

**Main Manuscript for**

**Rising temperatures and alcohol- and substance-related disorder hospitalizations**

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Main Text

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Table 1

**Abstract**

Over half of American adults regularly consume alcohol and other psychoactive substances. Despite plausible behavioral and physiological pathways, evidence is limited regarding whether daily increases in temperature are associated with alcohol- and substance-related disorders. We implemented a case-crossover design, coupled with distributed lag non-linear temperature terms (0-6 days), to estimate associations between daily ZIP Code-level temperature and alcohol- and substance-related disorder hospitalization rates in New York State across 20 years (1995–2014). We examined two groups of cause-specific hospitalizations (alcohol-, substance-related disorders) and four sub-causes of the substance-related disorders (cannabis-, cocaine-, opioid-, sedative-related admissions). We evaluated how these estimated associations varied by location, age group, sex, and social vulnerability. For alcohol-related disorder hospitalizations, a daily increase in temperature from the period daily average (10°C) to the 75th percentile (18.4°C) across 0-6 lag days was associated with a cumulative 4.3% (95%CI, 3.0%–5.5%) increase in daily hospitalization rates. This association was largely driven by temperature increases on the day of or day before hospitalization. This association was larger when using data outside New York City. We found evidence of an association for daily increases in temperature at temperatures lower than 10°C in substance-related disorder hospitalizations. We did not find evidence of an association between daily increases in higher temperatures (from 10°C to 18.4°C). We found no evidence of effect modification by location, age group, sex, and social vulnerability. Our study highlights the potential impacts of rising temperatures from a changing climate on mental health-related outcomes for all.

**Significance Statement**

It is commonly hypothesized that a warmer world will lead to wide-ranging adverse health consequences. However, a comprehensive assessment of the association of temperature with alcohol- and substance-disorder hospitalizations over multiple years of study is lacking. Plausible behavioral and physiological pathways exist, including more perspiration in warmer weather, and temperature-dependent efficacies of substances. We applied a modelling approach to two decades of complete temperature and hospitalization records in New York State (NYS) to estimate the association between rising temperatures and alcohol- and substance-related disorders. We found that increased temperature 0-6 days before hospitalization was associated with higher hospitalization rates for both alcohol- and substance-related disorders up to a threshold, with an increased risk distinct for alcohol and other psychoactive substances.

**Main Text**

**Introduction**

Alcohol and other psychoactive substances—including cannabis, cocaine, opioids, sedatives, and their historical equivalents—have been used recreationally, medicinally, and religiously by humans for thousands of years (1). Based on a Substance Abuse and Mental Health Services Administration (SAMHSA) survey in 2019 in the United States, 139.7 million people recently drank alcohol, with at least 25.8 million consuming illicit drugs (2). Most substance users do so in moderation (2). However, a substantial minority of individuals suffer from related disorders, defined as when recurrent use of alcohol or other substances causes clinically significant impairment (3), and require intervention, including inpatient treatment.

Warm and cold weather events are an important public health concern in today’s world, and one of the key drivers for seeking adaptation measures against climate change. Assessments of the health effects of weather and climate, and by extension of global climate change, have largely focused on parasitic and infectious diseases, and cardiorespiratory and other chronic diseases (4, 5). Recent work has focused on mental health-related mortality outcomes in the United States, such as suicide and violence (6, 7). There are plausible behavioral and physiological pathways for a relationship between changes in temperature and alcohol- and substance-related disorders; increased consumption in warmer weather, more perspiration, and temperature-dependent efficacies of certain substances, such as opioids, may all contribute to changes in alcohol and substance use and how a human body reacts to their consumption (8). Nevertheless, there remains an overall knowledge gap in consistently and comprehensively quantifying how temperature is associated with alcohol- and substance-related hospitalizations.

The aim of this study was to evaluate (a) how short term changes in exposure to daily temperature was associated with hospitalizations due to alcohol- or substance-related disorders (including alcohol, cannabis, cocaine, opioids and sedatives), and (b) how this association varied by location, age group, sex, and social vulnerability, using daily ZIP Code-level hospitalization data obtained from hospitals in NYS, the fourth largest state by population in the United States (9).

**Results**

*Hospitalizations*

There were 717,798 total hospitalization records in New York State for alcohol-related disorders and 794,305 for substance-related disorders during the study period (1995-2014). Admissions with missing, incomplete, or inaccurate records of sex, age, dates of admission, or residential ZIP Codes were excluded (16.4% of alcohol-related disorder and 9.2% of substance-related disorder hospitalizations). This left 671,625 complete hospitalization records for alcohol-related disorders and 721,469 for substance-related disorders (Table 1). Across sub-causes of substance-related disorders, total complete hospitalization records ranged from the highest for opioids (275,707) to lowest for sedatives (50,068).Across every cause, the age group with largest proportion of hospitalizations was 25-44 years, from 46% of alcohol-related disorder hospitalizations up to 61% of cocaine hospitalizations.Males made up the majority of hospitalizations across all causes, from 53% in sedatives to 63% in alcohol-related disorders.Most hospitalizations were in-patient, from 68% of cannabis hospitalizations to 87% of sedative hospitalizations.Most hospitalizations were also not in NYC, from 53% of hospitalizations for cocaine and opioids, to 67% for cannabis.

In New York State, the number of alcohol- and substance-related disorders varied by ZIP Code (Fig. 1). The maximal total number of hospitalizations in a single ZIP Code was 6,479 for alcohol-related disorder hospitalization in Troy (12180) and 8,026 substance-related disorder hospitalizations in East Harlem (10029). Many cases were concentrated in urban environments. Overall, there was a high correlation (R=0.98) between total numbers of hospitalizations for both alcohol- and substance-related disorders across all ZIP Codes.

Over time, the number of alcohol- and substance-related disorder hospitalizations increased across females and males, as well as in NYC and not NYC (Fig. 2). There were more substance-related disorders than alcohol-related disorders throughout the study period. Trends in increased substance-related disorder hospitalizations over time were driven by increases in cannabis and opioids, with increases then slight decreases for cocaine and sedatives (Fig. S1).

*Association of temperature with total hospitalizations*

For alcohol-related disorder hospitalizations, a daily increase in temperature from the period daily average (10°C) to the 75th percentile (18.4°C) across 0-6 lag days was associated with a cumulative 4.3% (95%CI, 3.0%–5.5%) increase in daily hospitalization rates, and a daily increase from the daily average to the 90th percentile (22.3°C) was associated with a cumulative 5.3% (95%CI, 3.5%–7.0%) increase (Fig. 3). Overall, there was a near-linear positive association between temperature and alcohol-related disorders hospitalizations across most of the temperature distribution. For substance-related disorders, we did not find evidence of an association between daily increases in temperatures from 10°C to 18.4°C, with a cumulative 1.2% (95%CI, -0.1%–2.4%) increase, nor from 10°C to 22.3°C, with a cumulative 1.4% (95%CI, -0.3%–3.1%) increase. Overall, there was a near-linear positive association between temperature and substance-related disorders hospitalizations below the mean temperature and no evidence of a change above. Cannabis-related admissions followed the overall substance-related disorder association patterns (e.g., a daily increase in temperature from 10°C to 18.4°C across 0-6 lag days was associated with a cumulative 0.2% (95%CI, -2.5%–2.9%) increase in daily hospitalization rates) (Fig. S2). Cocaine-related admissions also followed the overall substance-related disorder association patterns (e.g., a daily increase in temperature from 10°C to 18.4°C across 0-6 lag days was associated with a cumulative 1.6% (95%CI, -0.6%–3.9%) increase in daily hospitalization rates). For opioid-related admissions, there was an increase up to the mean temperature with a decrease above that. Sedative-related admissions indicated no overall discernible change across the temperature range.

*Association of temperature with hospitalizations by location*

For alcohol-related disorders, there was a larger increase in hospitalization rates at warmer temperatures outside NYC (e.g., a daily increase in temperature from 10°C to 22.3°C was associated with a cumulative 7.2% (95%CI,5.0%–9.5%) increase for outside NYC compared with a cumulative 2.7% (95%CI,-0.3%–5.7%) increase for NYC) (Fig. 4). For substance-related disorders, there was a larger increase in hospitalization rates at colder temperatures outside NYC (e.g., a daily increase in temperature from the 10th percentile (-4.1°C) to 10°C was associated with a cumulative 8.6% (95%CI,6.3%–10.8%) increase for outside NYC compared with a cumulative 4.9% (95%CI, 1.7%–8.1%) increase for NYC). For sub-causes of substance-related disorders, results were inconclusive (Fig. S3). Other sub-analyses (by females vs. males, age group, social vulnerability) did not provide conclusive evidence of conclusive effect modification (Figs. S4-S9).

*Secondary analyses*

Results of analyses of only including temperatures from the day of and day before (0-1 days) for associations of temperature with total hospitalizations for causes are found in Figs. S10-S11. The association of alcohol-related disorders at higher temperatures was potentially attenuated, though still a positive association (Fig. S10) (e.g., a daily increase in temperature from 10°C to 18.4°C across 2 lag days was associated with a cumulative 1.2% (95%CI, 0.2%–2.1%) increase, and a daily increase in temperature from 10°C to 22.3°C across 2 lag days was associated with a cumulative 1.7% (95%CI, 0.4%–2.9%) increase). The association of substance-related disorders at higher temperatures still showed indications of a potential increase, though still non-discernible from the null (Fig. S10) (e.g., a daily increase in temperature from 10°C to 18.4°C across 2 lag days was associated with a cumulative 0.5% (95%CI, -0.4%–1.4%) increase, and a daily increase in temperature from 10°C to 22.3°C across 2 lag days was associated with a cumulative 0.7% (95%CI, -0.6%–1.9%) increase). Overall conclusions were the same as the main analyses.

*Sensitivity analyses*

For relative humidity sensitivity analyses (Fig. S12), there was a correlation of R=0.99 and a slope of 1.00 (95%CI, 0.98–1.02) between estimates of associations with (main) and without (sensitivity) relative humidity in the model.

**Discussion**

In NYS from 1995–2014, a daily increase in temperature 0-6 days before hospitalization was associated with higher hospitalization rates for both alcohol- and substance-related disorders up to a threshold, above which no increases were discernible.

*Previous studies*

Limited previous studies of alcohol- and substance-related disorders in relation to temperature support the findings in this analysis. A near-linear association was found between alcohol or drug poisoning found during homeless rescue missions and temperature in Hamburg, Germany (10), while another study of alcohol use disorders in Paris, France found a correlation of 0.55 between weekly alcohol use disorders and mean temperature (11), though neither study adequately controlled for confounding bias, including season. Heatwaves in Hanoi, Vietnam, were associated with increases in admissions from mental disorders, but not from psychoactive substance use (12). In contrast to findings in this study, substance abuse-related mental illness emergency hospitalizations in Toronto, Canada were positively associated with highest temperatures (13).

*Plausibility of results*

That temperature influences hospitalizations from both alcohol- and substance-related disorders, although not previously quantified, is plausible. Changes in alcohol- and substance-related hospitalizations may result from changes in temperature for many behavioral or psychological reasons. Overall decreases in hospitalization rates below average temperatures may also be driven by lower enthusiasm to visit hospital, as it may, for example, seem more dangerous in particularly cold or inclement weather (14), especially while under the influence of a psychoactive substance. Higher hospitalizations in higher temperatures for alcohol-related disorders may potentially be driven by more time outdoors performing riskier activities, consuming more substances in more pleasant outdoor weather, more perspiration causing greater dehydration, or driving while under the influence (7). The observed temperature thresholds may be because once outdoor temperatures are sufficiently comfortable, further temperature increases may not increase outdoor activity. There was no clear evidence of increases in substance-related disorder hospitalizations for temperatures higher than the mean temperature. Nevertheless, for cocaine, there was a potential increase for higher temperatures, which may be driven by consumption with alcohol and increased sweating, increasing risk of cardiovascular and respiratory issues developing. Those who regularly take opioids have found that their efficacy is reduced in warmer weather, and may potentially take higher doses on warmer days (8).

*Strengths and limitations*

Leveraging complete hospitalization data from 671,625 alcohol- and 721,469 substance-related disorder hospitalizations over 20 years and a comprehensive record of ZIP Code-level daily temperatures and relative humidity, this study is the first, to our knowledge, comprehensive investigation of the association between temperature and alcohol- and substance-related hospitalizations.

The study has several limitations. First, a potential limitation is outcome misclassification, as it is likely that the most severe cases of alcohol- and substance-related disorders resulted in deaths before hospitalization was possible. Future work should attempt to link cases of deaths with hospitalization records to create a fuller picture of patients’ medical history. Second, exposure misclassification is inevitable, e.g., if those who were hospitalized were located at a different ZIP Code than their residential ZIP Code. However, it is not very likely that a large proportion of the cases would be away from their residential ZIP Code for the week—the exposure window we examined—prior to hospitalization. Exposure misclassification, therefore, is likely non-differential as it is not expected to be correlated with the outcomes assessed, potentially biasing towards the null (15). Third, the estimated associations may have been susceptible to confounding bias. By matching using the time-stratified case-crossover structure, where cases are matched to themselves during periods where they were not hospitalized, this design controls for factors varying across individuals, as well as day of the week, month and season, but the possibility of residual confounding by unknown or unmeasured factors which vary over the time scale of a few weeks cannot be ruled out. Any such variable, however, would have to covary with both hospitalization rates and temperature in ZIP Codes and be independent of the variables included in analyses to induce residual or unmeasured confounding*.* Fourth, this study was focused on New York State, though temperature is a pervasive exposure and the association with alcohol- and substance-related disorders should be further explored in locations with different communities and climates. Fifth, the consequences of these findings in the context of a changing climate are unclear. Adaptation may play a key role in mitigating the worst impacts of climate change on health (16). However, there are limits to the adaptive capacity of humans, and these results should be further explored in the context of adaptive capacity. Nevertheless, these results further indicate that public health practitioners preparing for climate change should consider outcomes such as substance use disorder or mental health events that are not usually linked to temperature. Sixth, this study was focused on each individual alcohol- and substance-related disorder per analysis. Further work should examine cases co-morbidities, as well as whether existing health conditions are exacerbated by alcohol and/or substance use combined with rising temperatures.

Our work highlights how hospitalizations from alcohol- and substance-related disorders are currently susceptible to elevated temperatures and could also be modified by rising temperatures resulting from climate change, unless countered by social infrastructure and health system interventions that mitigate these impacts. Public health interventions that broadly target alcohol and substance disorders in warmer weather—for example, targeted messaging on the risks of their consumption during warmer weather—should be a public health priority.

**Materials and Methods**

This study was approved by the Institutional Review Board at the Columbia Mailman School of Public Health and was classified as exempt from needing to obtain Informed Consent (Protocol IRB-AAAR0877).

*Study Population*

Hospital records were obtained across NYS from 1995 to 2014 from the New York Department of Health Statewide Planning and Research Cooperative System (SPARCS) (https://www.health.ny.gov/statistics/sparcs/). SPARCS is an administrative dataset collected from all non-military acute care facilities in NYS, covering ~98% of all NYS hospitalizations; as of 2015, SPARCS included 222 acute care facilities (17). For each admission record, International Classification of Diseases, Ninth Revision, Clinical Modification (ICD-9-CM) diagnosis codes were obtained, along with patient residential ZIP Code, date of admission, age, and sex.

*Outcomes*

Alcohol- and substance-related disorder cases were identified from the first four ICD-9-CM diagnostic position codes in each admission record. Both inpatient and outpatient admissions were included. Classifications were based on the Clinical Classifications Software (CCS) algorithm (18), commonly used in epidemiologic studies to group ICD codes into clinically-meaningful categories (Table S1) (14, 19, 20). Substance-related disorder records were further subdivided. This resulted in two broad causes (alcohol-related disorders, substance-related disorders) and four specific substance-related sub-causes (cannabis, cocaine, opioids, sedatives). For each cause, an admission was counted as a case if it included at least one matching code in the four ICD-9-CM codes, i.e., a single admission could be attributed to several causes.

*Exposure*

Daily average temperature, specific humidity, and pressure were obtained from the North American Land Data Assimilation System, NLDAS-2 Forcing (21), with full space and time coverage over the study period. NLDAS-2 estimates hourly mean weather values within 0.125° grids (~11 km 14 km in NYS). Similar to previous work (17, 19, 22, 23), weather variable grid daily averages were intersected with census tract-level population from 2010 US Census data. Population-weighted averages were then computed at the ZIP Code Tabulation Area (ZCTA) level, a consistent geographic representation of ZIP Codes (<https://www.census.gov/programs-surveys/geography/guidance/geo-areas/zctas.html>), referred to as ZIP Code hereafter (Fig. S13). Relative humidity (RH) was calculated from temperature, specific humidity, and pressure (Fig. S14) (24).

*Covariates*

Data on social vulnerability in NYS by census tract were used from the Centers for Disease Control and Prevention (CDC) Social Vulnerability Index (SVI) for 2014 (https://www.atsdr.cdc.gov/placeandhealth/svi/data\_documentation\_download.html). The SVI incorporates data from the US Census on socioeconomic status; household composition and disability; minority status and language; and housing type and transportation to determine the relative social vulnerability of every census tract in NYS (25). A census tract’s SVI value indicates the relative vulnerability of every NYS census tract compared with every other NYS census tract, ranking from 0 (lowest vulnerability in the state) to 1 (highest vulnerability in the state). To obtain ZIP Code-level SVI values, the 4,903 census tract SVI values were area-weighted into 1,794 ZIP Codes. The ZIP Codes were divided into SVI tertiles (low vulnerability to high vulnerability, 1 to 3; Fig. S15). Each SVI tertile contained 598 ZIP Codes. The same SVI tertile values were used for each ZIP Code throughout analyses.

*Statistical analysis*

A time-stratified case-crossover design was used, commonly used for analyzing associations with short-term exposures (26). In this design, temperature of the day of hospitalization and relevant preceding days (case period) are compared with the temperature of sets of days where the hospitalization did not occur (control periods). Comparing hospitalized individuals to themselves during other periods when they were not hospitalized eliminates confounding due to factors that vary across individuals. A conditional logistic regression (27) was used to quantify the association between daily average temperature and hospitalization rates, coupled with distributed lag non-linear model (dlnm) terms to estimate cumulative associations prior to the hospitalization (28). Cumulative associations were chosen to represent the total association in a parsimonious way. Six days’ cumulative association prior to hospitalization was chosen to include the most acute associations from high temperatures (29), while also maximizing power by not overlapping case and control periods. The cumulative association of only the temperature on the day of and day before was also estimated. Relative humidity was adjusted for, also including distributed lag terms, equivalent to the structure of the temperature terms. Specifically, via a logit function, the log-odds of hospitalization were modelled as follows:

where denotes whether subject in matched stratum was hospitalized, i.e., represents a group of a case and its matched controls; the matched stratum-specific intercepts (not estimated in conditional logistic models); the lag-specific natural spline terms as part of the dlnm terms for temperature; and the lag-specific natural spline terms as part of the dlnm terms for relative humidity. To select the optimal fit for the non-linear dlnm terms, models for alcohol-related disorders and substance-related disorders were fit separately using a variety of plausible degrees of freedom (dfs) to model the lag-specific exposure – response function (), as well as the function of the association over the examined lags (). A range of 2 to 5 for were considered, along with between 3 and 4 for . The optimal values were selected by choosing the combination of and with the lowest Akaike Information Criteria (AIC) values (30). The models with lowest AIC values for both causes were =4 and =3.

In addition to the main analyses investigating all hospitalizations together for each cause and sub-cause (alcohol-related disorders, substance-related disorders, cannabis, cocaine, opioids and sedatives), further assessment was made of whether estimated effects varied by location (NYC or not NYC), sex (female or male), age group (0-24 years, 25-44 years, 45-64 years or 65+ years), or by SVI tertile (low vulnerability to high vulnerability, 1 to 3), by conducting stratified analyses, using the same model as described above.

Unless stated otherwise, results are presented as cumulative percentage change in hospitalization rates were each of the lag days (0 to 6 days before) at the quoted temperature (e.g., the 25th percentile; 18.4°C) relative to 10°C, the New York State daily mean temperature throughout the study period. Statistical analyses were conducted using the R Statistical Software, version 4.1.1 (31) and dlnm, version 2.4.2 (32).

*Sensitivity analyses*

The sensitivity of the results to potential confounding by relative humidity was assessed by removing the relative humidity terms from the models.

**Acknowledgments**

CDC Disease Control and Prevention

DLNM Distributed lag non-linear model

NLDAS North American Land Data Assimilation System

NYC New York City

NYS New York State

SAMHSA Substance Abuse and Mental Health Services Administration

SVI Social Vulnerability Index

ZIP Zone Improvement Plan

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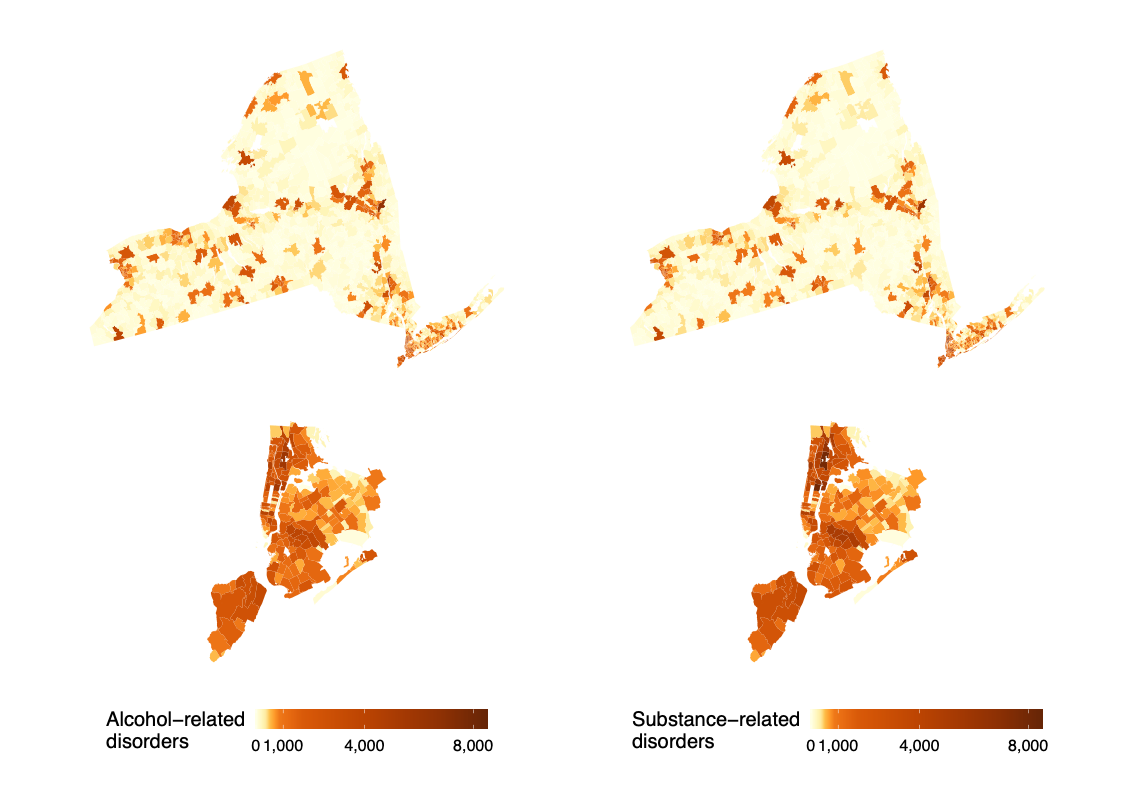
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**Figure 1.** Map of total hospitalizations by ZIP Code Tabulation Area of: (top left) alcohol-related disorder hospitalizations in New York State; (top right) substance-related disorder hospitalizations in New York State; (bottom left) alcohol-related disorder hospitalizations in New York City; and (bottom right) substance-related disorder hospitalizations in New York City for 1995-2014.

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**Figure 2.** Monthly alcohol and substance-related hospitalizations, by cause, sex, and location in New York State for 1995-2014.

**Figure 3.** Exposure-response curve of cumulative percentage change in hospitalization rates relative to average temperature (10°C) for alcohol- and substance-related disorder hospitalizations, were each of the lag days (0 to 6 days before) at the quoted temperature before hospitalization. Black lines show the point estimates and orange ribbons represent 95% confidence intervals.

**Figure 4.** Percentage change in hospitalization rates by selected percentiles of temperature relative to average temperature for alcohol- and substance-related disorder hospitalizations by location in New York State, were each of the lag days (0 to 6 days before) at the quoted temperature percentile before hospitalization. Points show the point estimates and whiskers represent 95% confidence intervals.

**Table 1.** Demographic characteristics for hospitalizations in New York State for 1995-2014.

| Characteristic | Alcohol-related  disorders, N = 671,6251 | Substance-related  disorders, N = 721,4691 | Cannabis, N = 139,2401 | Cocaine, N = 228,9891 | Opioids, N = 275,7071 | Sedatives, N = 50,0681 |
| --- | --- | --- | --- | --- | --- | --- |
| **Age group (years)** |  |  |  |  |  |  |
| 0-24 years | 58,320 (8.7%) | 120,077 (17%) | 52,307 (38%) | 20,097 (8.8%) | 34,964 (13%) | 5,740 (11%) |
| 25-44 years | 310,415 (46%) | 373,214 (52%) | 65,870 (47%) | 139,053 (61%) | 145,307 (53%) | 24,812 (50%) |
| 45-64 years | 271,144 (40%) | 209,459 (29%) | 20,534 (15%) | 68,280 (30%) | 89,615 (33%) | 17,203 (34%) |
| 65+ years | 31,746 (4.7%) | 18,719 (2.6%) | 529 (0.4%) | 1,559 (0.7%) | 5,821 (2.1%) | 2,313 (4.6%) |
| **Sex** |  |  |  |  |  |  |
| Female | 246,404 (37%) | 303,549 (42%) | 55,322 (40%) | 89,734 (39%) | 116,180 (42%) | 23,469 (47%) |
| Male | 425,221 (63%) | 417,920 (58%) | 83,918 (60%) | 139,255 (61%) | 159,527 (58%) | 26,599 (53%) |
| **Admission type** |  |  |  |  |  |  |
| In-patient | 510,449 (76%) | 535,334 (74%) | 94,756 (68%) | 191,250 (84%) | 229,442 (83%) | 43,352 (87%) |
| Out-patient | 161,176 (24%) | 186,135 (26%) | 44,484 (32%) | 37,739 (16%) | 46,265 (17%) | 6,716 (13%) |
| **Where in NYS** |  |  |  |  |  |  |
| NYC | 261,944 (39%) | 305,900 (42%) | 45,986 (33%) | 108,318 (47%) | 129,607 (47%) | 21,799 (44%) |
| Not NYC | 409,681 (61%) | 415,569 (58%) | 93,254 (67%) | 120,671 (53%) | 146,100 (53%) | 28,269 (56%) |
| 1n (%) | | | | | | |