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Climate and Mortality in Nonmetro Illinois: Retrospective Study, 1999-2021 and Projections of Mortality for 2030

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Abstract

Climatic predictions for the Illinois region are for extreme heat, heavy rainfall, and flashfloods, which suggest that heat-related illness and waterborne disease would be salient public-health concerns. Data analysis reveals that maximum temperatures in the nonmetro during 1999-2021 have increased at an annual compound growth rate of 0.32%. Specifically, of the 12,883 deaths that occurred during the summer months of 1999 to 2021, an estimated 5,926 to 6,828 of the deaths could be attributed to heat-related mortality. C*eteris paribus,* heat-related mortality is expected to grow at an ACGR of 1.6% and reach 6,841 to 7,884 deaths by 2030.

Introduction

Climate change has been labeled by the World Health Organization (WHO) as the greatest threat to global health in the 21st century[2]. Heat is the major concern; scientists argue that the earth's temperature has risen by 1.9^{0}F since 1880[3]. Heat exposure exacerbates existing health conditions; elderly, particularly the socioeconomically disadvantaged, are at the highest risk of heat-related mortality [4].

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[1] Professor, Illinois Institute for Rural Affairs, Western Illinois University.

[2] WHO (2021). COP26 special report on climate change and health: the health argument for climate action. Available at: https://www.who.int/publications/i/item/9789240036727.

[3] See, https://earthobservatory.nasa.gov/world-of-change/global-temperatures; the article states that the majority of warming has occurred since 1975, 0.15-0.20^{0}C increases for every 10 years.

[4] Bunker, A., Wildenhain, J., Vandenbergh, A., Henschke, N., Rocklöv, J., Hajat, S., & Sauerborn, R. (2016). Effects of air temperature on climate-sensitive mortality and morbidity outcomes in the elderly; a systematic review and meta-analysis of epidemiological evidence. *EBioMedicine*, *6*, 258-268.

Table 1 shows predictions of weather patterns[5], or ‘climate’, for Eastern North America which includes Illinois; climatic predictions for this region are for extreme heat, heavy rainfall, and flashfloods, which suggest that heat-related illness and waterborne disease would be salient public-health concerns[6].

Table 1: Climate Impact Drivers (CIDs), For the Illinois Region; Eastern North America

Event	Projections
Extreme heat	High confidence of increase
River flood	Medium confidence of increase
Heavy precipitation and pluvial flood	High confidence of increase
Atmospheric CO2 at surface	High confidence of increase
Air pollution weather	Undetermined; low confidence in direction of change

Source: International Panel for Climate Change; regional synthesis; https://interactive-atlas.ipcc.ch/.

The Center for Disease Control’s (CDC) “Building Resilience Against Climate Effects” (BRACE) framework[7] provides guidance for health departments to prepare and respond to these climate changes; the exercise involves a vulnerability assessment of the focal region. This paper does this for nonmetro Illinois.

Conceptual Framework

Climate change has both direct and indirect effects; direct effects such as droughts and flooding, the CIDs in Figure 1, cause physical injury and death. Indirectly, CIDs affect human health by enabling the spread of vector-borne diseases such as the West Nile virus[8].

The vulnerability of a community to climate change is a function of three factors: exposure, sensitivity, and adaptive capacity[9]. Briefly, exposure to climate variations that are detrimental to human

[5] Weather indicates the conditions of the atmosphere over a short period of time; climate is about weather patterns, behavior of weather over relatively long periods of time. Predictions are for the 21st century.

[6] The segment of public health that is concerned with assessing, understanding, and controlling the impacts of environment on people is called “environmental health”; see Moeller, D. W. (2011). *Environmental Health* (4th ed.). Harvard University Press.

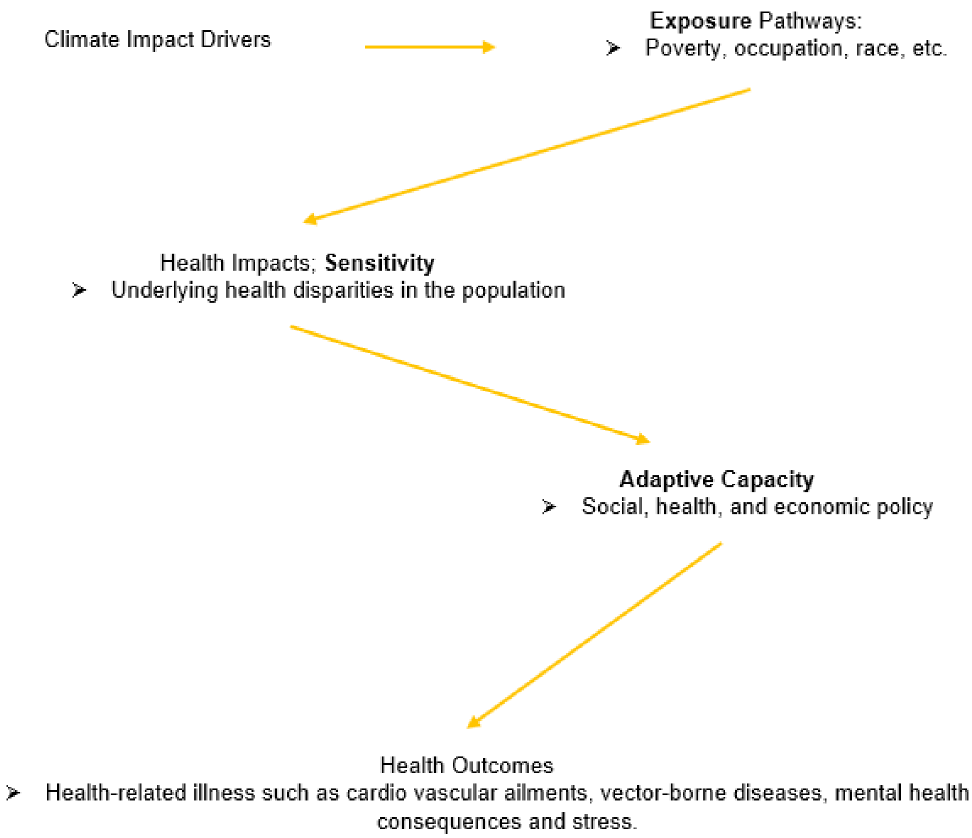
[7] https://www.cdc.gov/climateandhealth/BRACE.htm.

[8] Campbell-Lendrum, D., Manga, L., Bagayoko, M., & Sommerfeld, J. (2015). Climate change and vector-borne diseases: What are the implications for public health research and policy? *Philosophical Transactions of the Royal Society B: Biological Sciences*, 370(1665), 20130552.

[9] Preston, B.L. and Stafford-Smith, M. (2009). *Framing vulnerability and adaptive capacity assessment: Discussion paper*. CSIRO Climate Adaptation Flagship Working Paper No. 2. https://research.csiro.au/climate/publications/working-paper-series/.

health (sensitivity of the citizens) and the ability of a community to withstand these exposures (adaptive capacity[10] of the community) combine to form the concept of 'vulnerability'; figure 1 is a nomological network of the concept.

Figure 1: Vulnerability and its Correlates[11]



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[10] Broadly defined, adaptation is an organism's ability to cope with environmental changes in order to survive and reproduce; see, Smit, B., and Wandel, J (2006). Adaptation, adaptive capacity and vulnerability. *Global Environmental Change*,16(3), 282–292.

[11]Adapted from:
USGCRP, 2016: *The Impacts of Climate Change on Human Health in the United States: A Scientific Assessment*. Crimmins, A., J. Balbus, J.L. Gamble, C.B. Beard, J.E. Bell, D. Dodgen, R.J. Eisen, N. Fann, M.D. Hawkins, S.C. Herring, L. Jantarasami, D.M. Mills, S. Saha, M.C. Sarofim, J. Trtanj, and L. Ziska, Eds. U.S. Global Change Research Program, Washington, DC, 312 pp. http://dx.doi.org/10.7930/J0R49NQX

People can act to prevent or reduce environmental impacts[12]; CDC focuses on structural measures aimed at reducing the probability of being affected, for example, buying face masks to protect against air pollution[13] and regulating indoor temperatures during a heatwave[14]. What materials and resources facilitate people and systems to adjust to potential damage? Table 2 lists some of the place-based resources discussed in the climate change literature[15].

Table 2: Climate Change Adaptation, Examples of Approaches and Enablers

Approach	Definition, conceptual / operational
Heat early warning and response systems (HEWSs)	A suite of activities linking weather forecasts with risk-reduction strategies, for example, informing the public about an impending heatwave.
Nature-based solutions	Eco systems adaptation (and mitigation) to climate change; for example, urban-green infrastructure.
Lifestyle changes	Walk instead of taking the car; avoid behaviors such as air travel and consuming meat.
Enablers of Adaptive Capacity	
Knowledge of healthcare workers and other stakeholders	Two types of knowledge: (i) contextual, for example, knowledge of local healthcare needs and (ii) expert sources, for example, knowledge about HEWS.
Communication	Frequent interaction among stakeholders to clarify ambiguity in knowledge.
Resources	Having available buffer resources such as personnel and technology would help to adapt to a given situation.

[12] Both 'respondents' and 'operants' can be used to explain such behavior; see the conceptual framework in Athiyaman, A. (2022). Free expression among the races: Differences between the metro and the nonmetro. *Research Brief*, 4(21), November. Available online: http://www.iira.org/wp-content/uploads/2022/11/RB4_21_free-expression-among-races.pdf,

[13] Hansstein, F. V., & Echegaray, F. (2018). Exploring motivations behind pollution-mask use in a sample of young adults in urban China. *Global Health*, 14(1), 1-10.

[14] Murtagh, N., Gatersleben, B., & Fife-Schaw, C. (2019). Occupants' motivation to protect residential building stock from climate-related overheating: A study in southern England. *Journal of Cleaner Production*, 226, 186–194.

[15] See: Steg, L., & Vlek, C. (2009). Encouraging pro-environmental behaviour: An integrative review and research agenda. *Journal of environmental psychology*, *29*(3), 309-317; Lyng, H. B., Macrae, C., Guise, V., Haraldseid-Driftland, C., Fagerdal, B., Schibevaag, L., ... & Wiig, S. (2022). Exploring the nature of adaptive capacity for resilience in healthcare across different healthcare contexts; a metasynthesis of narratives. *Applied Ergonomics*, *104*, 103810.

Methodology

Spatial synoptic[16] classification (SSC) was used to identify weather types, or air masses, for the geographical location, nonmetro Illinois[17] (Figure 2). Table 3 lists details about the SSC networks, their location and population coverage.

Figure 2: Location of SSC Stations in Nonmetro Illinois

Note: SSC stations and their coverage, rural counties: (i) RFD: Ogle, Stephenson, Caroll, and Lee; (ii) UIN: Adams, Hancock, Schuyler, Brown, and Pike; (iii) PIA: Fulton and Knox; (iv) STL: Randolph and Washington; (v) MLI: Whiteside; (vi) SPI: Cass, Morgan, Montgomery, Christian, and Logan; (vii) PAH: Hardin, Johnson, Massac, Pulaski, Pope, and Union.

[16] The 'synoptic' concept is premised on the reasoning that the human physiology responds to the whole "umbrella" of air and not just a single weather or pressure patterns.

[17] See, https://sheridan.geog.kent.edu/ssc.html.

Table 3: The Seven SSC Networks that are Relevant for Nonmetro Illinois

Location	Nonmetro Population Covered by the Network	Position of Observatory: Lat	Position of Observatory: Long	Max Temp and Range; June-August, Summer, 1999-2021
MLI (Moline)	535,394	41.47	-90.52	92° F, range = 11.4° F
PAH (Paducah)	82,793	37.06	-88.77	96.3° F, range = 10.7° F
PIA (Peoria)	764,440	40.67	-89.68	94° F, range = 12.2° F
RFD (Rockford)	1,422,570	42.19	-89.09	91.3° F, range = 13.1° F
STL (St. Louis)	280,268	38.75	-90.37	97.3° F, range = 14.9° F
SPI (Springfield)	872,253	39.85	-89.68	96.4° F, range = 16.1° F
UIN (Quincy)	804,438	39.94	-91.19	95.5° F, range = 14.3° F

Source: www.ncei.noaa.gov; https://sheridan.geog.kent.edu/ssc.html.

Data relevant for weather types DT, MT+, and MT++ were sourced[18] for the SSCs. In addition, temperature-precipitation data for Illinois counties were sourced from National Oceanic and Atmospheric Administration[19]; the focus was on summer months, 1999-2021 (Table 3).

Observed deaths among the SSCs during the Summer months of 1999-2021, a 23-year time period, were obtained from the CDC Wonder database.[20] The mortality data were divided into two groups: elderly, ≥ 65 years of age and other, less than 65; gender of the diseased was also classified. An econometric model of the form:

$$Y = \mu + \alpha D_1 + \gamma D_2 + \beta_1 X_1 + \beta_2 X_2 + \epsilon \qquad \text{(Eq1)}$$

was calibrated, where,
Y = number of deaths; D_1 = 1 for Males, 0 for females; D_2 = 1 for age ≥ 65, 0 for < 65, and X_1 = maximum temperatures, and X_2 = SSC data on DT and MT.

[18] DT = dry tropical; MT = moist tropical; these are the common weather categories used to assess heat-related mortality; see Sheridan, S. C. (2002). The redevelopment of a weather-type classification scheme for North America. *International Journal of Climatology: A Journal of the Royal Meteorological Society*, *22*(1), 51-68.
[19] https://www.ncei.noaa.gov/pub/data/cirs/climdiv/.
[20] https://wonder.cdc.gov/mcd.html.

Findings

More females had died during the summer months of 1999-2021; the hottest temperature was registered at Franklin County, 98°F (Table 4). During 1999-2021, maximum temperatures in the nonmetro have increased at an annual compound growth rate of 0.32%.

Table 4: Number of Deaths by Gender and Maximum Summer Temperatures in Nonmetro Counties

(i) Number of Deaths during the Summer Months by Gender

Gender	199-2001	2002-2011	2012-2021
Male	42%	42%	46%
Female	58%	58%	54%
N	1772	5439	5672

Note: χ^2 = 18.052, p < .0001.

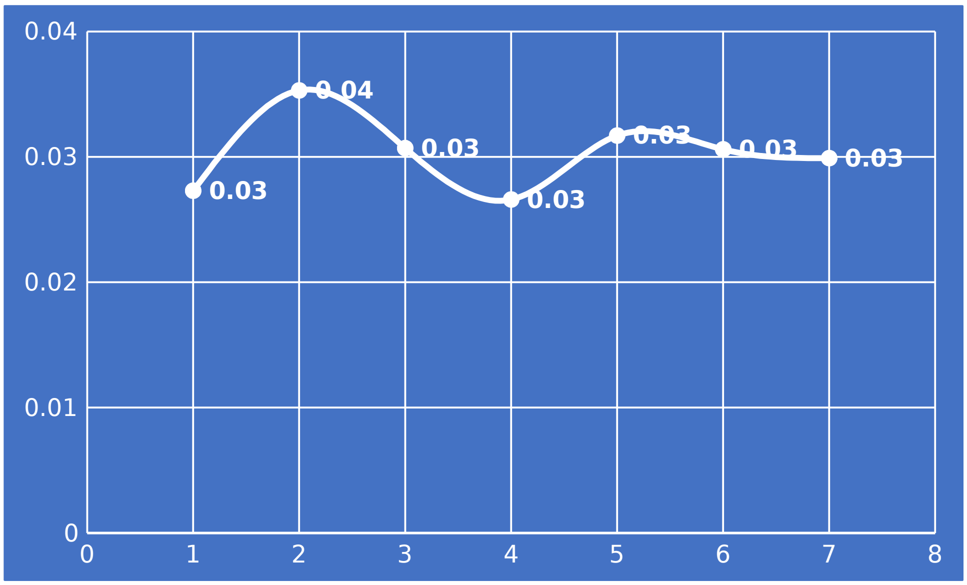
(ii) Maximum Summer Temperatures, 1999-2021, by County

County	Max. Temp.	County	Max. Temp.	County	Max. Temp.
Adams	97°F	Hancock	91°F	Morgan	95°F
Bureau	89°F	Henderson	92°F	Moultrie	87°F
Carroll	84°F	Iroquois	93°F	Ogle	91°F
Cass	87°F	Jasper	96°F	Perry	91°F
Christian	96°F	Jefferson	97°F	Pike	91°F
Clark	90°F	Jo Davies	87°F	Randolph	97°F
Clay	91°F	Johnson	87°F	Richland	91°F
Coles	96°F	Knox	92°F	Saline	95°F
Crawford	91°F	LaSalle	93°F	Schuyler	94°F
Cumberland	87°F	Lawrence	91°F	Shelby	90°F
Douglas	90°F	Lee	88°F	Stephens	91°F
Edgar	96°F	Livingston	93°F	Union	96°F
Effingham	97°F	Logan	94°F	Wabash	87°F
Fayette	90°F	Marion	97°F	Warren	89°F
Franklin	98°F	Mason	88°F	Washington	89°F
Fulton	94°F	Massac	96°F	Wayne	92°F
Greene	83°F	McDonough	93°F	White	92°F
Hamilton	74°F	Montgomery	96°F	Whiteside	92°F

Figure 3 shows the death rates for the SSC networks; the rate doesn't differ among the networks, F=1.34, p>.23. However, the number of days with weather pattern favorable for heat-related deaths differed significantly among the SSCs (Figure 3(ii)).

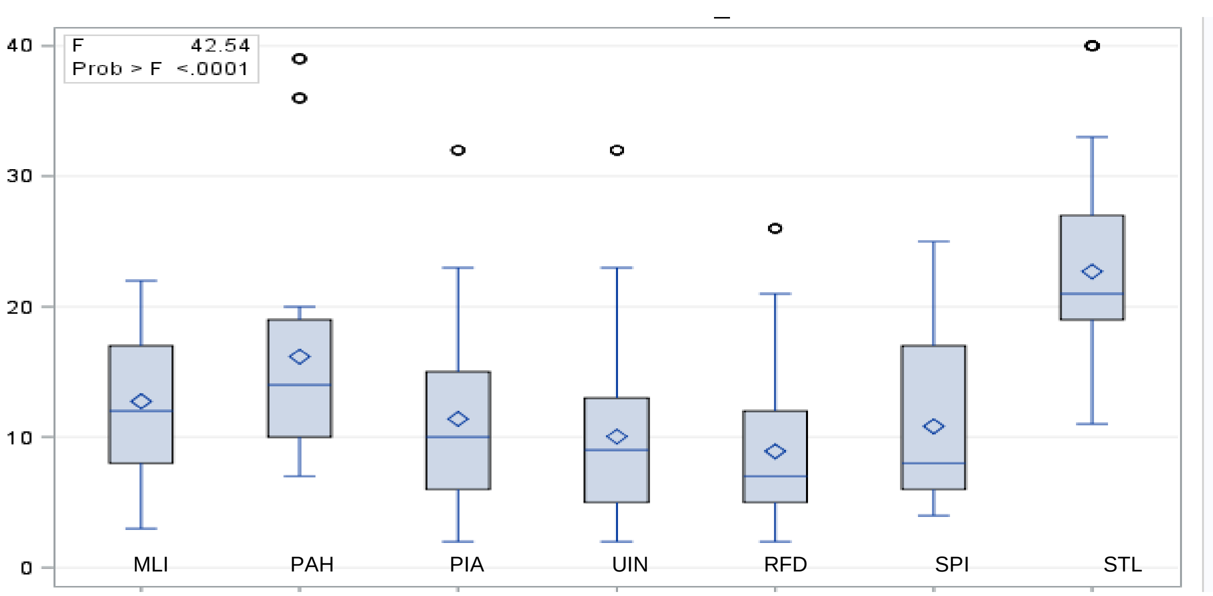
Figure 3: Death Rates and Moist Tropical Weather

(i) Death rates by SSCs



Note: ANOVA statistics: Model mean square = .00067138; error mean square = .00050124; F = 1.34.

(ii) Number of Days of Moist-Tropical Weather by SSC Network



Note: See Table 2 for SSC locations.

The estimated regression equation of death rate on the predictors (EQ1) was:

$$Y = -\underset{(.00635)}{.03580} + \underset{(.00038)}{0.0292}\, D_1 + \underset{(.000381)}{.04364}\, D_2 + \underset{(.000075)}{.00049}\, X_1 - \underset{(000030)}{.000074}\, X_2 + \epsilon$$

$R^2 = .95$

Standard errors are in parentheses.

All parameters were significant at the conventional α <.05 level; residuals did not show any peculiarities such as wrong functional form (Appendix 1), but the predictor "moist tropical weather" had the wrong sign. This could be due to the Covid-19 pandemic and resulting reductions in greenhouse gas emissions and atmospheric heat[21]. Empirical analysis supports this inference; the mean number of "DT, MT+, and MT++" days decreased from 18 in 2018 to 7-10 days during 2019 - 2020.

The partial correlations between the criterion variable, 'death rate', and the predictors were highest for the 'age' variable, $r^2 YD_2.D_1X_1X_2$ = .95; the lowest partial correlation was for the 'moist-tropical weather' variable, $r^2 YX_2.D_1D_2X_1$ = .009; this is not surprising given the poor validity of the variable, see discussion on parameter estimates above. The maximum summer temperature variable had a partial correlation of .07, summer heat explains 7% of variability in death rates. In practical terms, of the 12,883 deaths that occurred during the summer months of 1999 to 2021, an estimated 5926 to 6828 of the deaths could be attributed to heat-related mortality[22]. Table 5 shows mortality predictions for 2030 by SSCs.

Table 5: Predicted Number of Heat-Related Deaths by SSCs, 2030

SSC Network	Population <65		Population ≥ 65	
	Male	Female	Male	Female
MLI (Moline)	235	146	196	216
PAH (Paducah)	80	51	226	231
PIA (Peoria)	269	65	321	152
RFD (Rockford)	572	263	524	577
STL (St. Louis)	181	87	170	200
SPI (Springfield)	236	312	418	458
UIN (Quincy)	427	440	393	436

Note: Higher level estimates are shown; Appendix 2 contains both lower and higher limits of projected mortality numbers.

[21] See, https://climate.nasa.gov/news/3129/emis-sion-reductions-from-pandemic-had-unexpected-effects-on-atmosphere/.

[22] Based on the "Binomial Effect Size Display" computations; see Rosenthal, R., Rosnow, R. L., & Rubin, D. B. (2000). *Contrasts and effect sizes in behavioral research: A correlational approach.* Cambridge: Cambridge University Press.

Summary and Conclusion

To my knowledge, this is the first analysis to describe climate and mortality in nonmetro Illinois. Of the 12,883 deaths that occurred during the summer months of 1999 to 2021, an estimated 46% to 53% of the deaths could be attributed to heat-related mortality. Summer temperatures in nonmetro Illinois have been on the rise since 1999, temperatures increased at an ACGR of 0.32% from 1999-2021; predictions are that climate change would continue to pose significant challenges to the future of health in the country[23].

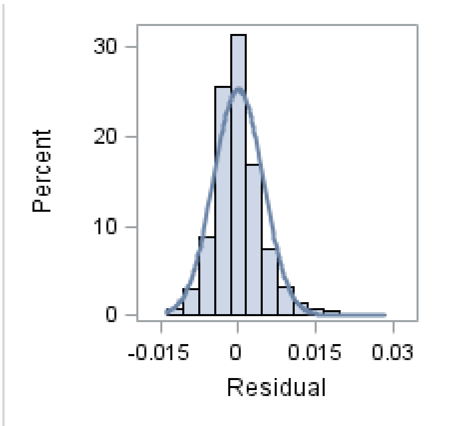
To tackle this major health challenge, there is an urgent need for policy that are built on science and evidence. BRACE is a solution, but it has been criticized for being overly technical and "academic"[24]. Furthermore, rural local health departments (LHDs) are not adequately resourced to engage in climate change mitigation and adaptation efforts[25].

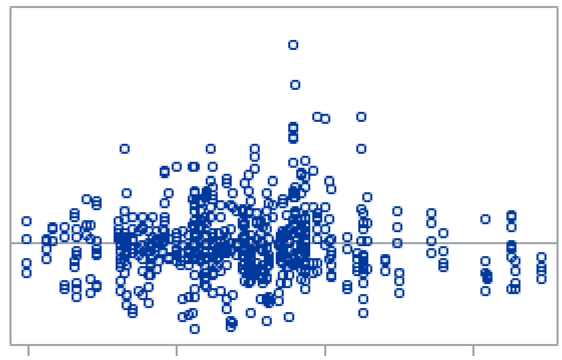
This research overcomes these limitations; it provides LHDs in nonmetro Illinois with:

(i) An exposure-response model for heat-related mortality in the region;
(ii) Information about sources of data on climate, the seven SSC networks relevant for nonmetro Illinois, and
(iii) An econometric model to project future health impacts of climate on Illinoisans residing in the SSC network regions.

[23] Dzau, V. J. (2023). Anticipating the Future of Health and Medicine—The National Academy of Medicine Prepares for Its Next 50 Years. *JAMA*.
[24] Zuber, A. (2018). *Protecting American Health from Climate Change: What is needed to expand adaptation planning by US state and local health departments?* (Doctoral dissertation, The University of North Carolina at Chapel Hill).
[25] Vo, M. V., Ebi, K. L., Busch Isaksen, T. M., Hess, J. J., & Errett, N. A. (2022). Addressing Capacity Constraints of Rural Local Health Departments to Support Climate Change Adaptation: Action Is Needed Now. *International Journal of Environmental Research and Public Health*, *19*(20), 13651.

Appendix 1: Model Fit Diagnostics, Residual Plots





Appendix 2: Lower and Upper Interval Estimates of Heat-Related Mortality for Nonmetro Illinois, 2030.

(i) Lower Limits

SSC Network	Population <65		Population ≥ 65	
	Male	Female	Male	Female
MLI (Moline)	204	127	170	188
PAH (Paducah)	69	45	197	196
PIA (Peoria)	234	56	278	132
RFD (Rockford)	496	228	455	501
STL (St. Louis)	157	76	148	174
SPI (Springfield)	205	271	363	398
UIN (Quincy)	371	382	341	381

(ii) Upper Limits

SSC Network	Population <65		Population ≥ 65	
	Male	Female	Male	Female
MLI (Moline)	235	146	196	216
PAH (Paducah)	80	51	226	231
PIA (Peoria)	269	65	321	152
RFD (Rockford)	572	263	524	577
STL (St. Louis)	181	87	170	200
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