas-Plano-Irving had the largest population among the 12 MSAs, with an average of 45 daily emergency hospital admissions due to kidney diseases, representing the highest daily average of kidney disease-related emergency hospital admissions. In contrast, Waco had the smallest population with an average of 1.9 daily emergency hospital admission cases. Austin-Round Rock, Dallas-Plano-Irving, El Paso, Houston-The Woodlands-Sugar Land, and San Antonio-New Braunfels are the five largest MSAs in Texas in terms of population size. There were 519,955 cases of emergency hospital admissions related to kidney disease in Texas from 2004 to 2013. Table 2 summarizes the subgroup population sizes for our study.

Upon analyzing the graphical representation of the Generalized Additive Model (GAM) across various Metropolitan Statistical Areas (MSAs), we noticed distinct patterns emerged. Notably, in the Austin-Round Rock, Beaumont-Port Arthur, Corpus Christi, Houston-The Woodlands-Sugar Land, Killeen-Temple, and McAllen-Edinburg-Mission MSAs, we observed a U-shaped or J-shaped relationship. Conversely, the majority of the remaining MSAs exhibited a prevailing positive linear association between temperature and the risk of emergency hospital admissions.

Fig. 1 reveals that the pooled estimation indicated a statistically significant effect of heat on all kidney disease-related emergency hospital admissions, equating to 1.73 % (95 % CI [1.43, 2.03]), implying that for each 1 °C increase in temperature, the relative risk of hospital admission related to all types of kidney diseases increases by 1.73 %. Most of the estimation results were statistically significant for each MSA, with Beaumont-Port Arthur showing the most significant heat effect on emergency hospital admissions (3.74 %, 95 % CI [1.25, 6.40]) and El Paso Land having the lowest significant effect (1.49 %, 95 % CI [0.52, 2.47]). However, the estimation results for Austin, Brownsville, Corpus Christi, Killeen, and McAllen were insignificant.

Fig. 2 displays the pooled estimation results of the heat effect on kidney disease-related emergency hospital admissions for different age groups and causes of admission. The heat effect on emergency hospital admissions for people aged 18–65 was the largest, at 2.55 % (95 % CI [2.12, 2.98]), compared to other age groups. Regarding cause-specific pooled estimation, we found a statistically significant association between high temperature and emergency hospital admissions caused by AKI (3.34 % (95 % CI [2.86, 3.82])), kidney stones (1.76 % (95 % CI [0.94, 2.60])), and UTIs (1.06 % (95 % CI [0.61, 1.51])). The estimated effects for nephritis and nephrosis and other lower urinary tract disorders were not significant.

Figs. 3 and 4 demonstrate the impact of heat on kidney disease-

Table 2
Counts and portions of emergency hospital admission related to kidney diseases by individual characteristics and subtypes of kidney diseases.

Basic characteristics	Count	Proportion (%)
Total case	519,955	
Age		
0–18	34,949	6.72
18–65	220,622	42.43
65–75	81,408	15.66
75+	182,976	35.19
Kidney diseases subtypes		
Nephritis and nephrosis	81,704	15.71
Acute kidney injury (AKI)	165,591	31.85
Urinary tract infection (UTI)	187,566	36.07
Kidney stone	53,418	10.27
Other lower urinary tract disorders	17,495	3.36
Race		
African American	75,480	14.52
White	326,475	62.79
Other Race	117,547	22.61
Ethnicity		
Hispanic	144,553	27.80
Non-Hispanic	374,099	71.95

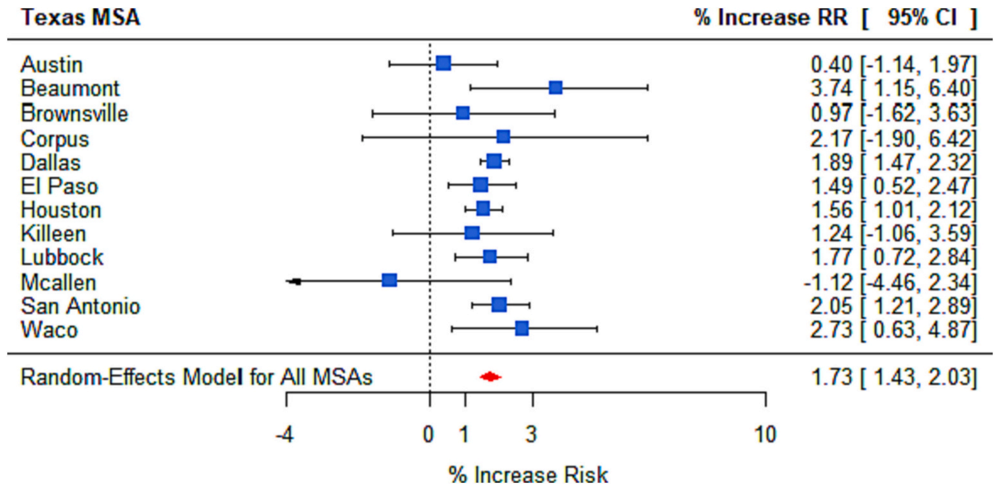


Fig. 1. Meta-analysis for heat effect on emergency hospital admission related to all kinds of kidney diseases at lag 0–1 in 12 major Texas MSAs during 2004–2013.

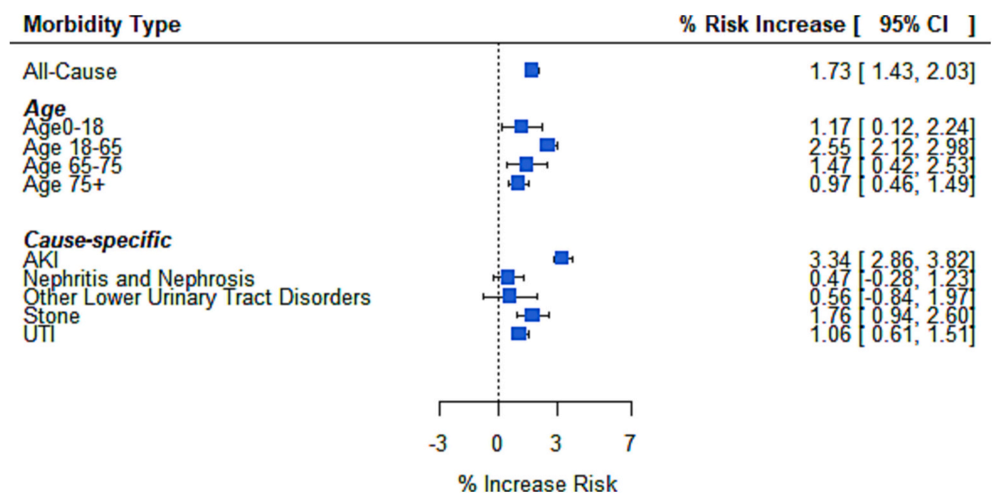


Fig. 2. Pooled estimates of heat effect on age-stratified and subtype kidney disease related emergency hospital admission at the MSA-level in Texas during 2004–2013.

related emergency hospital admissions for different racial and ethnic groups within the five largest Metropolitan Statistical Areas (MSAs) in Texas, namely Austin-Round Rock, Dallas-Plano-Irving, El Paso, Houston-The Woodlands-Sugar Land, and San Antonio-New Braunfels. Specifically, our findings suggest that in Austin-Round Rock (African American: 1.17 % (95%CI[−3.43, 5.98]); White: 0.85 % (95%CI [−1.05, 2.79])), Houston-The Woodlands-Sugar Land (African American: 2.20 % (95%CI[0.99, 3.41]); White: 1.11 % (95%CI [0.38, 1.84])), San Antonio-New Braunfels (African American: 1.94 % (95%CI[−1.04, 5.00]); White: 1.28 % (95%CI[0.11, 2.46])), and Dallas-Plano-Irving (African American: 2.26 %(95%CI[1.26, 3.27]); White: 1.80 % (95%CI[1.30, 2.29])), the estimated effects for African Americans are greater than those for the White population. The analysis revealed that in El Paso, the White population has a greater estimated effect compared to African Americans but smaller than other racial groups. Moreover, our research shows that in Dallas-Plano-Irving (Hispanic: 2.22 % (95%CI[1.08, 3.36]); Non-Hispanic: 1.84 % (95%CI[1.39, 2.30])), Houston-The Woodlands-Sugar Land (Hispanic: 2.19 % (95%CI[0.90, 3.49]); Non-Hispanic: 1.42 % (95%CI[0.81, 2.03])), El Paso (Hispanic: 1.62 % (95%CI[0.54, 2.71]); Non-Hispanic: 1.26 % (95%CI[−0.78, 3.34])), and San Antonio-New Braunfels (Hispanic: 2.92 % (95%CI[1.72, 4.14]); Non-Hispanic: 1.23 % (95%CI[0.11, 2.37])), the estimated effects for the Hispanic group are higher than those for the Non-Hispanic group. In Austin-Round Rock, the Non-Hispanic group displays a greater estimated effect than the Hispanic group.

Fig. 5 presents the sensitivity analysis results by adjusting the lag range and incorporating air pollution into the estimation. As we increased the model's lag length, the estimated relationship between temperature and emergency hospital admission grew. The highest estimated effect was observed using lag0–1, at 1.73 % (95 % CI [1.43, 2.03]) without controlling for ozone, and 1.68 % (95 % CI [1.31, 2.05]) with ozone controlled in the model. These estimation results diminished as we extended the lag length, reaching the lowest estimates when using lag0–6. Confounding by ozone was minimal.

4. Discussion

We conducted a multi-city study investigating the association between high temperature and hospital admission in Texas, covering 12 MSAs in Texas during 2004–2013. Our research found systematic proof of a noticeable impact of high temperature on emergency hospital admissions related to all kinds of studied kidney diseases. The heat was linked to rising emergency hospital admissions across various subtypes of kidney diseases and age groups. We have also presented evidence indicating that high temperatures elevate the risk of hospital admission among racial and ethnic minority groups.

Kidney failure has been linked to various factors that may contribute to hospitalizations during heat waves, such as direct heat-related

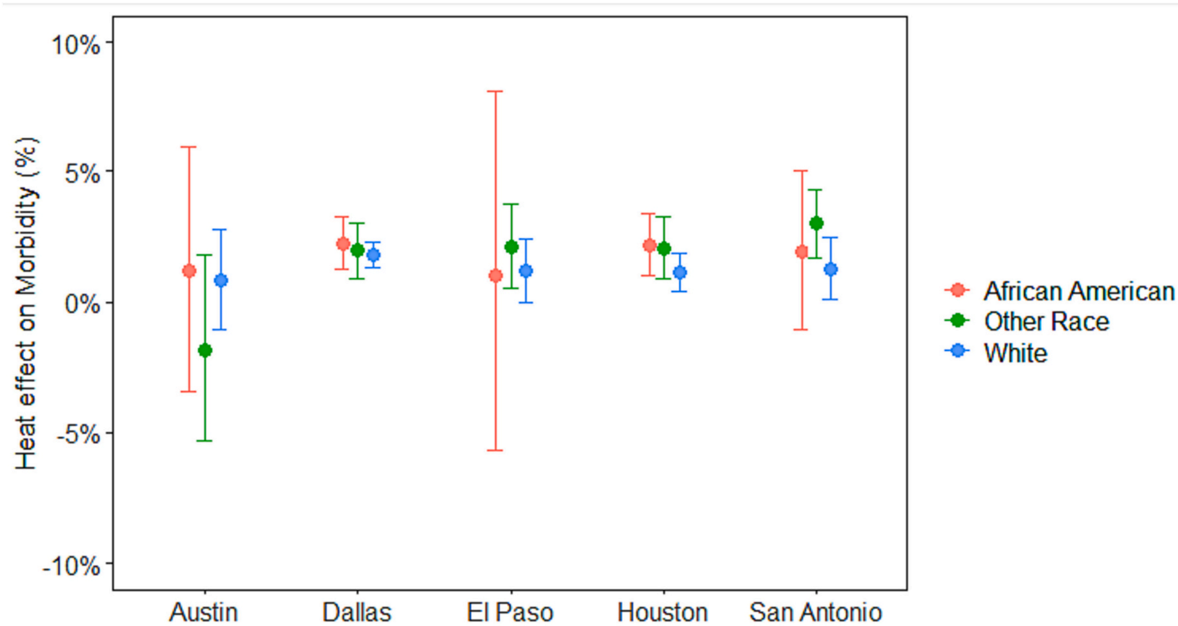


Fig. 3. Estimates of heat effect on race-stratified morbidity related to kidney diseases for five largest MSA in Texas including Austin-Round Rock, Dallas-Plano-Irving, El Paso, Houston-The Woodlands-Sugar Land, and San Antonio-New Braunfels during 2004–2013.

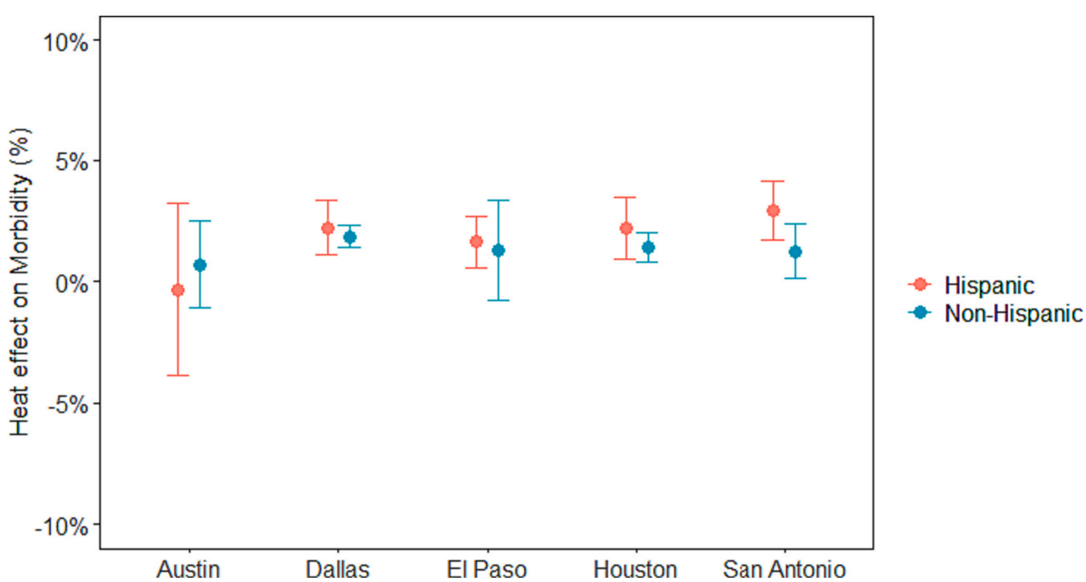


Fig. 4. Estimates of heat effect on ethnicity-stratified morbidity for five largest MSA in Texas including Austin-Round Rock, Dallas-Plano-Irving, El Paso, Houston-The Woodlands-Sugar Land, and San Antonio-New Braunfels during 2004–2013.

damage and prerenal acute injuries associated with dehydration (Bobb et al., 2014). High temperatures can lead to increased fluid loss through sweating and evaporation, potentially leading to dehydration. Dehydration can strain the kidneys, reducing their effectiveness in filtering waste products and toxins. This can exacerbate existing kidney conditions or contribute to the development of kidney problems. Dehydration can also result in concentrated urine, potentially elevating the risk of UTIs and the formation of kidney stones.

Our first result about the heat impact on all samples suggests that the relative risk of emergency hospital admission due to kidney diseases increases by 1.73 % (95 % CI [1.43, 2.03]) on average with a 1°C increase in temperature. These results are parallel to several studies that have also found a significant correlation between high temperature and kidney health. For example, Qu et al. (2022) found that extreme heat exposure was associated with a 1.7 % (lag day 0) to 3.1 % (lag day 2) higher risk of emergency department visits related to kidney disease in New York State during 2005–2013. Borg et al. (2017) found that hospitalizations increased when the daily maximum temperature exceeded 36 °C, and the effect was more pronounced when temperatures exceeded 38 °C. Gronlund et al. (2014) found a 3.9 % increase in hospital admissions for renal diseases in the U.S. Lee et al. (2019) conducted a meta-analysis by systematically reviewing earlier papers and found that high temperature was associated with a 30 % increase in kidney disease morbidity, while Liu et al. (2021) found that a 1 °C increase in temperature is associated with a 1 % increase in the risk of kidney-related morbidity. The deviation from our results may be explained by the differences in the estimation method, measurement of health outcome, and study objectives. For example, direct heat-related emergency

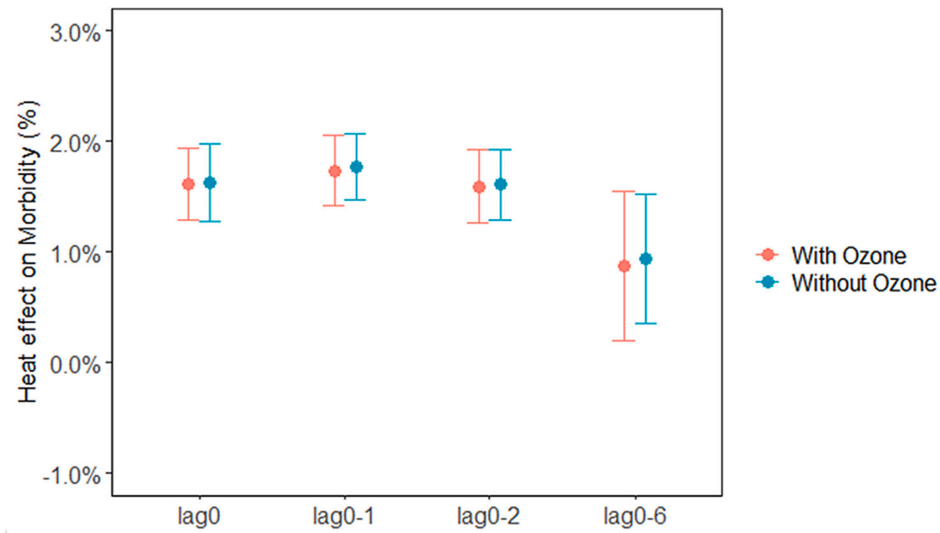


Fig. 5. Sensitivity analysis by changing lag range and adding pollution (ozone) into the estimation model.

department visits respond more acutely to temperature change compared with the emergency hospital admission. Additionally, the number of emergency department visits is generally more significant than the number of hospital admissions because the majority of people visiting the emergency department can heal and leave the hospital before being admitted to the hospital for further treatment. Actually, Lee et al. (2019) found that there was a significant increase in renal emergency department visits when temperatures exceeded certain thresholds. According to Qu et al. (2022) extreme heat exposure was associated with 3.1 % higher risk of hospital visits related with kidney diseases.

We found that the effect estimates varied across different MSAs in Texas. Earlier literature has shown that the heat impact on morbidity and mortality can vary across regions considering different climate conditions, demographic characteristics and air-conditioning applications. Earlier literature has often used the overall population for estimation without considering the different regions' characteristics. For example, in Qu et al. (2022) and Fletcher et al. (2012) who studied New York State, the estimation results for the overall state could be biased by that in New York City, where the population is much denser than the rest of cities. To our knowledge, this is the first study to conduct a meta-analysis using detailed dataset to study the heat impact on kidney disease-related emergency hospital admission, allowing us to better capture the different effects in each region.

Our findings showed that people aged between 18 and 65 had the highest effect estimates. This result concords with earlier literature (Fletcher et al., 2012; Hansen et al., 2008; Lee et al., 2019; Qu et al., 2022). Hansen et al. (2008) found a significant increase in the relative risk of hospital admission for renal diseases among people aged 15–64, which was higher than the effect estimates found among people group aged over 65. Qu et al. (2022) found that the heat effects on emergency department visits related to renal diseases were the highest among age group 18–65 years when they using a lag over 1 for estimation. Similarly, Fletcher et al. (2012) also found the largest effect estimates for age 25–44 compared with other age groups. For instead, in the studies developed by Borg et al. (2017) and Lee et al. (2019) the association between heat and hospitalizations was stronger among individuals over the age of 65, as well as the risk of renal emergency department visits increased more in the elderly population than in younger age groups. However, there is no final agreement of the existing literature. Our result is inconsistent with some other literature showing the older groups are the most susceptible to heat in terms of kidney-disease-related hospital admission (Borg et al., 2019; Gronlund et al., 2014). Nonetheless, individuals aged 18–64 tend to engage in more outdoor activities and strenuous physical tasks compared to their older counterparts (Borg et al., 2017; Kim et al., 2018; Liu et al., 2021; Qu et al., 2022). According to the Outdoor Participation Trends Report (Outdoor Foundation, 2022), the middle age group spends the most time outdoors compared to other age groups. Therefore, this could increase their exposure to heat and susceptibility to heat-related kidney diseases.

Additionally, our findings are also consistent with earlier research showing that the heat effect estimates vary across different subtypes of kidney diseases, especially the estimates on AKI, UTI, and kidney stones. This result is slightly lower than ours considering summers in California are not as hot as in Texas. Bobb et al. (2014) found the heat effect of 1.10 % (95 % CI, 1.04–1.16) on UTI using a national dataset. Tasian et al. (2014) found the cumulative relative risk of kidney stone presentation for a daily mean temperature of 30 °C versus 10 °C was 1.36 in Dallas (95 % CI: 1.10, 1.69). Malig et al. (2019) used California data from 1999 to 2009, and found that a 1 °C increase in mean temperatures in the warm season was associated with significant increases in renal admissions of 1.06 % for UTI and 3.1 % for urinary stones.

Our findings emphasize health disparities, with different effect estimates observed across regions. Race and ethnicity play a role in public health, particularly in relation to heat-related hospitalizations and mortality (Berberian et al., 2022; Bernstein et al., 2022; Gronlund, 2014; Jung et al., 2021; Knowlton et al., 2009; O'Neill et al., 2005). Racial and ethnic minorities often experience low income, poor health, and reside in areas with limited access to air-conditioning (Anderson and Bell, 2009; Anderson and Bell, 2011; Gronlund, 2014; Rogot et al., 1992). In our analysis, differences between racial and ethnic groups were not statistically significant due to limited number of observations within certain population groups. Therefore, we only focused on testing the differences in point estimates using the data in the five largest MSAs. Our study indicates that African Americans in Dallas, Houston, and San Antonio metropolitan areas are more vulnerable to the effects of extreme heat on emergency hospital admissions compared to White populations. We also found that Hispanics in El Paso, Houston, and San Antonio face a higher risk of hospitalization during high temperatures than Non-Hispanic individuals. While the results in other large MSAs are opposite, the fact that we consistently observe higher risks in multiple areas underscores the existence of disparities in how different communities are impacted by extreme heat, even if the magnitude of these disparities varies. These results underscore the need for targeted interventions to mitigate the impacts of extreme heat on vulnerable groups, especially African Americans and Hispanics. These findings are also in line with a study by Green et al. (2010) that examined the association between temperature and hospital admissions for acute kidney injury in California, and found that the association was stronger in non-white populations compared to white populations. Another study by Remigio et al. (2019) also found that heat was associated with a greater risk of hospitalization for acute kidney injury in non-white populations in the United States. Ahead of interventions, improved surveillance of heat-related kidney illnesses should include documentation of the occupation of those admitted and the activity being carried out on the day of and the day prior to admission. This will allow for the initiation of targeted community and occupational-level interventions.

Our sensitivity analysis revealed two insights. First, ozone levels could contribute to hospital admissions. Some studies have identified a significant correlation between temperature and ozone (Bloomer et al., 2009; Norval et al., 2011; Sheffield et al., 2015), with ground-level ozone exposure linked to adverse health outcomes (Reid et al., 2012). Following the adjustment for ozone in our model, we observed a decrease in the effect estimate. However, it's important to note that this decrease is not statistically significant, as indicated by the Wald test results. Second, our results confirmed a significant association between high temperatures and same-day emergency hospital admissions for kidney diseases. The effect estimate was highest at a lag range of 0–1 and lowest at 0–6, remaining statistically significant. This aligns with previous research that noted the impact of temperature on kidney-disease-related emergency hospital admissions persists for 1–6 subsequent days (Ogbomo et al., 2017; Qu et al., 2022).

Based on the study's results, there are several policy implications. First, the study indicates the need of implementing more effective early warning systems in advance of heatwaves or extreme heat events. It is also crucial to raise public awareness of kidney-related diseases caused by high temperatures. Second, public investment in air conditioning accessibility and other cooling strategies could be beneficial, particularly for high-risk groups, such as racial and ethnic minorities who often lack the resources to avoid dehydration and heat stress. Third, the study shows that residents between 18 and 64 are more susceptible to heat-related kidney diseases due to their exposure to heat, suggesting the need for improving occupational heat safety regulations that ensure employers provide necessary rest breaks, hydration, and other preventative measures to protect their workers. Finally, further research is needed to further explore the relationship between heat and kidney disease-related hospital admissions in different regions and demographic groups. Conducting household surveys to collect data on public risk perceptions, personal mitigation behaviors and air conditioning usage could offer useful insights.

Our study's limitations stem from the variables we could obtain from emergency hospital admission data. Personal behaviors, such as heat avoidance strategies, air-conditioner usage, and mobility patterns, are not observable. Texas residents, who frequently experience hot weather, may be more aware of heat's adverse effects and adopt protective measures like using air-conditioners or staying indoors during extremely hot days compared to those in colder regions (O'Neill et al., 2005). In our data, heat exposure was determined using emergency hospital admission addresses, which may not accurately reflect long-term exposure as individuals may not always live at the same address. Moreover, temperature measurements were taken at fixed sites within each metropolitan area, potentially leading to misclassification of actual heat exposure (Kuras et al., 2017). For instance, temperatures can vary within each metropolitan area, and urban areas are often warmer than suburbs (Buyantuyev and Wu, 2010; Gaffin et al., 2008; Oke, 1982). Future research could address these issues by employing more detailed datasets.

5. Conclusion

Our study provided evidence of the heat impact on kidney disease-related hospital admission over a wide scale in Texas and across different population groups. Regions and race/ethnicity also appeared to alter the heat effects on kidney disease-related emergency hospital admission. To our best knowledge, this is the first study that systematically explored the heat effect on emergency hospital admission related to kidney diseases in Texas statewide. Overall, our findings highlight the importance of understanding and addressing the impacts of climate change on human health in Texas or other regions with similar weather conditions about the increasing risk of high temperature in a changing climate, especially in vulnerable populations such as those with pre-existing kidney diseases and those employed in jobs requiring heavy workload and without access to effective protections such as water and shaded rest.

CRediT authorship contribution statement

Chunyu Guo: Methodology, Writing – original draft, visualization **Kai Zhang**: Conceptualization, methodology, supervision, and writing **Erjia Ge**: Writing – review & editing **Manzhu Yu**: Writing – review & editing **Changwei Li**: Writing – review & editing **Xiangqian Lao**: Writing – review & editing **Shuang Li**: Writing – review & editing **Jason Glaser**: Writing – review & editing **Yongqun He**: Writing – review & editing **Marina Almeida-Silva**: Writing – review & editing **Sisi Meng**: Writing – review & editing **Wei-Chung Su**: Writing – review & editing **Shao Lin**: Writing – review & editing **Junfeng Zhang**: Writing – review & editing.

Declaration of competing interest

The authors declare that they have no known competing financial interests or personal relationships that could have appeared to influence the work reported in this paper.

Data availability

The authors do not have permission to share data.

Acknowledgments

KZ was partially funded by the American Heart Association grant (19TPA34830085) and the Empire Innovation Program (EIP) of the State University of New York (SUNY).

References

Anderson, B.G., Bell, M.L., 2009. Weather-related mortality: how heat, cold, and heat waves affect mortality in the United States. Epidemiology (Cambridge, Mass.) 20 (2), 205.
Anderson, G.B., Bell, M.L., 2011. Heat waves in the United States: mortality risk during heat waves and effect modification by heat wave characteristics in 43 US communities. Environ. Health Perspect. 119 (2), 210–218.
Berberian, A.G., Gonzalez, D.J., Cushing, L.J., 2022. Racial disparities in climate change-related health effects in the United States. Curr. Environ. Health Rep. 9 (3), 451–464.
Bernstein, A.S., Sun, S., Weinberger, K.R., Spangler, K.R., Sheffield, P.E., Wellenius, G.A., 2022. Warm season and emergency department visits to US children's hospitals. Environ. Health Perspect. 130 (1), 017001.
Bloomer, B.J., Stehr, J.W., Piety, C.A., Salawitch, R.J., Dickerson, R.R., 2009. Observed relationships of ozone air pollution with temperature and emissions. Geophys. Res. Lett. 36 (9).
Bobb, J.F., Obermeyer, Z., Wang, Y., Dominici, F., 2014. Cause-specific risk of hospital admission related to extreme heat in older adults. Jama 312 (24), 2659–2667.
Borg, M., Bi, P., Nitschke, M., Williams, S., McDonald, S., 2017. The impact of daily temperature on renal disease incidence: an ecological study. Environ. Health 16 (1), 1–30.
Borg, M., Nitschke, M., Williams, S., McDonald, S., Nairn, J., Bi, P., 2019. Using the excess heat factor to indicate heatwave-related urinary disease: a case study in Adelaide, South Australia. Int. J. Biometeorol. 63, 435–447.
Buyantuyev, A., Wu, J., 2010. Urban heat islands and landscape heterogeneity: linking spatiotemporal variations in surface temperatures to land-cover and socioeconomic patterns. Landsc. Ecol. 25, 17–33.
Chen, T.-H., Li, X., Zhao, J., Zhang, K., 2017. Impacts of cold weather on all-cause and cause-specific mortality in Texas, 1990–2011. Environ. Pollut. 225, 244–251.

Coates, J., Mar, K.A., Ojha, N., Butler, T.M., 2016. The influence of temperature on ozone production under varying NO x conditions–a modelling study. Atmos. Chem. Phys. 16 (18), 11601–11615.

Fletcher, B.A., Lin, S., Fitzgerald, E.F., Hwang, S.-A., 2012. Association of summer temperatures with hospital admissions for renal diseases in New York State: a case-crossover study. Am. J. Epidemiol. 175 (9), 907–916.

Gaffin, S., Rosenzweig, C., Khanbilvardi, R., Parshall, L., Mahani, S., Glickman, H., Goldberg, R., Blake, R., Slosberg, R., Hillel, D., 2008. Variations in New York city's urban heat island strength over time and space. Theor. Appl. Climatol. 94, 1–11.

Green, R.S., Basu, R., Malig, B., Broadwin, R., Kim, J.J., Ostro, B., 2010. The effect of temperature on hospital admissions in nine California counties. Int. J. Public Health 55 (2), 113–121.

Gronlund, C.J., 2014. Racial and socioeconomic disparities in heat-related health effects and their mechanisms: a review. Curr. Epidemiol. Rep. 1 (3), 165–173.

Gronlund, C.J., Zanobetti, A., Schwartz, J.D., Wellenius, G.A., O'Neill, M.S., 2014. Heat, heat waves, and hospital admissions among the elderly in the United States, 1992–2006. Environ. Health Perspect. 122 (11), 1187–1192.

Guo, C., Ge, E., Lee, S., Lu, Y., Bassill, N.P., Zhang, N., Zhang, W., Lu, Y., Hu, Y., Chakraborty, J., 2023a. Impact of heat on emergency hospital admission in Texas: geographic and racial/ethnic disparities. J. Expo. Sci. Environ. Epidemiol. 1–8.

Guo, C., Lanza, K., Li, D., Zhou, Y., Aunan, K., Loo, B.P., Lee, J., Luo, B., Duan, X., Zhang, W., 2023b. Impact of heat on all-cause and cause-specific mortality: a multi-city study in Texas. Environ. Res. 224, 115453.

Hansen, A., Bi, L., Saniotis, A., Nitschke, M., 2013. Vulnerability to extreme heat and climate change: is ethnicity a factor? Glob. Health Action 6 (1), 21364.

Hansen, A.L., Bi, P., Ryan, P., Nitschke, M., Pisaniello, D., Tucker, G., 2008. The effect of heat waves on hospital admissions for renal disease in a temperate city of Australia. Int. J. Epidemiol. 37 (6), 1359–1365.

Harlan, S.L., Chowell, G., Yang, S., Petitti, D.B., Morales Butler, E.J., Ruddell, B.L., Ruddell, D.M., 2014. Heat-related deaths in hot cities: estimates of human tolerance to high temperature thresholds. Int. J. Environ. Res. Public Health 11 (3), 3304–3326.

Jung, J., Uejio, C.K., Adeyeye, T.E., Kintziger, K.W., Duclos, C., Reid, K., Jordan, M., Spector, J.T., Insaf, T.Z., 2021. Using social security number to identify sub-populations vulnerable to the health impacts from extreme heat in Florida, US. Environ. Res. 202, 111738.

Kim, E., Kim, H., Kim, Y.C., Lee, J.P., 2018. Association between extreme temperature and kidney disease in South Korea, 2003–2013: stratified by sex and age groups. Sci. Total Environ. 642, 800–808.

Knowlton, K., Rotkin-Ellman, M., King, G., Margolis, H.G., Smith, D., Solomon, G., Trent, R., English, P., 2009. The 2006 California heat wave: impacts on hospitalizations and emergency department visits. Environ. Health Perspect. 117 (1), 61–67.

Kuras, E.R., Richardson, M.B., Calkins, M.M., Ebi, K.L., Hess, J.J., Kintziger, K.W., Jagger, M.A., Middel, A., Scott, A.A., Spector, J.T., 2017. Opportunities and challenges for personal heat exposure research. Environ. Health Perspect. 125 (8), 085001.

Lee, W.-S., Kim, W.-S., Lim, Y.-H., Hong, Y.-C., 2019. High temperatures and kidney disease morbidity: a systematic review and meta-analysis. J. Prev. Med. Public Health 52 (1), 1.

Liu, J., Varghese, B.M., Hansen, A., Borg, M.A., Zhang, Y., Driscoll, T., Morgan, G., Dear, K., Gourley, M., Capon, A., 2021. Hot weather as a risk factor for kidney disease outcomes: a systematic review and meta-analysis of epidemiological evidence. Sci. Total Environ. 801, 149806.

Liu, S., Ganduglia, C.M., Li, X., Delclos, G.L., Franzini, L., Zhang, K., 2016. Fine particulate matter components and emergency department visits among a privately insured population in Greater Houston. Sci. Total Environ. 566, 521–527.

Liu, Y., Kan, H., Xu, J., Rogers, D., Peng, L., Ye, X., Chen, R., Zhang, Y., Wang, W., 2014. Temporal relationship between hospital admissions for pneumonia and weather conditions in Shanghai, China: a time-series analysis. BMJ Open 4 (7), e004961.

Malig, B.J., Guirguis, K., Gershunov, A., Basu, R., 2019. Associations between ambient temperature and hepatobiliary and renal hospitalizations in California, 1999 to 2009. Environ. Res. 177, 108566.

Marsha, A., Sain, S., Heaton, M., Monaghan, A., Wilhelmi, O., 2018. Influences of climatic and population changes on heat-related mortality in Houston, Texas, USA. Clim. Chang. 146 (3), 471–485.

McTavish, R.K., Richard, L., McArthur, E., Shariff, S.Z., Acedillo, R., Parikh, C.R., Wald, R., Wilk, P., Garg, A.X., 2018. Association between high environmental heat and risk of acute kidney injury among older adults in a northern climate: a matched case-control study. Am. J. Kidney Dis. 71 (2), 200–208.

Norval, M., Lucas, R., Cullen, A., De Gruijl, F., Longstreth, J., Takizawa, Y., Van Der Leun, J., 2011. The human health effects of ozone depletion and interactions with climate change. Photochem. Photobiol. Sci. 10 (2), 199–225.

Ogbomo, A.S., Gronlund, C.J., O'Neill, M.S., Konen, T., Cameron, L., Wahl, R., 2017. Vulnerability to extreme-heat-associated hospitalization in three counties in Michigan, USA, 2000–2009. Int. J. Biometeorol. 61, 833–843.

Oke, T.R., 1982. The energetic basis of the urban heat island. Q. J. R. Meteorol. Soc. 108 (455), 1–24.

Outdoor Foundation, 2022. 2022 Outdoor Participation Trends Report. https://outdoorindustry.org/wp-content/uploads/2015/03/2022-Outdoor-Participation-Trends-Report-1.pdf (last accessed by Nov.2023).

O'Neill, M.S., Zanobetti, A., Schwartz, J., 2005. Disparities by race in heat-related mortality in four US cities: the role of air conditioning prevalence. J. Urban Health 82 (2), 191–197.

Qu, Y., Zhang, W., Boutelle, A.-Y.M., Ryan, I., Deng, X., Liu, X., Lin, S., 2022. Associations between ambient extreme heat exposure and emergency department visits related to kidney disease. Am. J. Kidney Dis. 81 (5), 507–516.

Reid, C.E., Snowden, J.M., Kontgis, C., Tager, I.B., 2012. The role of ambient ozone in epidemiologic studies of heat-related mortality. Environ. Health Perspect. 120 (12), 1627–1630.

Remigio, R.V., Jiang, C., Raimann, J., Kotanko, P., Usvyat, L., Maddux, F.W., Kinney, P., Sapkota, A., 2019. Association of extreme heat events with hospital admission or mortality among patients with end-stage renal disease. JAMA Netw. Open 2 (8), e198904.

Rogot, E., Sorlie, P.D., Backlund, E., 1992. Air-conditioning and mortality in hot weather. Am. J. Epidemiol. 136 (1), 106–116.

Schramm, P.J., Vaidyanathan, A., Radhakrishnan, L., Gates, A., Hartnett, K., Breysse, P., 2021. Heat-related emergency department visits during the northwestern heat wave—United States, June 2021. Morb. Mortal. Wkly Rep. 70 (29), 1020.

Sheffield, P.E., Zhou, J., Shmool, J.L.C., Clougherty, J.E., 2015. Ambient ozone exposure and children's acute asthma in New York City: a case-crossover analysis. Environ. Health 14 (1), 1–10.

Tasian, G.E., Pulido, J.E., Gasparrini, A., Saigal, C.S., Horton, B.P., Landis, J.R., Madison, R., Keren, R., Project, U.D.i.A., 2014. Daily mean temperature and clinical kidney stone presentation in five US metropolitan areas: a time-series analysis. Environ. Health Perspect. 122 (10), 1081–1087.

Texas Commission on Environmental Quality. https://www.tceq.texas.gov/airquality/monops.

Texas Demographic Center, 2020. 2020 Census Data Release. https://demographics.texas.gov/data/decennial/2020/.

Thongprayoon, C., Krambeck, A.E., Rule, A.D., 2020. Determining the true burden of kidney stone disease. Nat. Rev. Nephrol. 16 (12), 736–746.

Turner, A., LaVeist, A.T.A., Richard, P., Gaskin, D.J., 2021. Economic impacts of health disparities in Texas 2020. In: Episcopal Health Foundation. https://www.episcopalhealth.org/wp-content.

Ye, X., Wolff, R., Yu, W., Vaneckova, P., Pan, X., Tong, S., 2012. Ambient temperature and morbidity: a review of epidemiological evidence. Environ. Health Perspect. 120 (1), 19–28.

Zanobetti, A., O'neill, M.S., Gronlund, C.J., Schwartz, J.D., 2012. Summer temperature variability and long-term survival among elderly people with chronic disease. Proc. Natl. Acad. Sci. 109 (17), 6608–6613.

Zhang, K., Chen, Y.-H., Schwartz, J.D., Rood, R.B., O'Neill, M.S., 2014. Using forecast and observed weather data to assess performance of forecast products in identifying heat waves and estimating heat wave effects on mortality. Environ. Health Perspect. 122 (9), 912–918.

Zhang, K., Chen, T.-H., Begley, C.E., 2015. Impact of the 2011 heat wave on mortality and emergency department visits in Houston, Texas. Environ. Health 14 (1), 1–7.