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Heat-health Outcome Thresholds

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A previous report indicates that temperatures in New Mexico are expected to continue to rise[1] and contribute to a forecasted doubling of heat-related illnesses (HRI) cases by 2030.[2] Climate vulnerability studies reveal that as temperatures increase, (with or without periods of extreme heat and/or periods of heat referred to as abnormally hot days, or deviant days[3]) people with the same social vulnerabilities identified in other natural disasters are at high risk of impact.[4] Social vulnerabilities, social-economic status and housing insecurity, for example, are not unique to HRI, nor temperature extremes. HRI also impacts people at temperatures lower than extreme temperatures. Prominent methods to identify these temperature thresholds have relied on measures of risk ratios, rate ratios, reference-adjusted rate ratios, attributable fractions and related measures that are then analyzed with loglinear and/or time-series models.[5]

Current warning threshold research sets heat warnings at 94 ^{o}F, the temperature when HRI morbidity probability risk starts to climb above other heat-sensitive morbidities, based on analysis of proportional hazards. This analysis of expected morbidity, or the inverse of Kaplan-Meier Survival analysis (also called 'failure analysis'), also finds the 50th percentile risk of HRI occurring at 94 ^{o}F. Risk of HRI, however, begins well before 94 ^{o}F. For example, a prior analysis of syndromic surveillance emergency department (ED) HRI cases in Roswell, New Mexico (unpublished data), by daily temperature data [obtained from National Oceanic and Atmospheric Administration (NOAA) climate stations] revealed that people went to the Emergency Department (ED) for HRI at a wide variety of temperatures, from 76-107 ^{o}F, similar to but narrower than the current analysis which has greater numbers and broader statewide morbidity data. This indicates that multiple heat (temperature) thresholds need to be established to inform the public of the rising risk of morbidity well ahead of mortality. This analysis provides a new method to derive and promulgate a three-tiered set of public health advisories, warnings and alerts, based on criteria temperatures to reduce both morbidity and mortality.

Methods
HRI morbidity failure by temperature analyses is based on Emergency Department (ED) and hospital inpatient data linked to temperatures at the corresponding city and/or town with the objective to identify significant temperature thresholds for the issuance of public health advisories, warnings, and alerts levels. Failure analysis, the inverse of survival probability, is *F(t) = 1 – S (t),* where *S(t)* is defined as:

$$\widehat{S}(t) = \prod_{i:\ t_i \le t} \left(1 - \frac{d_i}{n_i}\right),$$

t is temperature (integer), d_{i} is the number of events at t and n_{i} is the number of total HRI morbidity failures seen in facilities. Multiple-day maximum temperatures were tested based on literature and observations.

<u>ED Visits</u> for the years 2010-2021 include admit diagnoses, co-morbidities, external cause codes (e.g., place of occurrence), demographics, ecological location information (city, town, and regions, such as public health regions and others) and dates.

<u>Hospital Admissions</u> from 2010-2021 include admissions with primary and secondary diagnoses, comorbidities, external cause codes, demographics, ecological location, and dates.

HRI is flagged as a "1" when primary or secondary diagnoses include International Classification of Diseases, Ninth Revision, Clinical Modification (ICD-9-CM) codes of 992.0-992.9, E900.0, or E900.9 and/or International Classification of Diseases, Tenth Revision, Clinical Modification (ICD-10-CM) codes of T67.0-T67.9; X30.0 or X32.0. Cases with coding for heat exposures from man-made origin (ICD-9-CM code of E900.1 or ICD-10-CM of W92.0) were excluded. These codes were identified and validated based on CDC nationally consistent data measures.[7]

Temperatures for 2010-2021 were obtained from 106 NOAA ground stations that provide daily maximum and minimum temperature for most of the state's population, extended to include places not directly covered by stations by linking to the nearest appropriate station as data surrogates. Station placename was then used for the ecological linkage of daily maximums by place of residence or medical care facility found in the morbidity records. HRI cases are summarized by temperature and then analyzed with failure analysis (SAS 9.4, Proc Lifetest).

Extensive testing of models was conducted with each demographic (age, sex, race/ethnicity, residence in one of five New Mexico public health regions) and then with all covariates with failure and proportional hazard models. Further, failure analyses and preliminary proportional hazard analyses for tests of covariate and interaction contributions were both utilized for identifying temperature-sensitive heat-health outcome thresholds.

Classic failure analysis frames the findings around the median, identifying the middle 50% of HRI morbidity by temperatures that encompass quartiles of 25% to 75% of HRI cases. A new "modified inclusive" analysis expands that framing of HRI morbidity by looking more broadly at the range of temperatures that provides the best information for identifying an initial temperature threshold when people start to seek medical care for HRI so that people can be prepared and anticipate possible morbidity. The subsequent thresholds for warnings and alerts identified in this report were established to make sense, be memorable and not overburden or fatigue the public with too many alarms.[6]

Results

From 2010-2021, there were 9,535,932 ED visits with 3,919 HRI cases and 2,419,067 hospital admissions with 489 HRI cases. Data included primary and secondary diagnoses (co-morbidities), demographics, dates, exposure information, and ecological location information (placename). After correcting city and town misspellings, assigning surrogate stations and conducting station linkages, 3,848 ED HRI visits were associated with daily ground temperature stations, 72 could not be linked to NOAA temperature monitor stations, and 14 cases were removed as duplicates. One surrogate example is the Rio Grande River communities north of Bernalillo and south of Santa Fe which are not directly covered by stations. For these, the surrogate was assigned as the station at Jemez Dam.

One HRI visit was admitted prior to 2010 and 306 visits did not match up by date of temperature, leaving 3,527 resident ED HRI visits linked to temperatures. Further, there were 489 inpatient HRI cases, 5 of which did not match with stations, and 41 of which did not match with a daily temperature, leaving 443 inpatient HRI cases linked with temperatures. Thus, 3,960 HRI cases were then evaluated with failure analysis.

Classic failure analysis (using two-day maximum temperatures) showed that the median likelihood for HRI morbidity occurred at 94 °F. Table 1 provides results for the classic analysis in the first row of data. Additionally, Figure 1 illustrates the median centroid, 94 °F, with an arrow and the inter-quartile range, shown as the smaller box. The second data row of Table 1 shows the modified inclusive analysis results with associated proportions with respect to temperatures for identifying HRI morbidity. For example, 50% of HRI occurred at temperatures ranging from 94 °F through 112 °F (the highest temperature in the analysis). HRI morbidity risk increased disproportionately at lower temperatures and significantly at 80 °F (data not shown) and this risk then jumped at 90 °F, 94 °F, and again at 100 °F and ended at 112 °F. Additionally, 80 °F was the initial temperature that comprised 90% of all HRIs (see Figure 1 with the larger box starting at 80 °F).

HRI ED visits were associated with daily maximum temperatures at a statistically significant level (data not shown), whereas hospitalizations were more robust when analyzed with two-day maximums. Three- and five-day maximums had a diminishing effect on the presence of low-temperature anomalies and increased the median while not changing the characteristics of the HRI-temperature risk distribution (data not shown).

The evaluated demographics and most covariates did not significantly modify, covary or interact with the core functional heat-health failure probabilities. For example, with respect to age, those 18-63 years old (working ages) experienced two thirds of the overall

Table 1. Heat-health Outcome (Morbidity Failure by Temperature) Thresholds

Interpretation of Analysis	50% of HRI Cases	90% of HRI Cases	95% of HRI Cases
Classics Analysis, Centered on Median (**94**°)	88°, **94**°, 98°F (Quartiles)	73°, **94**°, 102°F	64°, **94**°, 105°F
Modified Inclusive Range, Beginning-End Temperatures.	94-112°F	**80 -112°F**	72 -112°F

HRI morbidity. Older and younger ages did not have different HRI morbidity risks at the same temperatures. Both males and females had the same heat-health failure probabilities. Lineages, ethnicity, and heritages all had the same heat-health failure probabilities. Finally, New Mexico public health regions did not reveal differences in HRI morbidity by temperature (data not shown).

Discussion

While temperature was the primary factor associated with HRI and demographics were not, other variables could be important for future analysis. For example, place of occurrence may be important, but the external cause coding was too sparse and inconsistent to make any robust conclusions at this time for measures of homelessness or outside exposure and HRI morbidity. Geography suggests an important but not completely revealed functional role in HRI failure probability thresholds. The indications are that rural (and possibly mixed urban and rural), mountainous and high plans regions, as found in Climate Divisions and Eco-Regions from EPA[8] suggest covariations. While it may be possible to evaluate combinations, in particular mountains and high plains versus desert and tablelands (plateaus), which could yield slightly different failure curves, there needs to be refinement to increase counts, reduce sparsity and increase statistical quantification.

Utilizing modified inclusion analysis with two-day maximum temperatures provided the best fit to establish multiple heat (temperature) thresholds to inform the public of the rising risk of morbidity and to prevent or reduce cases mortality. The initial heat-health outcome threshold should be set at 80^{o} because HRI risk increased significantly at this temperature and because 90% of all HRIs were captured when this initial temperature was utilized. The next threshold should be set at 90^{o} which is where HRI risk jumped again and 100^{o}F is the final threshold.

Lastly, HRI morbidity (and mortality) at low temperatures provided data analysis challenges because they are generally rare. Further, two-day maximum temperatures for HRI differences reveal that there was also a jump in risk at 74 ^{o}F but cases then fell at 75 ^{o}F, likely when coolers are turned on. There were also HRI cases with questionable low temperatures that were not addressed with multiple or 3–5-day maximum lags under 70 ^{o}F.

There are two limitations to this analysis. First, data for access to healthcare, a known issue in New Mexico for those in underserved and/or remote locations and social vulnerabilities (at levels that are more precise and relevant than the county level) were not available. Second, because mortality has been too rare to analyze (under 10 HRI deaths per year in NM, until recently) it is likely obscured by the determination of the underlying cause of death where further study may reveal HRI as the more common contributing cause of death.

Conclusions

To prevent or reduce HRI in NM, temperature thresholds should be set at 80 ^{o}F, 90 ^{o}F and 100^{o}F for public health advisories, warnings, and alerts, respectively. The temperatures are easy to remember, capture 90% of the HRI cases in EDs and hospitals, and are in line with recent literature identifying the median HRI temperature resulting in morbidity.

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Figure 1. HRI Morbidity Failure Probability by Maximum Two-Day Temperatures