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Impact of heat on mental health emergency visits: a time series study from all public emergency centres, in Curitiba, Brazil

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ABSTRACT

Objectives Quantify the risk of mental health (MH)-related emergency department visits (EDVs) due to heat, in the city of Curitiba, Brazil.

Design Daily time series analysis, using quasi-Poisson combined with distributed lag non-linear model on EDV for MH disorders, from 2017 to 2021.

Setting All nine emergency centres from the public health system, in Curitiba.

Participants 101 452 EDVs for MH disorders and suicide attempts over 5 years, from patients residing inside the territory of Curitiba.

Main outcome measure Relative risk of EDV (RR_{EDV}) due to extreme mean temperature (24.5°C, 99th percentile) relative to the median (18.02°C), controlling for long-term trends, air pollution and humidity, and measuring effects delayed up to 10 days.

Results Extreme heat was associated with higher single-lag EDV risk of RR_{EDV} 1.03(95% CI 1.01 to 1.05—single-lag 2), and cumulatively of RR_{EDV} 1.15 (95% CI 1.05 to 1.26—lag-cumulative 0–6). Strong risk was observed for patients with suicide attempts (RR_{EDV} 1.85, 95% CI 1.08 to 3.16) and neurotic disorders (RR_{EDV} 1.18, 95% CI 1.06 to 1.31). As to demographic subgroups, females (RR_{EDV} 1.20, 95% CI 1.08 to 1.34) and patients aged 18–64 (RR_{EDV} 1.18, 95% CI 1.07 to 1.30) were significantly endangered. Extreme heat resulted in lower risks of EDV for patients with organic disorders (RR_{EDV} 0.60, 95% CI 0.40 to 0.89), personality disorders (RR_{EDV} 0.48, 95% CI 0.26 to 0.91) and MH in general in the elderly ≥65 (RR_{EDV} 0.77, 95% CI 0.60 to 0.98). We found no significant RR_{EDV} among males and patients aged 0–17.

Conclusion The risk of MH-related EDV due to heat is elevated for the entire study population, but very differentiated by subgroups. This opens avenue for adaptation policies in healthcare: such as monitoring populations at risk and establishing an early warning systems to prevent exacerbation of MH episodes and to reduce suicide attempts. Further studies are welcome, why the reported risk differences occur and what, if any, role healthcare seeking barriers might play.

STRENGTHS AND LIMITATIONS OF THIS STUDY

- ⇒ We used emergency department visits (EDVs) due to mental health from all the nine public emergency centres, in the city of Curitiba.
- ⇒ The emergency system is free and does not require referrals, as hospitals normally do, which increases our sample and better captures the short-term effect of heat.
- ⇒ Stratified analyses by mental health subgroups (F00–F99) and suicide attempts (X60–X84) were carried out.
- ⇒ The use of EDVs and other healthcare use-related metrics may oversee patients who were unable to seek a doctor, due to socioeconomic barriers.
- ⇒ We had no access to data from the private system, which may have altered the profile of our sample.

INTRODUCTION

Research on the impacts of climate change (CC) on mental health (MH) has substantially increased in the past few years.[1] Recent work by Berrang-Ford *et al*, however, found that MH outcomes are least studied in the CC and health discourse globally.[2] Furthermore, only a small number of studies have been carried out in low-income and middle-income countries (LMIC), such as Brazil, where the most climate-vulnerable populations live.[3] A nationwide study carried out in Brazil supports that MH patients from poorer areas are more susceptible during heat.[4] The authors showed that in low-income or middle-income cities, there was a 17.2% higher risk of hospitalisation after a 5°C increase in temperature, while in high-income cites, this risk was only 5.5%, for the same temperature variation.[4]

This difference in the heat susceptibility among patients from lower and higher income areas has been attributed, first, to the higher prevalence of common mental disorders among the poor, low educated and unemployed layers of society.[5] Also, socioeconomically disadvantaged patients are at special risk of being directly exposed to heat, given inadequate housing and working

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conditions.[5] Simultaneously, the adaptive capacity, such as access to air conditioning, is lower.[6] Finally, the budget allocated to provide care for psychiatric patients in poorer countries is low—in average, limited to 1.9% of their total health funding, against 5.10% in richer nations.[7] Consequently, fewer MH diagnoses are made and availability of medication for treatment is scarce, exacerbating health inequalities.

Brazil accounts for one of the highest proportions of MH disorders. In 2019, the prevalence was 16.7%, in contrast to the 13.0% global average, from the Global Burden of Diseases study.[8] Regarding anxiety, the country has the second highest global prevalence: 7.4%, only behind Portugal.[8] This high prevalence will place a larger number of people with MH disorders at risk of heat exposure. Moreover, the MH burden in Brazil was reported to be 2317.70 disability-adjusted life-years (DALYs) per 100 000 people—the highest in Latin America, where the average rate is 1733.40 DALYs per 100 000 people.[9]

The mechanisms underlying heat impact on MH are currently incompletely understood. The pathways identified in the literature include (1) impairment of the physiological body thermoregulation, caused by MH diseases and psychotropic medications[6 10–12] and (2) patients inefficient cooling behaviour, given possible cognitive disability.[10] Against this complex background and given that the global average temperature has already increased by 1.1°C, Berrang-Ford *et al* identified the need for increased research on the effects of heat exposure on MH, like this study, as most of the other MH publications analysed correlation to extreme events, for example, floods, droughts and rainfall.[2 13] Therefore, we aimed to quantify the relative risk of emergency department visit (EDV) due to MH conditions (Relative risk of EDV, RR_{EDV}) from heat and investigate the delayed effects between exposure and outcome, by using public EDVs as proxy for MH disorder. To our knowledge, apart from China, this is the first time in LMICs that EDV is used as proxy for MH, as most studies use hospitalisation numbers. Specifically, we intended to analyse heat-vulnerability of different MH subgroups (F00–F99), suicide attempt (X60–X84), age and sex categories.

METHODS

Study area and population

Curitiba is the largest capital city in southern Brazil (figure 1) with a population of 1 773 733, in 2022.[14] Despite being considered an upper-middle-income city by the World Bank, the socioeconomic inequalities are evident, expressed by a Gini index of 0.525, against an average of 0.492 in the state.[15] Accordingly, the households average income in the richest neighbourhood is approximately 10 times the income in the poorest neighbourhood.[16]

Health dataset

Digitised anonymised health data from all nine public facilities in Curitiba was obtained from the State Health Secretary in an aggregate form on its open website. These nine urgency and emergency units (UPAs) provide free healthcare and are part of the Public Brazilian Health System (SUS), representing 100% of the public EDVs in Curitiba. The private system, in contrast, requires additional payment and accounts mostly for three hospitals and numerous clinics, which provide faster consultations with minimal waiting time; however, they were not freely available and could not be included in this research.

A total of 101 452 daily entrances were collected from a 5-year period, from 1 January 2017 to 31 December 2021. Age, sex and residential area were included as covariates. Patients were excluded if (1) registration with the above information was missing and (2) residential area was not located inside of Curitiba's territory.

Health records encompassed the following MH subgroups, by the International Classification of Diseases (ICD-10th)[17]:

F00–F09: organic disorders.
F10–F19: substance misuse.
F20–F29: schizophrenia.
F30–F39: mood disorders.
F40–F49: neurotic disorders.
F50–F59: behavioural disorders.
F60–F69: personality disorders.
F70–F79: intellectual disabilities.
F80–F89: specific developmental disorders.
F90–F99: behavioural and emotional disorders with onset in childhood/adolescence.
X60–X84: suicide attempt.

Temperature dataset

Daily mean temperature (T_{mean}) was obtained from the meteorological stations number 2, 3 and 5 (black pins, figure 1), with over 93% of complete data. Based on previous studies,[18–20] we opted to use the T_{mean}, instead of minimum or maximum temperature, assuming that the best predictor of heat stress is the average which patients are exposed during the day. Due to the irregular geographical distribution of meteorological sources, as illustrated by figure 1, we could not perform subregional analysis—linking different health facilities to the nearest temperature station. Therefore, we averaged the data from the three sources in one representative value for the entire city. After averaging, data were 100% complete.

Pearson's correlation served two purposes here. First, it was used to validate data from the station 5, located in the outer area, by using data from the inner stations 2 and 3. Second, it confirmed that two or more weather datasets were correlated, and could, therefore, be averaged. A moderate high (>0.700) coefficient was considered as cut-off. Detailed information about monitoring sites, coordinates, missing values, Pearson's correlations and excluded stations are reported in online supplemental tables S1 and S2.

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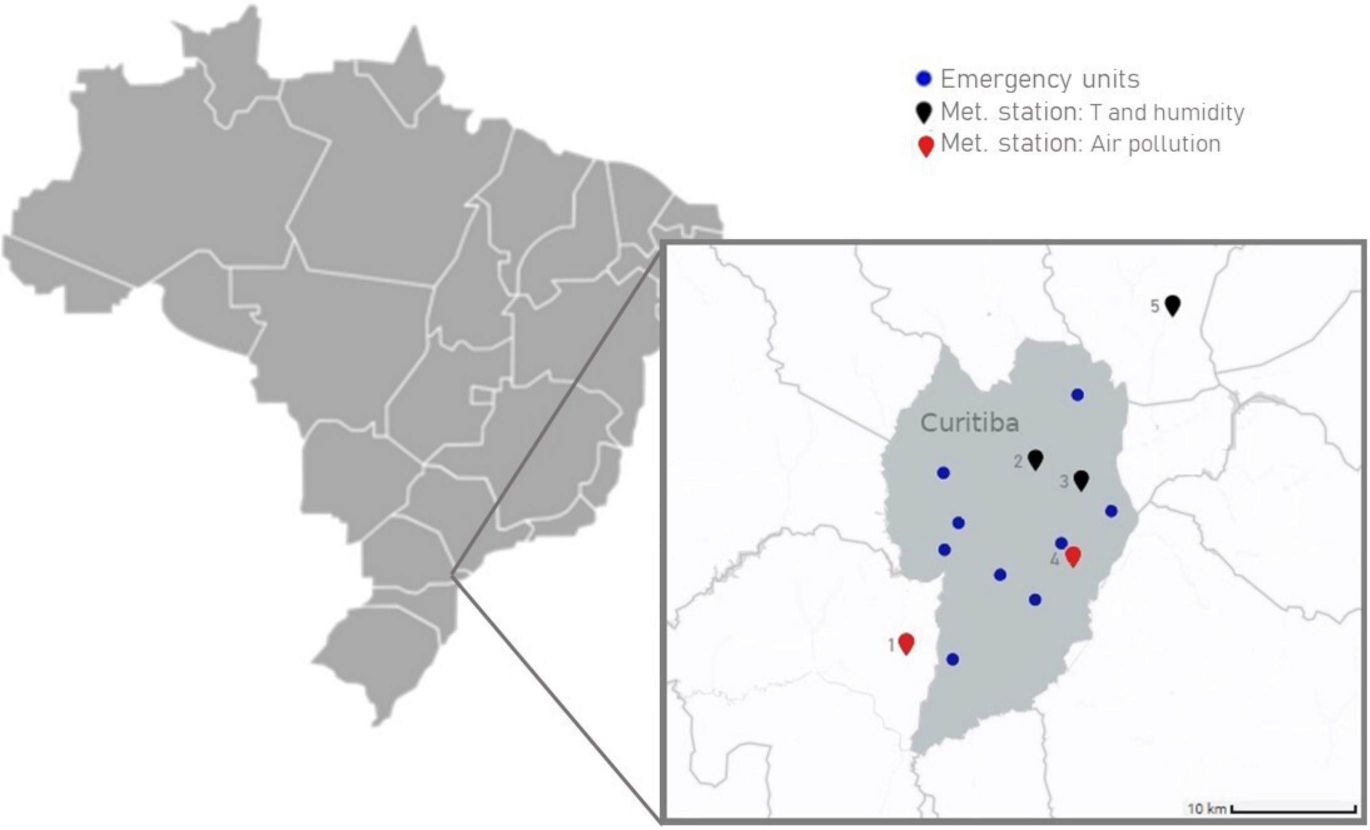

Figure 1 Brazilian territory shown in grey, with inset of the city of Curitiba (435 036 km^2) and of its metropolitan region. The nine blue circles represent all the public emergency units (UPAs) in the city; the three black pins indicate the meteorological stations from where data of temperature and humidity were used; the two red pins show the meteorological sites from where air pollution data were retrieved. Variables retrieved from each monitoring site: 1. REPAR: O3 and PM10, 2. INMET Curitiba: Tmean, 3. Simepar Curitiba: Tmean and humidity, 4. Boqueirão: O3 and PM10 and 5. INMET Colombo: Tmean and humidity. The owners of the monitoring sites were: 1. Petrobras, 2 and 5: National Brazilian Meteorological Institute; 3. Paraná Environmental Monitoring and Technology System; 4. Water and Earth Institute. Source: authors. Image partly created using Mapbox.com. Met. Station, meteorological stations; T, temperature.

Controlling for confounders

We adjusted for the potential confounding effect of air pollution, by including daily mean concentrations of ozone (O_3) and particulate matter ≤10 µm (PM_{10}) to the model. These data were provided by the outer monitoring site number 1 (red pins, figure 1), and validated by the inner station 4, which could not be effectively included in the model, given insufficient dataset. We could not control for other air pollutants, as data were also incomplete. Finally, we controlled for the effect of humidity (%), which was averaged from the monitoring sites 3 and 5. Extensive details on the data choices can be found in online supplemental tables S1 and S2.

Statistical modelling

The delayed non-linear relationship between daily T_{mean} and overdispersed EDVs was modelled using quasi-Poisson regression in combination with distributed lag non-linear model.[21] This method allows the outcome to be dependent not only on the intensity of the exposure, but also on the cumulation of multiple exposures in the past.[22]

In the quasi-Poisson regression, seasonality and other long-term trends were adjusted for, using natural cubic spline with 7 df per year. Confounders were controlled for, using natural cubic splines with 5 df for air pollutants (O_3 and PM_{10}), and with 3 df for humidity. The exposure–response association between T_{mean} and EDVs was modelled with 3 knots: on the 1st, 50th and 99th percentiles.

When accounting for delayed effects, the maximum lag allowed was 10 days—based on literature showing significant effects appeared at or before lag 7 after exposure.[1] We opted to extend the lag to 10 days, to capture any possible delayed EDV, specifying 4 df for lag patterned. Several sensitivity analyses were performed and included changing df for seasonality, air pollution, humidity and lags. Also, knots were placed at different percentiles and natural cubic or b-splines were tested. The best fitting models were determined using quasi-Akaike information criterion. Controlling for 'day of the week' reduced the model robustness, since there was no significant variation among days. Therefore, this variable was removed from the model.

The final model equation is represented below:

$$E(Yt) = Bo + s(T,\ timedf) + f(T_{mean}, lagdf, vardf) + f(Hum, df)$$

$$+f(03, df) + f(PM1O, df) \sim quasi - Poisson$$

Where:
E (Yt): EDVs.
βo: y interception.
s (T, timedf): function of time, with 7 df.
f (T_{mean}, lagdf, vardf): cross basis function, with 10 and 4 df.
f (Hum, df)+f (O3, df)+f(PM10, df): cross basis functions for confounders, with 3, 5 and 5 df.

Four different exposures were considered, for a matter of comparison: extreme cold (1st percentile of T_{mean} – P1), moderate cold (P5), moderate heat (P95) and extreme heat (P99). RR_{EDV} under the four exposures was compared with the median (T_{mean} 18.02°C), and results are presented as immediate ('single lag') and cumulative effect ('lag_{CUM}').

Stratified analyses were performed according to MH subgroups, sex and age subgroups: 0–17, 18–64 and elderly ≥65. For subgroup analyses, extreme heat (P99) was used. Complete analysis was carried out in R Software, V.4.2.1, through 'dlnm' package, V.2.4.7 and statistical significance of 95% (p<0.05) was considered for all results.[23 24]

Patient and public involvement

Patients and/or the public were not involved in the study development—design, conduction, reporting or dissemination plans of this research.

RESULTS

Descriptive results

The number of EDV for MH during the 5 years was 101 452. This amounted to fewer than 0.5% of the overall EDVs for all causes. Females accounted for approximately 60%, and the age group 18–64, for 86% of EDVs. The average age of patients at the emergency department was 37 years. Neurotic disorders—mostly anxiety—were responsible for the majority of visits (61.4%), followed by substance misuse (12.2%), and mood disorders (8.75%). During the study period, the average T_{mean} was 17.8°C and peaked at 27.3°C. Descriptive results are displayed in table 1.

MH in general: single-lag and cumulative risks

Table 2 displays both single-lag (a) and cumulative (b) risks for MH in general, resulting from different temperature exposures. Under extreme heat (P99), a significant increase in RR_{EDV} of 1.03 was observed starting at single-lag 1 (95% CI 1.00 to 1.04), which persisted until single-lag 4. The risks from individual single-lags due to extreme heat cumulated (as shown in table 2B), and peaked at lag_{CUM} 0–6, with 15% higher risk of EDV (RR_{EDV} 1.15, 95% CI 1.05 to 1.26). Effects dissipated at lag_{CUM} 0–8. Similar, but shorter and less intense, pattern was observed for moderate heat.

In contrast, both extreme and moderate cold reduced RR_{EDV}. Effects appeared immediately at single-lag 0 and lasted until single-lag 2, varying from RR_{EDV} 0.92 (95% CI 0.88 to 0.97—P1, single-lag 0) to RR_{EDV} 0.98 (95% CI 0.96 to 0.99—P5, single-lag 2). Cumulatively, under extreme cold (table 2B), RR_{EDV} reached its lowest point at lag_{CUM} 0–4 (RR_{EDV} 0.83, 95% CI 0.75 to 0.93), indicating a 17% lower risk of EDV.

Figure 2A displays all the effects observed at lag_{CUM} 0–6, for different temperature ranges: lower RR_{EDV} for cold and higher RR_{EDV} for heat. Two blue and two red dotted lines represent P1, P5, P95 and P99, respectively. In longer periods, lag_{CUM} 0–10, as presented by figure 2B, effects dissipated, and no statistically significant RR_{EDV} is found, in any temperature exposure.

Cumulative risk, by age and sex subgroups

Table 3 displays results for complete subgroup analyses, while figure 3 presents results for MH in general (figure 3A) and also specifically for sex and age subgroups (figure 3B–F), all calculated under extreme heat (P99). Females presented higher risk of EDV, which peaked at lag_{CUM} 0–6 (RR_{EDV} 1.20, 95% CI 1.08 to 1.34), and persisted until lag_{CUM} 0–9 (figure 3B). Males and patients aged 0–17 showed no significant effect under extreme heat (figure 3C,D). Differently, for patients aged 18–64 the RR_{EDV} increased substantially (figure 3E), and at lag_{CUM} 0–10, RR_{EDV} remained still 1.16 (95% CI 1.03 to 1.32). Contrarily, elderly ≥65 had a reduced RR_{EDV} due to heat, and at lag_{CUM} 0–4, RR_{EDV} was 0.77 (95% CI 0.60 to 0.98) (figure 3F).

Cumulative risk, by MH subgroups

Two MH subgroups were under higher risk from extreme heat: patients who attempted suicide and patients with neurotic disorders (table 3). Patients attempting suicide had a higher RR_{EDV} of 1.21 (95% CI 1.04 to 1.41) directly at lag 0 of extreme heat. This risk gradually increased and peaked at lag_{CUM} 0–10, with RR_{EDV} 1.85 (95% CI 1.08 to 3.16)—the highest effect for this study. Given this extreme effect, we performed an extra analysis for patients attempting suicide by sex. We could observe that females had higher RR_{EDV} for suicide attempt than males (RR_{EDV} 2.53, 95% CI 1.57 to 5.16 x RR_{EDV} 1.51, 95% CI 0.79 to 2.93, at lag_{CUM} 0–10—online supplemental table S3). Additionally, patients with neurotic disorders showed an increased EDV risk initially at lag_{CUM} 0–2, and at lag_{CUM} 0–6 they presented an RR_{EDV} of 1.18 (95% CI 1.05 to 1.32).

In contrast, two MH subgroups showed a reduced RR_{EDV} from extreme heat. Patients with organic disorders presented, at lag_{CUM} 0–4, RR_{EDV} 0.60 (95% CI 0.40 to 0.89), while patients with personality disorders demonstrated, at lag 0, RR_{EDV} of 0.48 (95% CI 0.26 to 0.91).

This association between T_{mean} (x), RR_{EDV} (y) and lag (z) is represented by the three-dimensional (3D)

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Table 1 Health and meteorological descriptive data

				Percentiles			
	n (%)	**Mean±SD**	**Minimum**	**25th**	**50th**	**75th**	**Maximum**
EDV for MH in general							
Total	101 452 (100%)	55.56±21.60	8	39	53	69	135
Male	41 361 (40.77%)	22.65±8.91	4	16	22	28	58
Female	60 091 (59.23%)	32.91±13.96	4	22	31	42	81
0–17 years old	6751 (6.65%)	3.7±2.63	0	2	3	5	20
18–64 years old	87 747 (86.05%)	48.05±18.72	8	33.25	46	60	119
≥65 years old	6955 (6.85%)	3.80±2.40	0	2	3	5	15
Patients age	/	37.18±16.42	0	24	35	48	118
EDV for MH subgroups							
F00–F09 | organic disorders	2522 (2.48%)	1.38±1.39	0	0	1	2	9
F10–F19 | substance misuse	12 404 (12.23%)	6.79±3.39	0	4	6	9	22
F20–F29 | schizophrenia	7270 (7.16%)	3.98±2.43	0	2	4	5	14
F30–F39 | mood disorders	8883 (8.75%)	4.86±2.87	0	3	5	6	17
F40–F49 | neurotic disorders	62 354 (61.46%)	34.15±15.39	2	22	32	44	102
F50–F59 | behavioural disorders	2243 (2.21%)	1.23±1.47	0	0	1	2	11
F60–F69 | personality disorders	219 (0.21%)	0.12±0.35	0	0	0	0	2
F70–F79 | intelectual disability	96 (0.09%)	0.05±0.24	0	0	0	0	3
F80–F89 | developmental disorders	108 (0.10%)	0.06±0.24	0	0	0	0	2
F90–F99 | BEDOC	988 (0.97%)	0.54±0.76	0	0	0	1	5
X60–X84 | suicide attempt	4365 (4.30%)	2.39±1.92	0	1	2	3	14
Meteorological variables							
T_{mean} (°C)	/	17.83±3.61	4.2	15.3	18.02	20.52	27.3
Relative humidity (%)	/	81.91±8.24	42.57	77.27	82.72	87.48	99.43
Heat index T_{mean} (°C)	/	17.84±3.94	3.35	15.14	18.12	20.79	27.8
O_3 (ppb)	/	12.92±5.48	1.19	8.97	11.95	15.76	36.55
PM_{10} (µg/m³)	/	17.69±11.95	2.66	9.51	14.45	21.94	89.33

BEDOC, behavioural and emotional disorders with onset during childhood/adolescence; EDV, emergency department visit; MH, mental health; Ppb, parts per billion; T_{max}, maximum temperature; T_{mean}, mean temperature; T_{min}, minimum temperature.

graphs (figure 4). The two MH subgroups with higher risk under heat are also displayed (figure 4B,C). MH in general (figure 4A) and neurotic disorders (figure 4B) had increased RR_{EDV} only after a period of heat exposure. Differently, suicide attempt (figure 4C) had immediately, at lag 0, the period with the highest RR_{EDV}. Effects of all three reduced gradually along the lags.

DISCUSSION

To our knowledge, apart from China, this is the first time in LMICs that EDV was assessed as a proxy for MH disorders.[1] We observed that extreme heat-related risk starts at lag_{CUM} 0–2, peaks at lag_{CUM} 0–6, with 15% increased RR_{EDV} and lasts until lag_{CUM} 0–8. Furthermore, we found a dose–response relationship, where extreme heat was associated with higher RR_{EDV} for MH in general than moderate heat. Our results corroborate and strengthen the literature on the high heat-susceptibility of MH in general.[20 25] It is hypothesised that MH disorders and the psychotropic medications, such as antipsychotics and hypnotics, typically used as treatments, prevent a proper heat dissipation through sweating or vasodilation, thus leading to heat-related outcomes, (eg, dehydration and heatstroke).[6 10–12] Further, neurotransmitter and hormonal imbalance triggered by meteorological factors can exacerbate chronic MH disorders.[12] Cognitive impairment occasionally associated with MH disorders may also lead patients to non-efficient cooling behaviours, such as not keeping hydrated or taking off extra clothes.[10] Although, these findings may still have been attenuated by the colder climate in Curitiba. A previous meta-analysis found that heat-related MH risk was higher in tropical and subtropical climates, whereas Curitiba city is considered temperate.[26 27] So even in temperate zones, we could see higher RR_{EDV} of MH from extreme heat.

A previous study by da Silva *et al* in Curitiba measured the risk of hospitalisation for MH due to heat and air pollutants, from 2010 to 2016.[28] The authors found that

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Table 2 RR$_{EDV}$ for MH in general

Lag effects	Extreme cold (P1)	Moderate cold (P5)	Moderate heat (P95)	Extreme heat (P99)
(A) Single-lag risk (RREDV, *95% CI)				
lag0	**0.92*** (0.88–0.97)	0.97 (0.93–1.00)	1.02 (0.99–1.05)	1.03 (0.99–1.06)
lag1	**0.95*** (0.92–0.97)	**0.97*** (0.95–0.99)	**1.02*** (1.00–1.03)	**1.03*** (1.00–1.04)
lag2	**0.97*** (0.94–0.99)	**0.98*** (0.96–0.99)	**1.02*** (1.00–1.03)	**1.03*** (1.01–1.04)
lag3	0.98 (0.96–1.01)	0.98 (0.96–1.00)	1.01 (0.99–1.03)	**1.02*** (1.00–1.04)
lag4	0.99 (0.97–1.02)	0.99 (0.97–1.01)	1.01 (0.99–1.02)	**1.02*** (1.00–1.04)
lag5	1.00 (0.98–1.02)	1.00 (0.98–1.01)	1.00 (0.99–1.02)	1.01 (0.99–1.03)
lag6	1.01 (0.98–1.03)	1.01 (0.99–1.03)	1.00 (0.99–1.01)	1.00 (0.99–1.02)
lag7	1.01 (0.98–1.04)	1.01 (0.99–1.03)	0.99 (0.98–1.01)	0.99 (0.98–1.02)
lag8	1.01 (0.99–1.04)	1.02 (0.99–1.03)	0.99 (0.98–1.01)	0.99 (0.97–1.01)
lag9	1.02 (0.99–1.05)	1.02 (0.99–1.04)	0.99 (0.97–1.00)	0.99 (0.97–1.01)
lag10	1.02 (0.97–1.07)	1.02 (0.98–1.05)	0.98 (0.96–1.01)	0.98 (0.95–1.02)
(B) Cumulative risk (RREDV, *95% CI)				
lag0	**0.92*** (0.88–0.97)	0.97 (0.93–1.00)	1.02 (0.99–1.05)	1.03 (0.99–1.06)
lag0–1	**0.88*** (0.81–0.94)	**0.94*** (0.89–0.99)	1.04 (0.99–1.08)	1.05 (0.99–1.11)
lag0–2	**0.85*** (0.78–0.92)	**0.92*** (0.86–0.98)	**1.06*** (1.01–1.11)	**1.08*** (1.01–1.15)
lag0–3	**0.84*** (0.76–0.92)	**0.90*** (0.85–0.97)	**1.07*** (1.01–1.13)	**1.10*** (1.03–1.15)
lag0–4	**0.83*** (0.75–0.93)	**0.90*** (0.83–0.96)	**1.08*** (1.02–1.15)	**1.13*** (1.04–1.22)
lag0–5	**0.84*** (0.74–0.94)	**0.90*** (0.83–0.97)	**1.09*** (1.02–1.16)	**1.14*** (1.05–1.24)
lag0–6	**0.84*** (0.74–0.95)	**0.90*** (0.83–0.98)	**1.09*** (1.02–1.17)	**1.15*** (1.05–1.26)
lag0–7	**0.85*** (0.74–0.97)	0.92 (0.84–1.01)	**1.09*** (1.00–1.17)	**1.14*** (1.03–1.27)
lag0–8	0.86 (0.74–1.00)	0.93 (0.84–1.03)	1.08 (0.99–1.17)	**1.13*** (1.02–1.27)
lag0–9	0.88 (0.75–1.03)	0.95 (0.85–1.06)	1.07 (0.98–1.16)	1.12 (0.99–1.26)
lag0–10	0.90 (0.75–1.07)	0.97 (0.86–1.09)	1.05 (0.95–1.15)	1.10 (0.97–1.25)

Relative risk (RREDV) of EDV for different single-lags and lagCUM of exposure. Four percentiles of daily Tmean are shown: extreme cold (P1st, 8.5°C), moderate cold (P5th, 11.6°C), moderate heat (P95th, 23.2°C) and extreme heat (P99th, 24.5°C).
Temperature reference: 18.02°C.
*Bold represents the significant results.
MH, mental health; P, percentile; RREDV, relative risk of emergency department visit.

females and males had higher risks of being admitted to a hospital, on the day of heat exposure. However, several differences between our study and da Silva *et al* paper should be delineated: (1) we used EDV rather than hospitalisations for MH. In Brazil, with few exceptions, patients are first attended at the emergency centres, and only then, if accepted, transferred to a tertiary hospital after a waiting time. Therefore, using EDV rather than hospitalisation can potentially remove the bias of low hospital bed availability for MH diseases, common in Brazil and other LMICs—to better capture the short-term effect of heat.[29]

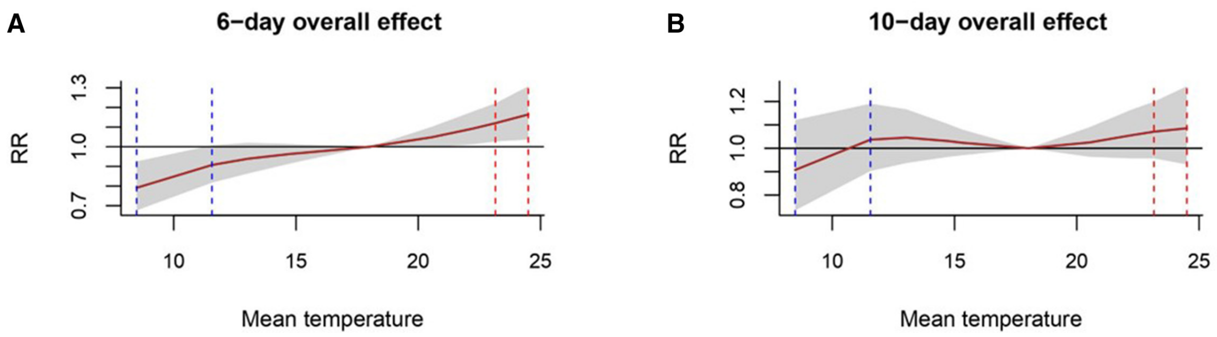

Figure 2 Cumulative effects of temperature on RR for an EDV calculated for short-term (lagCUM 0–6 days (A) and long-term (lagCUM 0–10 (B), respectively. Reference Tmean: 18.02°C. Grey area represents the 95% CI, blue dotted lines are the extreme (P1) and moderate (P5) cold, while red dotted lines are the extreme (P99) and moderate (P95) heat. EDV, emergency department visit; RR, relative risk.

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Table 3 Subgroup analysis

Lag effect	lag0	lag0–4	lag0–6	lag0–10
Sex				
Female	1.02 (0.98–1.07)	**1.18*** (1.08–1.30)	**1.20*** (1.08–1.34)	1.14 (0.98–1.33)
Male	1.02 (0.97–1.07)	1.04 (0.94–1.16)	1.06 (0.94–1.20)	1.03 (0.87–1.22)
Age				
0–17	1.05 (0.94–1.18)	1.26 (0.99–1.60)	1.12 (0.84–1.49)	0.795 (0.53–1.19)
18–64	1.03 (0.99–1.07)	**1.15*** (1.06–1.24)	**1.18*** (1.07–1.30)	**1.16*** (1.02–1.32)
≥65	0.90 (0.80–1.01)	**0.77*** (0.60–0.98)	0.77 (0.58–1.03)	0.70 (0.47–1.05)
MH subgroup				
Organic	0.87 (0.73–1.04)	**0.60*** (0.40–0.89)	0.63 (0.39–1.00)	0.50 (0.26–0.96)
Personality	**0.48*** (0.26–0.91)	0.96 (0.26–3.60)	0.67 (0.14–3.31)	0.12 (0.01–1.20)
Neurotic	1.03 (0.99–1.08)	**1.17*** (1.06–1.28)	**1.18*** (1.05–1.32)	1.08 (0.93–1.26)
Suicide attempt	**1.21*** (1.04–1.41)	**1.53*** (1.11–2.13)	**1.63*** (1.11–2.40)	**1.85*** (1.08–3.16)

Cumulative RREDV under extreme heat (P99th, 24.5°C) for sex, age groups and MH subgroups that were found to be heat-sensitive.
Cumulative RR_{EDV} at extreme heat - T_{mean} 24.5°C (RR_{EDV}, 95% CI). T_{mean} reference: 18.02°C.
*Bold represents the significant results.
MH, mental health; P, percentile; RREDV, relative risk of emergency department visit.

(2) It also expands the study population, because the emergency centres (UPAs) are completely free and accessible without referral, whereas at the hospital, doctors have a propensity of admitting only severe patients. Our sample consisted of 101 452 EDVs in a 5-year period, compared with 5397 hospital admissions in 7 years presented in da Silva *et al* (2020). (3) The authors did not present a RR estimate for MH in general, focusing instead on results stratified by sex and age groups. (4) Finally, our study included ICD-10th for suicide attempt and performed subgroup analysis by all MH diagnoses.

The RR_{EDV} from two MH subgroups increased by heat exposure: neurotic disorder (80% anxiety) and suicide attempt. A 2016 study showed that cortisol levels, an important stress hormone, increased under heat exposure.[30] These hormones are also responsible for inducing anxiety symptoms, such as fear or shortness of breath, which could hypothetically explain part of this acute rise in EDV for neurotic disorders.[31] Suicide attempt was the most affected condition, with 85% higher RR_{EDV} at lag_{CUM} 0–10. Heat had already been linked to aggressive and impulsive behaviours, which is the possible explanation for this increase.[32 33] Another study showed that patients who had made multiple suicide attempts in the past have higher risks of new self-harm episode under heat exposure than those who were attempting it for the first time, corroborating their higher heat vulnerability.[34] This suggests that heat intensity exacerbates the effect of individual characteristics, such as neurotransmitter concentrations and receptor responsivity, on suicidal and

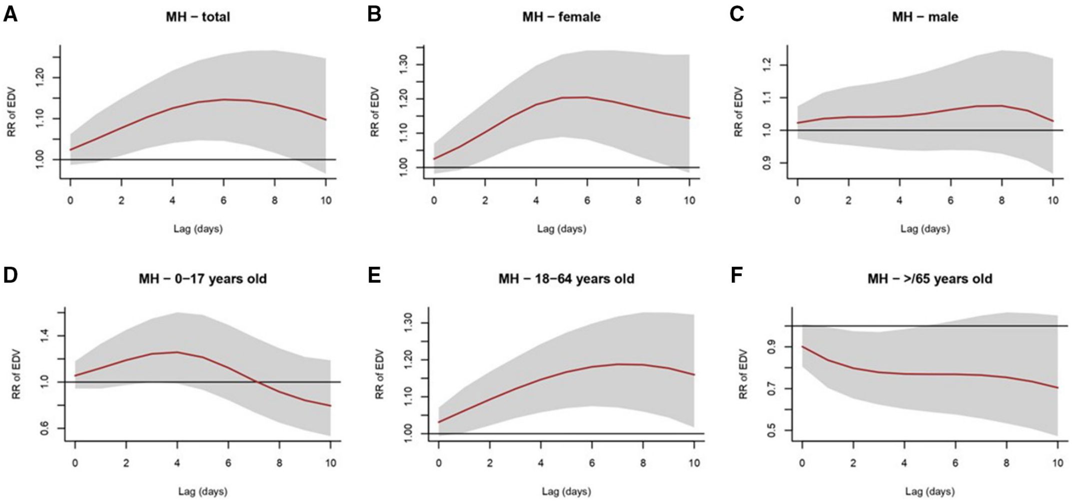

Figure 3 Extreme heat effect (P99, daily Tmean 24.5°C) over different subgroups, during different lags. Tmean reference: 18.02°C. Subgroups formed for analysis were (A) MH total, (B) female, (C) male, (D) age from 0 to 17 years old, (E) age from 18 to 64 years old and (F) elderly ≥65 years old. P, percentile. Grey area represents 95% CI. EDV, emergency department visit; MH, mental health; RR, relative risk.

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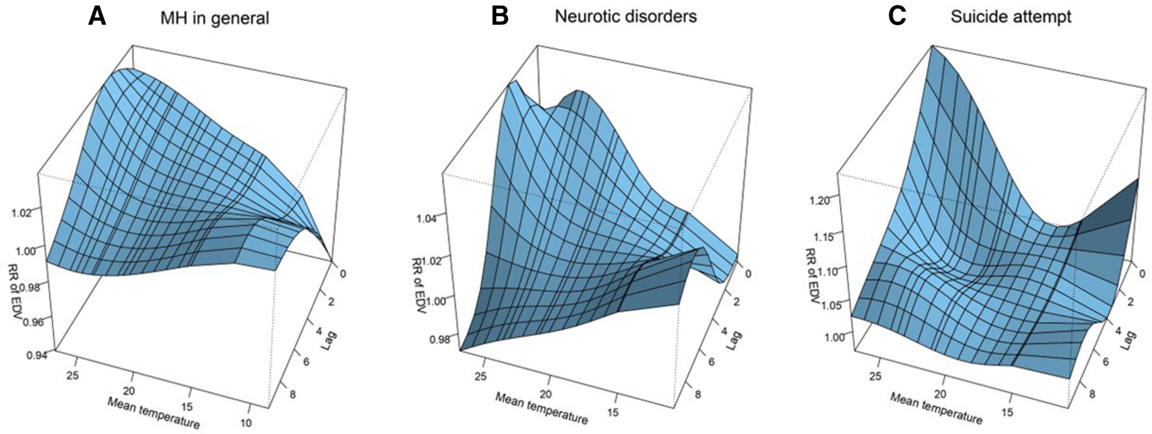

Figure 4 Three-dimensional graphs of the relationship among heat (x), RREDV (y) and lag (z) for (A) MH in general, (B) neurotic disorders and (C) suicide attempt. Tmean reference: 18.02°C. MH, mental health; RREDV, relative risk of emergency department visit.

self-harm episodes.[34 35] In accordance to existing literature, in our extra analysis, females presented significantly higher RR_{EDV} for suicide attempt than males.[36]

Despite previous literature indicating adverse effects of heat on patients with substance misuse, schizophrenia and mood disorders,[37] we did not observe any association. Also, although there is no literature on the topic, heat was shown to have reduced RR_{EDV} on patients with personality disorder in this study.[37] Future studies should investigate whether these groups are in fact not affected by heat exposure or if our study design could not capture them properly, which is our main hypothesis. Research is also needed to address the less prevalent conditions, such as intellectual disability and developmental disorders (autism spectrum), for which low EDV numbers may prevent accurate analyses.

We found, under extreme heat, a reduced RR_{EDV} of up to 23% for elderly ≥65, and 40% for patients with organic disorders, for example, dementia—MH subgroup formed mostly by elderly, as well. This is in opposition to the findings of most studies, as the elderly are likely to have disrupted heat-dissipation mechanisms.[38 39] We hypothesise that, similar to the 2003 heatwave in France, both groups may have remained at home rather than seeking help.[40] COVID-19 lockdowns may have also played a role. There was an abrupt decrease on EDV (online supplemental figure S4), in March 2020 and again in March 2021, when cases spread throughout the country. Given that elderly ≥65 years were the most susceptible group to COVID-19, the fear of contamination and adherence to the lockdown may have prevented them from looking for emergency centres, thus resulting in the apparent protective effect of heat.[29]

Patients aged 18–64 were the only age subgroup to be negatively affected by extreme heat, placing the economically active population at greatest potential burden. MH is already responsible for absenteeism from work and loss of productivity, so this evidence sheds light on the extra economic hazards potentially resulting from a rise in heat exposure associated with CC.[41]

Females represented 60% of our sample and were highly affected by extreme heat, while males were the minority and were not affected. Contrarily, da Silva *et al* found that males comprised 60% of the hospitalisation numbers in Curitiba—instead of EDV—and that the risk of hospitalisation was similarly high for both sexes. We hypothesise that females, by searching for emergency centres and receiving treatment instantaneously may avoid the need of hospitalisation afterwards, whereas this effect is not extended to males. Additionally, women receive, in general, lower income than men, which could also potentially increase their vulnerability to heat.[42] Our results strengthen evidence that females are among the groups holding the highest MH prevalence and burden, and this sex difference could become more pronounced with CC.[28 29]

In the current study, cold exposure contributed to a reduced RR_{EDV} on MH in general from lag 0 until lag_{CUM} 0–7. Other studies have reported the same observed effect, but the literature is inconsistent.[43 44] Reinforcing our results, Mullins and White indicated that the beneficial effects of cold exposure are stronger in cooler climates, as in Curitiba.[45] The authors suggested that such effects are related to the reduction of sleeping disturbance under cold, but further mechanisms remain widely unknown.[45] However, as CC is projected to progress in the future, the importance of exposures to cold will decrease, whereas the one to heat will increase.

Several confounders were included in the model, in order to increase robustness of our analysis. For this purpose, we collected extra data for humidity, O3 and PM10. Other potential confounders could not be used, due to data incompleteness. The sensitivity analysis can be found in online supplemental table S8. We observed that humidity and O3 influenced minimally in the result, however, we opted to keep all the variables in the main model, despite their strength, as the findings can be more trustworthy in different circumstances. Further studies are welcome in order to delineate the effects of possible confounders in the city of Curitiba.

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Some limitations of this study should be considered when interpreting our results. Although EDV is a reasonable proxy indicator of health impacts of CC, the ideal outcome would have been the direct measurement of MH symptoms among the general population, using a representative survey. This is of course difficult as it requires a large sample and substantial resources in time and money. Therefore, we used EDV as the best proxy. We acknowledged that different healthcare access barriers might have biased the results. Such barriers could be due to access costs, distance to the facility or stigma. In addition, patients with MH might have stayed at home because of the extreme heat outside. Another limitation of our study is that we could only use data from the public healthcare system (SUS). According to a national report, SUS patients have, in general, lower income and educational level than patients who afford paying for private care.[46] Considering that low socioeconomic status amplifies MH risks,[4] our results may be of greater intensity, if compared with those who rely on the private system, as they have more adaptation means. Two lines of research are highly recommended for the future. First, studies investigating the differences between public and private patients would help delineate priorities for policy-makers in Curitiba. Second, a population-based study with MH status as outcome may increase understanding of the actual heat-related burden of MH since patients who were prevented from seeking medical care or decided not to do so for a variety of reasons, including their MH condition, would also be included.

The past 8 years—2015 to 2022—were the warmest ever reported and the next five are projected to set new heat records.[47] In this context, our study calls for urgent adaptation actions targeting MH patients. Early warning systems (EWSs) have the potential to increase patient, health professional and caregiver preparedness. By strengthening awareness against the risks of heat and advising effective actions, for example, improving hydration and taking frequent showers, thousands of deaths were avoided in France, in the years following the deadly 2003 heatwave.[48] Likewise, in Brazil, EWSs may prevent MH outcomes such as suicide attempts and reduce EDV numbers, reducing maintenance costs of public health. Concurrently, in primary care, the existing risk stratification could expand the focus on MH patients, followed by active search and treatment during hot periods, which would provide care in the early stages of the condition rather than waiting for severe manifestation of the outcome. This approach attempts to ensure treatment for all patients, thereby reducing healthcare access inequalities. Finally, susceptible populations would benefit from interventions to increase their adaptation capacity, such as creating local cooling centres and implementing household strategies to reduce indoor air temperature, for example, white roof painting programmes.[49]

CONCLUSION

This research addressed a highly understudied field and highlighted the heat susceptibility of MH patients, while global temperature rapidly rises, and MH disorders become remarkably prevalent in Brazil. We observed that particularly at risk are patients attempting suicide, with neurotic disorders, females and patients aged 18–64. Our study also showed the importance of triangulating public health and weather data, to better understand effects of CC on health. Patients from the Brazilian public system would benefit from the development of an early warning and response system to increase CC resilience, reduce MH exacerbation and prevent suicide attempts.

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The impact of heat on mental health-related emergency visits: a time series study from all public emergency centers, in Curitiba, Brazil

Supplementary materials

Summary

Table S1 - Geographical details from meteorological stations, including the ones not included in this study.

Stations	Owner	Coordinates	Temperature	Humidity	Air pollution
INMET Curitiba $_1$	INMET	lat -25,4486111 / long -49,23055554	x		
INMET Colombo $_2$	INMET	lat -25,32222 / long -49,1575	x	x	
SIMEPAR Curitiba $_1$	SIMEPAR	lat -25,44817 / long -49,23033	x		
SIMEPAR Pinhais	SIMEPAR	lat -25,3907 / long -49,1299		x	
REPAR $_2$	Petrobras	lat -25,331145 / long -49,232795			x
IAT Boqueirão $_1$	IAT	Lat -25,50309 / long -49,23681			x
CSN $_2$	Companhia Siderúrgica Nacional	lat -25,34932 / long -49,2257			x
ASSIS $_2$	LACTEC	lat -25,3435 / long -49,2420			x
CIC $_1$	IAT	Lat -25,50402 / long -49,32978			x

$_1$ - Station located inside of Curitiba. $_2$ - Station located in the metropolitan region. INMET: National Brazilian Meteorological Institute. SIMEPAR: Paraná Environmental Monitoring and Technology System. IAT: Water and Earth Institute. LACTEC: Technology for Development Institute.

Table S2 - Pearson's correlation among stations.

Humidity		Humidity	Pearson's correlation*	Notes
INMET Colombo (99,99%)	x	INMET Curitiba (71,2%)	0.781	**INMET Curitiba** was excluded, given low data availability (71,2%).
INMET Curitiba (71,2%)	x	Simepar Curitiba (99,99%)	0.808	**INMET Curitiba** was excluded, given low data availability (71,2%).
INMET Colombo (99,99%)	x	Simepar Curitiba (99,99%)	0.879	Two stations with high data availability and correlated to each other (>0.700).

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Maximum temperature		Maximum temperature	Pearson's correlation*	Notes
INMET Colombo (99,13%)	x	SIMEPAR Curitiba (99,99%)	0.940	Both included
INMET Curitiba (98,5%)	x	SIMEPAR Curitiba (99,99%	0.990	Both included
INMET Colombo (99,13%)	x	INMET Curitiba (98,5%)	0.943	Both included, however we did not use maximum temperature for the analysis. We decided to use mean temperature.

Mean temperature		Mean temperature	Pearson's correlation*	Notes
INMET Colombo (93%)	x	SIMEPAR Curitiba (99,99%)	0.970	Both included
INMET Curitiba (96,5%)	x	SIMEPAR Curitiba (99,99%)	0.987	Both included
INMET Colombo (93%)	x	INMET Curitiba (96,5%)	0.967	Both included

Minimum temperature		Minimum temperature	Pearson's correlation*	Notes
INMET Colombo (99,8%)	x	SIMEPAR Curitiba (99,99%)	0.930	Both included
INMET Curitiba (98,5%)	x	SIMEPAR Curitiba (99,99%)	0.941	Both included
INMET Colombo (99,8%)	x	INMET Curitiba (98,5%)	0.951	Both included, however we did not use minimum temperature for the analysis. We decided to use mean temperature.

PM10		PM10	Pearson's correlation*	Notes
Boqueirão (15,6%)	x	REPAR (73,25)	0.723	Boqueirão was only used to validate data from station REPAR, which was in the outer area. Despite data from REPAR was relatively incomplete, we opted to keep it in the analysis, as it was our only possibility to control for this important confounder.

O3		O3	Pearson's correlation*	Notes
Boqueirão (27%)	x	REPAR (87,46%)	0.851	Boqueirão was only used to validate data from station REPAR, which was in the outer area. Despite data from REPAR was relatively incomplete, we opted to keep it in the analysis, as it was our only possibility to control for this important confounder.
Boqueirão (27%)	x	ASSIS (64%)	0.846	Assis was excluded given the extremely incomplete dataset.

SO2		SO2	Pearson's correlation*	Notes
Boqueirão (27,5%)	x	REPAR (76%)	0.02	Boqueirão here served to validate

				REPAR, which was in the outer area. However, both were not correlated (<0.700).
Boqueirão (27,5%)	x	ASSIS (55%)	0.13	Boqueirão here served to validate ASSIS, which was in the outer area. However, both were not correlated (<0.700).
Boqueirão (27,5%)	x	CSN (84%)	0.06	Boqueirão here served to validate CSN, which was in the outer area. However, both were not correlated (<0.700).

NO2		NO2	Pearson's correlation*	Notes
CIC (45%)	x	REPAR (82%)	0.325	CIC here served to validate REPAR, which was in the outer area. However, both were not correlated (<0.700).
CIC (45%)	x	ASSIS (19%)	0.246	CIC here served to validate ASSIS, which was in the outer area. However, both were not correlated (<0.700) and ASSIS had an extremely incomplete dataset.
CIC (45%)	x	CSN (86%)	0.654	CIC here served to validate CSN, which was in the outer area. However, both were not correlated (<0.700).

* Statistically significant. Interval of Confidence of 95%. % percentage of available data in the station. Red color represents the excluded stations, either due to low data availability or to weak correlation (< +0.700). Green color represents included stations. Information in parenthesis: data availability for the specific variable. ‘Boqueirão’ was used only to validate ‘REPAR’.

Table S3 - Results from suicide attempt, segmented in females and males.

Cumulative risk (RR, *CI 95%) calculated under extreme temperature (P99). Temperature reference: 18.1oC.		
Lag effect	Female	Male
Lag0	1.21* (0.97-1.51)	**1.20*** (1.00-1.44)
Lag0-1	1.39 (0.99-1.95)	**1.34*** (1.01-1.78)
Lag0-2	**1.53*** (1.03-2.26)	**1.41*** (1.02-1.96)
Lag0-3	**1.63*** (1.06-2.51)	1.42 (0.99-2.04)
Lag0-4	**1.73*** (1.08-2.79)	1.41 (0.95-2.10)
Lag0-5	**1.86*** (1.11-3.12)	1.41 (0.91-2.17)
Lag0-6	**2.02*** (1.16-3.53)	1.43 (0.90-2.73)
Lag0-7	**2.21*** (1.20-4.07)	1.46 (0.88-2.44)
Lag0-8	**2.37*** (1.21-4.63)	1.50 (0.85-2.62)
Lag0-9	**2.49*** (1.22-5.08)	1.51 (0.83-2.75)
Lag0-10	**2.53*** (1.16-5.52)	1.51 (0.79-2.90)

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Figure S4 - Time series plot of EDV for MH in general.

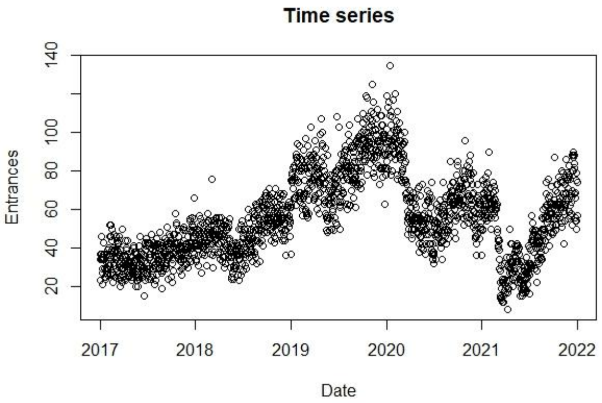

Figure S5 - Time series plot of humidity along the time.

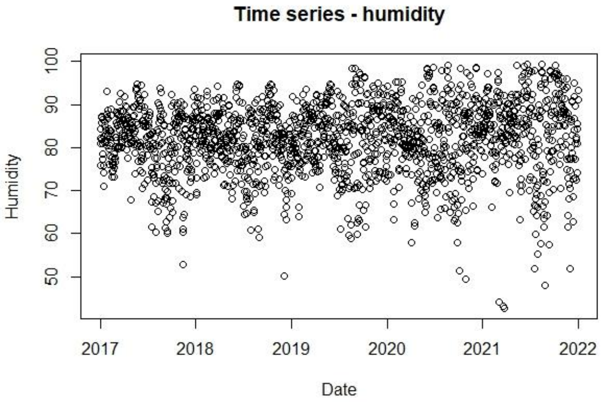

Figure S6 - Time series plot of mean temperature along the time.

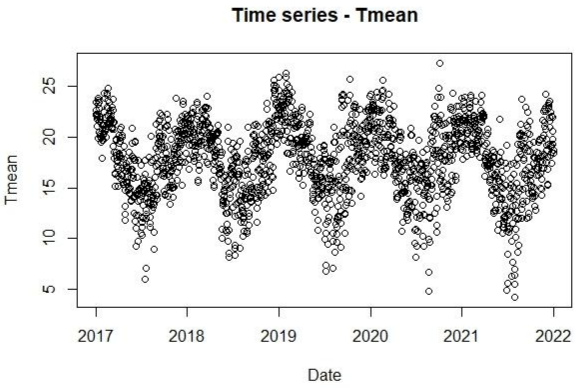

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Figure S7 - Time series plot of heat index (with mean temperature and humidity) along time.

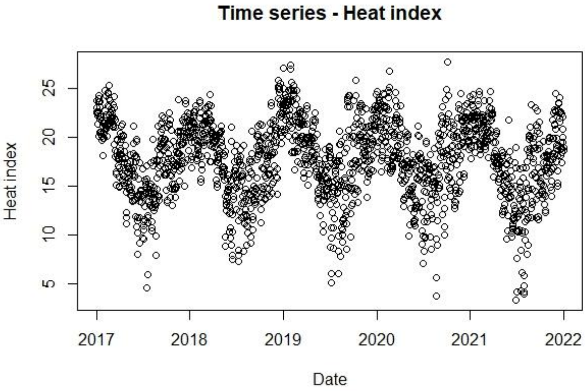

Table S8 - Results from the sensitivity analysis when isolated confounders were added to the model.

Sensitivity analysis, with different variables included in the model, calculated under extreme heat (P99) in comparison to the median (P50).

Lag effect	Model (Temperature+Humidity +O3+PM10)	Model (Temperature)	Model (Temperature + PM10)	Model (Temperature + O3)	Model (Temperature + Humidity)	Model (Heat Index)
lag0	1.03 (0.99-1.06)	1.02 (0.99-1.05)	1.01 (0.98-1.04)	1.02 (0.99-1.05)	1.03 (0.99-1.06)	**1.02*** (1.00-1.05)
lag0-2	**1.08*** (1.01-1.15)	**1.06*** (1.01-1.11)	1.03 (0.97-1.09)	**1.06*** (1.00-1.12)	**1.07*** (1.02-1.13)	**1.06*** (1.02-1.10)
lag0-6	**1.15*** (1.05-1.26)	**1.07*** (1.00-1.15)	1.06 (0.98-1.15)	**1.09*** (1.01-1.18)	**1.11*** (1.03-1.20)	**1.07*** (1.01-1.14)
lag0-10	1.10 (0.97-1.25)	1.05 (0.96-1.15)	1.02 (0.91-1.14)	1.07 (0.96-1.19)	1.05 (0.95-1.17)	1.05 (0.97-1.14)