Suicide and Associations with Air Pollution and Ambient Temperature: A Systematic Review and Meta-Analysis

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Abstract: Given health threats of climate change, a comprehensive review of the impacts of ambient temperature and air pollution on suicide is needed. We performed systematic literature review and meta-analysis of suicide risks associated with short-term exposure to ambient temperature and air pollution. PubMed, Scopus, and Web of Science were searched for English-language publications using relevant keywords. Observational studies assessing risks of daily suicide and suicide attempts associated with temperature, particulate matter with aerodynamic diameter \( \leq 10 \mu \text{m} (\text{PM}_{10}) \) and \( \leq 2.5 \text{ mm} (\text{PM}_{2.5}) \), ozone \((O_3)\), sulfur dioxide \((\text{SO}_2)\), nitrogen dioxide \((\text{NO}_2)\), and carbon monoxide \((\text{CO})\) were included. Data extraction was independently performed in duplicate. Random-effect meta-analysis was applied to pool risk ratios (RRs) for increases in daily suicide per interquartile range (IQR) increase in exposure. Meta-regression analysis was applied to examine effect modification by income level based on gross national income (GNI) per capita, national suicide rates, and average level of exposure factors. In total 2274 articles were screened, with 18 studies meeting inclusion criteria for air pollution and 32 studies for temperature. RRs of suicide per 7.1 °C temperature was 1.09 (95% CI: 1.06, 1.13). RRs of suicide per IQR increase in PM2.5, PM10, and NO2 were 1.02 (95% CI: 1.00, 1.05), 1.01 (95% CI: 1.00, 1.03), and 1.03 (95% CI: 1.00, 1.07). O3, SO2, and CO were not associated with suicide. RR of suicide was significantly higher in higher-income than lower-income countries (1.09, 95% CI: 1.07, 1.11 and 1.20, 95% CI: 1.14, 1.26 per 7.1 °C increased temperature, respectively). Suicide risks associated with air pollution did not significantly differ by income level, national suicide rates, or average exposure levels. Research gaps were found for interactions between air pollution and temperature on suicide risks.

Keywords: suicide; air pollution; temperature; climate change; mortality; time-series; case-crossover

1. Introduction

Suicide and suicide attempts (SA) are global concerns with 703,000 deaths/year worldwide and 77% of suicide deaths in low- and middle-income countries in 2019 [1]. Suicide was the eighteenth leading cause of global mortality in 2016 and second leading cause among those age 15–29 years [1,2]. The World Health Organization (WHO) adopted the Mental Health Action Plan 2013–2020 including action goals for improved governance for mental health, mental health and social care services, suicide prevention programs, information system of mental health, and research evidence [3].

Suicide involves complicated interactions of various psychological, demographic, biological, and environmental factors [3–9]. There is an emerging field of research for the complexity of the suicide phenomenon from the intersections between biological and nonbiological factors. For example, neurological diseases can present with psychiatric diseases and intersect for the morphological and functional lesions in brain, which complicates biological models for suicide risk [10,11]. Potential environmental factors affecting suicide include air pollution and ambient temperature [8]. Although not fully identified, a biological rationale for impacts of air pollution and high temperature on suicide, including...
gene expression extending to the brain, neurotransmitters, and behavioral responses [12], is available from animal studies (Figure 1). Exposure to traffic-related air pollution may cause defects in neural maintenance/regeneration and structural abnormalities in the brain through decreases in brain-derived neurotrophic factor [12]. Particulate matter (PM) and ozone (O₃) were reported to activate hypothalamic-pituitary-adrenal stress response axis and overactivation or dysfunction of the hypothalamic-pituitary-adrenal axis can lead to depressive behaviors accompanied by elevated plasma levels of adrenocorticotropic hormone and corticosterone [12,13]. High air pollution levels are associated with inflammatory effects on the brain involved in the pathogenesis of neurotoxicity and SA [14]. Diesel exhaust particles and O₃ may decrease serotonin levels leading to aggressive and depressive behaviors [13]. High temperature can cause acute failure of thermoregulation and, consequently, hyperthermia [15]. High temperature may increase feelings of hostility and aggressive thoughts through imbalance of serotonin and neuroinflammation in the brain, both caused by hyperthermia [16]. High temperature might be associated with higher levels of aggression [17], which is associated with elevated suicidal behaviors [18]. The experience of sudden warmth in the daytime after cold nights can trigger temperature-related overreaction in brown adipose tissue, intensify anxiety, leading to suicidal behaviors [19].

Air pollution and temperature can be highly correlated [20] and are simultaneously exacerbated by climate change (Figure 1) [21], although the correlation differs by pollutant. Air pollution may be a confounding factor for impacts of temperature on suicide and vice versa as both are associated with neuroinflammation in the brain and serotonin

**Figure 1.** Main putative pathogenic mechanisms of exposure and reciprocal relationships for air pollution, high temperature, and suicide risk.
neurotransmission. Although possible mechanisms of interaction are not fully understood, increased air pollution during warm periods through open windows and outdoor activities or changes in PM chemical composition are possible pathways [22,23]. Human body thermoregulatory system triggered by heat stress can activate cardiovascular and respiratory reactions, increasing total intake of air pollutants [24]. Temperature can influence transportation and chemical transformation of air pollutants and, therefore, pollutants’ chemical composition and toxicity [25]. Further investigations are needed on interactive effects and confounding between air pollution and temperature.

Numerous population-based observational studies examined acute impacts of temperature and air pollution on suicide mortality, attempts, and ideation. To date, there are few systematic review studies on these associations [8,19,26–30]. For example, studies reported significant associations between suicide and short-term PM exposure with aerodynamic diameter $\leq 10$ mm ($PM_{10}$) by combining evidence from four studies [29], and $PM_{10}$ and PM with aerodynamic diameter $\leq 2.5$ mm ($PM_{2.5}$) by combining 10 studies [26]. A systematic review of $O_3$ and suicide reported that quality of evidence is too low to conclude causal associations [28]. A recent narrative review suggested impacts of $PM_{10}$, $PM_{2.5}$, sulfur dioxide ($SO_2$), nitrogen dioxide ($NO_2$), $O_3$, and carbon monoxide (CO) on suicide [30]. Systematic reviews with meta-analysis for temperature suggested higher suicide rates and emergency room visits for SA associated with high temperature [19,31].

The existing findings on air pollution, temperature, and suicide differ among studies. Little is known about how associations differ by study characteristics (e.g., income, climate, air quality, baseline suicide rates). Further, existing studies lack assessments of risk of bias [31], which examines the variation of potential bias to help judge whether the design and conduct of the study compromised believability of the link between exposure and outcome [32,33]. Appraising published studies is essential to aid decision-making in clinical practices and interventions [34].

This systematic review and meta-analysis aimed to summarize (1) the influence of air pollution and temperature on suicide; (2) differences in associations between air pollution or temperature and suicide by regional characteristics; and (3) limitations of identified studies (risk of bias) regarding study design and methodologies. Studies of air pollution and temperature vary in lag time (e.g., from daily to yearly scales) [8]. We focused on short-term exposure of days to weeks. This review is unique in its assessment of risk of bias of epidemiological studies as well as its focus on both air pollution and temperature, including potential interactions, in relation to suicide.

2. Materials and Methods

2.1. Literature Search

The authors performed systematic literature searches using Pubmed, Scopus, and Web of Science for English-language publications before August 2020. Search terms included “air pollution”, “air pollutant”, “PM$_{2.5}$”, “PM$_{10}$”, “particulate”, “temperature”, “ambient temperature”, “air temperature”, “climate”, “weather”, “observation *”, “cohort”, “case control”, “epidemiology”, and “suicide”. Truncation filters (*) were used to represent any combination of letters. We performed multiple searches with different combinations of search terms for each database (Table S1). Grey literature was not searched. Additional studies were identified using Google Scholar from backward reference searching (examining references cited in the included studies) and forward citation chaining (examining papers that cited the included studies) conducted in May 2021.

2.2. Study Examination

This research is reported in accordance with the MOOSE Checklist for Meta-analyses of Observational Studies (Table S2) and the PRISMA statement [35,36]. The authors independently screened titles, abstracts, and full texts of the references in duplication based on our inclusion/exclusion criteria (Table 1). We included population-based observational studies addressing relationships of suicide with daily or weekly changes in ambient air
pollutants or temperature. We selected articles with cohort, case-control, time-series, case-crossover, or cross-sectional study designs. Our targeted various outcomes of suicide including complete suicide, suicide attempt (SA), suicidal ideation, self-inflicted injury, and self-harm, and specific International Classification of Diseases (ICD) codes were not used as criteria to include or exclude suicide outcomes in this review. Studies examining exposure to tobacco smoke, occupational exposure to air pollution, or CO poisoning from vehicles were excluded. Observational studies using simplistic statistical methods (e.g., basic correlations) were excluded.

Table 1. PICOS inclusion/exclusion criteria.

| Parameter          | Inclusion                                                                 | Exclusion                                                                 |
|--------------------|---------------------------------------------------------------------------|---------------------------------------------------------------------------|
| Patient            | Health outcomes related with suicide as measured in studies.              | N/A                                                                       |
| Intervention (exposure) | • Air pollutants <br> • Ambient temperature                               | Exposure to tobacco smoke or second-hand smoke. <br> Exposure to occupational air pollution or temperature (high or cold). <br> Exposure to carbon monoxide or benzene poisoning from vehicles. |
| Comparison         | All subpopulations based on biological factors (e.g., age, sex), socioeconomic factors, or contextual factors | N/A                                                                       |
| Outcome            | Complete suicide, suicide attempt, suicidal ideation, self-inflicted injury, self-harm. Data can be based on mortality data, hospital data, survey data, and etc. | Suicide by carbon monoxide from automobiles (carbon monoxide poisoning). |
| Study types        | Epidemiologic study: population-based observational study such as cohort study, case-control study, cross-sectional study, case-crossover study, survival analysis, time-series analysis, etc. | Systematic review and/or meta-analysis; commentary; editorial articles; news; book or book chapter; meeting report. <br> Research addressing burden of disease rather than exposure-response relationships. <br> Scientific articles not written in English. <br> Not a population-based epidemiological study such as experimental studies, animal studies, studies of toxicology or ecology, etc. <br> Human exposure studies without exposure-response relationship analysis or case report. |

2.3. Data Extraction and Synthesis

Using a pregenerated data extraction form, authors independently extracted information of each included study in duplication: author, publication year, study location, study duration, health outcomes (e.g., mortality, hospitalizations), ICD codes, study design, statistical methods, increment of pollution or temperature for presentation of estimated associations, risk estimates (e.g., RRs) and 95% confidence intervals (CIs) or other presentation of study results, considered confounders, and findings for interactions between temperature and air pollution. For air pollution and temperature, we extracted exposure variables (i.e., which variables were considered), exposure methods, period of exposure, and lag period.

To qualitatively summarize findings, we classified associations into 4 groups: statistically significantly positive, positive but not significant, negative but not significant, and significantly negative.

To quantitatively pool risk estimates, we used random-effect meta-analysis for time-series analysis and time-stratified case-crossover studies examining suicide risk in associations with daily temperature or air pollution, with separate meta-analyses for temperature and each air pollutant. Heterogeneity of included studies was examined by standard $I^2$.
test and publication bias by Egger’s test [37]. When publication bias existed, we used the trim-and-fill method to calculate publication bias-adjusted RR [38]. We included single-city, multi-city, and multi-country studies. For multi-city or multi-country studies, we used pooled estimates in our meta-analysis and when available, used city- or country-specific estimates for analysis of effect modifications.

We conducted random-effect meta-regression analyses for potential effect modifiers. We classified risk estimates by country’s income level using gross national income (GNI) (US$) per capita in 2019 from the World Bank [39] with two groups based on the threshold used by the World Bank: ≥$12,375, <$12,375. The national suicide rates in 2016 from the WHO were matched to locations of included studies and grouped into three tertile groups (<14, 14–15.9, and ≥16 suicides/100,000 population). Study results were categorized into two groups for exposure (separately for temperature and each air pollutant) based on the median of reported average exposure levels across studies. In sensitivity analysis (Text S1 in Supplementary Materials), we applied meta-regression analysis for gross domestic product (GDP) per capita (US$) and purchasing power parity (PPP) per capita (US$) [39].

2.4. Assessment of Risk of Bias

We assessed risk of bias for included studies using the OHAT Risk of Bias Rating Tool for Human and Animal Studies [40]. For each of the six OHAT criteria (selection bias, confounding bias, attrition/exclusion bias, detection bias, selective reporting bias, appropriateness of statistical analysis), each study was rated one of 4 scores: 0 (definitely high risk of bias), 1 (probably high risk), 2 (probably low risk), or 3 (definitely low risk). Scores were then averaged across the 6 criteria, to estimate overall probability of risk of bias in each study. Each study’s average score was classified into one of four groups to estimate overall probability of risk of bias: definitely high risk of bias (0–0.9), probably high risk (1–1.9), probably low risk (2–2.7), or definitely low risk (≥2.8). Assessment of risk of bias for each study was conducted by the same two investigators who conducted screening and data extraction for that study. When assessment differed by investigator, the study was revisited by this study’s first author. Overall risk of bias was separately rated for each exposure factor (i.e., temperature, air pollutant) across studies.

3. Results

3.1. Characteristics of the Included Studies

The searches initially identified 2274 unique articles (Figure 2). After excluding ineligible studies and adding additional articles found from citation chaining, 50 studies were eligible for data synthesis. Of these, 18 studies investigated air pollution and 32 investigated temperature. The major reason for exclusion during full-text screening was use of simplistic statistical analyses (n = 25).

Study designs varied among the 50 included studies (Table 2). Time-series analysis and case-crossover designs were the most dominant study designs, with 6 (33.3%) time-series and 12 (66.7%) time-stratified case-crossover studies of the 18 air pollution studies, and 17 (53.1%) time-series and 9 (28.1%) time-stratified case-crossover studies of the 32 temperature studies. Overall, South Korea (n = 9), mainland China and the Taiwan (n = 9), US (n = 7), and Japan (n = 7) were the most the most studied countries. The 18 air pollution studies were based in 9 countries, while the 32 temperature studies were conducted in 26 countries.

Four (22.2%) of the air pollution studies and 5 (15.6%) of the temperature studies considered hospital visits of SA, whereas the others considered mortality. About 34% (n = 17) studies of the total 50 studies did not provide ICD codes. Nine different sets of ICD codes were used to define suicide cases: ICD-10 X60-84 (n = 13, 39.4% of the 33 studies that provided ICD codes); ICD-9 E950-E958 and ICD-10 X60-X84 (n = 6, 18.2%); ICD-9 E950-E959 (n = 4, 12.1%); ICD-9 E950-E958 (n = 2, 3.0%); ICD-10 X60-X84 and Y87.0 (n = 2, 3.0%); ICD-9 E950-E959 and ICD-10 X60-X84 (n = 2, 3.0%); ICD-9 E950-E959, E980-E989 (excluding E988.8), ICD-10 X60-X84, and Y10-Y34 excluding Y33.9 (n = 1, 3.0%); and ICD-9 E950-E959 and E980-E989 (n = 1, 3.0%).
Figure 2. Flowchart of identified studies for systematic review.

Most air pollution studies (n = 14, 77.8%) examined multiple air pollutants: PM$_{10}$ (n = 11, 64.7%), PM$_{2.5}$ (n = 9, 50%), O$_3$ (n = 9, 50%), NO$_2$ (n = 10, 55.6%), SO$_2$ (n = 9, 50%), and CO (n = 5, 27.8%). One study focused on days with Asian dust storms. While the majority of air pollution studies (n = 16, 88.9%) used air pollution data from monitors, one used kriging approaches. All air pollution studies considered daily changes in air pollution, except one that considered weekly changes.

Three of the 32 temperature studies adjusted for potential confounding by air pollution, including one of the 18 time-series and case-crossover studies included in our meta-analysis, however, temperature was adjusted in all 13 air pollution studies included in the meta-analysis. In summary, studies adjusted for potential confounding by temperature in assessing suicide risks of air pollution and rarely adjusted for potential confounding by air pollution in estimating associations between temperature and suicide.
### Table 2. Characteristics of the included studies.

| First Author, Publication Year [Reference] | Location | Study Timeframe | Suicide Deaths: Number or Rate (100,000 Population) | Age Range (Years) | Study Design | Exposure Variables for Air Pollution and/or Temperature | Exposure Methods | Health Outcome | ICD Codes (If Applicable) | Increment of Exposure for Estimates of the Association | Considered Confounders |
|------------------------------------------|----------|----------------|---------------------------------------------------|----------------|-------------|-----------------------------------------------------|----------------|----------------|------------------------|-------------------------------------------------|----------------------|
| Antidolfo-Garcia, 2011 [41]              | Mexico City | 2000–2016      | Rate: 1.98                                        | ≥10            | Time-series | PM_{2.5}, PM_{10}, NO_{2}, NO_{x}                   | Monitors        | Mortality      | NR                     | 1 unit                                                                 | Daily averages for temperature and relative humidity, holiday |
| Bakken, 2015 [42]                        | Salt Lake County, Utah, US | 2005–2010      | 1546                                              | All            | Case-crossover | NO_{2}, PM_{2.5}, PM_{10-25}                       | Monitors        | Mortality      | NR                     | IQR increase                                                                 | Calendar time for week, monthly mean, minimum, and maximum temperature, resolution hour, irradiation, relative humidity, atmosphere pressure, rainfall |
| Band, 2017 [43]                          | Sao Paulo, Brazil | 1996–2011      | Rate: 8.7                                         | NR             | Time-series | Weekly minimum temperature                         | Monitors        | Mortality      | ICD-10: X60-X84                     | 1 unit                                                                 | Month, rainfall, sunshine duration, visibility, cloud cover, wind speed |
| Barker, 1994 [44]                        | Oxford, England | 1976–1989      | 12,279                                            | NR             | Time-series | temperature (monthly)                              | NR             | Suicide cases  | NR                     | 1 unit                                                                 | Day of the week, month |
| Basagaña, 2011 [45]                      | Catalonia, Spain | 1985–2006      | 503,389                                           | All            | Time-series | Temperature                                         | Monitors        | Mortality      | ICD-10: X60-X84, ICD-9: E950-I959 | 100°F (43.3°C)                                                                 | Holidays, day of the week, seasonal trends (calendar time) |
| Basu, 2019 [46]                          | California, US | 2005–2013      | 322,678                                           | All            | Time-series | Apparent temperature                               | Monitors        | Mortality      | ICD-9: E950-959, ICD-10: X60-X84 | 10 unit increase (microgram / cubic meter) | Day of the week, long-term seasonality, temperature, duration of sunshine |
| Casas, 2017 [47]                         | Belgium      | 2002–2011      | 20,533                                            | ≥5             | Case-crossover | Daily average PM_{10} and daily maximum 8-h average O_{3} | Kringing model | Mortality      | ICD-10: X60-84, Y10-34 | 10 degree of Celsius increase | Mean relative humidity, thunderstorms, rainfall, sulfites, mean atmospheric pressure (tested, but not included in the analytic model) |
| Deisenhammer, 2003 [48]                  | Tyrol, Austria | 1995–2000      | 702 (518 males, 184 females)                      | NR             | Case-crossover | Temperature                                         | Monitors        | Mortality      | NR                     | NA                                                                 | Year, week, day of the week |
| Dixon, 2018 [49]                         | 9 counties in US | 1975–2010      | NR                                                | All            | Time-series | Daily maximum and minimum temperature              | Monitors        | Mortality      | ICD-9: E950-959, ICD-10: X60-X84 | 20% increase (85 percentile <) and nonheatwave days | Temperature, precipitation, relative humidity and holidays |
| Fernandez-Nino, 2018b [50]               | 4 cities in Colombia | 2011–2014      | 1942                                              | All            | Time-series | PM_{2.5}, PM_{10}, O_{3}, NO_{2}, NO_{x}, CO | Monitors        | Mortality      | ICD-10: X60-X84 or Y87.0 | 1 unit                                                                 | Rainfall, holidays, day of the week, month, year |
| Fernandez-Nino, 2018a [51]               | 5 cities in Colombia | 2005–2015     | Rate: 0.08 to 0.57 for men and from 0.01 to 0.14 for women | All            | Time-series | Daily mean temperature                                | One monitoring station | Mortality      | ICD-10: X60-X84 or Y87.0 | 1 unit                                                                 |
| Fournoulaikis, 2016 [52]                 | 29 European countries | 2000–2012 | Rate: 3.6 to 40.0 for men, 0.7 to 14.4 for women | All            | Cross-sectional | Temperature                                         | Standardized mortality rate | Mortality      | NR                     | Economic variables, weather variables | 1 unit                                                                 |
| Gojnovski AM, 2013 [53]                  | Aitana, Karakolstan | 2005–2010 | 695                                               | All            | Time-series | Daily mean temperature, maximum temp, mean apparent temperature, maximum apparent temperature | Monitors        | Mortality      | ICD-10: X60-X84 | 1 unit                                                                 | Month, year, holiday |
| Hiltunen, 2012 [54]                      | Helsinki, Finland | 1980–1990, 1997–1999 | 3845                                              | All            | Time-series | Daily mean temperature                               | Monitors        | Mortality      | NR                     | 1 unit                                                                 | Global solar radiation, precipitation |
| Hiltunen, 2014 [55]                      | Helsinki, Finland | 1974–2010 | 10,902                                            | All            | Time-series | Diurnal temperature                                  | Monitors        | Mortality      | NR                     | 1 unit                                                                 | 21 meteorological factors |
| Hu, 2020 [56]                            | Shenzhen, China | 2013–2017     | 6642 dispatches for suicides                      | All            | Time-series | Daily mean temperature                               | NR             | Ambulance dispatches | ICD-10: X60-X84 | 1 unit                                                                 | Calendar time, O_{3}, CO, NO_{2}, PM_{2.5}, temperature (same day), holiday, day of the week |
| Kaysermuhs, 2020 [57]                    | Ankara, Turkey | 2017–2019      | 6777                                              | All            | Time-series | Daily mean, maximum, minimum temperature             | One monitoring station | Hospital admissions | NR                     | IQR increase                                                                 | Seasonality, average humidity, average actual pressure (hPa) |
| Kim, 2010 [58]                           | 7 Metropolitan cities in South Korea | 2004 | 4341                                              | All            | Case-crossover | PM_{2.5}, PM_{10}                                    | Monitors        | Mortality      | NR                     | 1 unit                                                                 | Holidays, mean hours of sunlight from the previous 2 days, temperature, dew point temperature, air pressure |
| Kim, 2011 [59]                           | South Korea | 2003–2005 | 45,651                                            | All            | Time-series | Daily mean temperature                                | Monitors        | Mortality      | ICD-10: X60-X84 | 1 unit                                                                 | Sunshine, relative humidity, holidays, long-term trends |
| First Author, Publication Year [Reference] | Location | Study Timeframe | Suicide Death Number or Rate (100,000 Population) | Age Range (Years) | Study Design | Exposure Variables for Air Pollution and/or Temperature | Exposure Methods | Health Outcome | ICD Codes (If Applicable) | Increment of Exposure for Estimates of the Association | Considered Confounders |
|------------------------------------------|----------|----------------|-----------------------------------------------|------------------|-------------|--------------------------------------------------|-----------------|--------------|-------------------|----------------------------------|------------------------|
| **Kim, 2015 [60]** | 16 regions in South Korea | 2006–2011 | NR | All | Time-series (weekly) | PM$_{10}$, O$_3$, SO$_2$, NO$_2$, CO | Monitors | Mortality | ICD-10: X60-X64 | 1 unit | Celebrity suicide, average national monthly suicide number for the past 5 years by month matching each weekly (seasonality adjustment), sunlight hours, temperature, consumer price index, unemployment rate, stock index, end-of-week, holiday |
| **Kim, 2016 [61]** | 15 major cities in Korea, Japan | 1972–2010 | 66224 in Korea, 126,705 in Japan, 17,879 in Taiwan | ≥0 | Case-crossover | Daily mean temperature | NR | Daily mortality rate | ICD-9: E950.0-E958.9, ICD-10: X60-X64 | 2) IQR increase | Age, sex, sunshine duration, relative humidity, atmospheric pressure, snow fall, month, holiday |
| **Kim, 2018 [62]** | 10 large cities in three Northeast Asian countries (South Korea, Japan, Taiwan) | 1979-2010 | 134,011 | All | Case-crossover | PM$_{10}$, PM$_{2.5}$, NO$_2$, SO$_2$, CO | Monitors | Mortality | ICD-9: E950.0-E958.9, ICD-10: X60-X64 | 10 unit | Daily of the week, month, year, temperature, sunshine hours, public hospital, relative humidity, sea level atmospheric pressure, total precipitation |
| **Kim, 2019 [63]** | Year, month, day of week, relative humidity, N (%) and daily total of sunshine duration (hours) | 4–22 years | 1320,148 | All | Case-crossover | Daily mean temperature (°C) | Monitors | Mortality | Between minimum suicide temperature and maximum suicide temperature | Year, month, day of the week, relative mortality (%) and daily total of sunshine duration (hours) |
| **Kubo, 2021 [64]** | 46 prefectures, Japan | 2012–2015 | 151,801 | ≥10 | Case-crossover | Daily mean temperature (°C) | Single monitoring station in each city | Emergency room visits | NR | NR | Daily daylight hours, relative humidity |
| **Loo, 2018 [65]** | South Korea | 2002–2013 | 73,445 | All | Case-crossover | PM$_{10}$, NO$_2$, SO$_2$, O$_3$, CO | Monitors | Mortality | ICD-10: X60-X64 | 1 unit | Temperature, relative humidity, air pressure, influenza epidemics, holidays |
| **Loo, 2019 [66]** | Seoul, South Korea | 2011–2015 | 30,704 | All | Case-crossover | Asian dust storms (ADSs) | Modeling data | Mortality | ICD-10: X60-X64 | Date of the week, month, year, holiday, temperature, rainfall, sunlight hours, influenza epidemics |
| **Loo, 2020 [67]** | Seoul, South Korea | 2008–2016 | Average daily number: 5 | All | Case-crossover | Daily mean temperature (°C) | Monitors | Emergency room visits | Self-harm among ICD-10: S00-S99 | 10 unit | Holidays and 2-day moving averages (lag 0–1) of relative humidity, sunshine and precipitation |
| **Li, 2018 [68]** | Beijing, China | 2009–2012 | 2172 | All | Case-crossover | PM$_{2.5}$ | Monitors | Mortality | ICD-10: X60-X64 | 10 unit | Long-term trend, seasonality, year, month, day of the week, temperature, relative humidity |
| **Likhvar, 2011 [69]** | 47 prefectures, Japan | 1972–1995 | 501,930 | All | Time-series | Maximum temperature on the same day | Monitors | Daily suicide death | ICD-9: E950–E958, ICD-10: X60–X64 | 1 unit | Time, humidity, pressure, sunshine duration, holiday, day of the week |
| **Liu, 2016 [70]** | Guangzhou, China | 2005–2012 | 1550 | All | Case-crossover | Daily PM$_{10}$, PM$_{2.5}$, NO$_2$ | Monitors | Mortality | ICD-10: X60-X64 | IQR increase | Month, year, day of the week, weather factors (mean temperature, relative humidity, atmospheric pressure, sunshine duration) |
| **Liu, 2019 [71]** | Beijing, China | 2008–2014 | 61,264 | All | Time-series | PM$_{2.5}$ | Monitors | Emergency ambulance dispatch | NR | 10$\text{µg/m}^3$ increase | Differentials between the 95th percentile of temperature and the minimum mortality temperature (MMT) |
| **Luan, 2019 [72]** | 31 Metropolitan cities in China | 2008–2013 | 39,347 | All | Time-series | Temperature | Monitors | Mortality | ICD-10: X60-X64 | Humidity, day of the week, holiday, calendar date |
| **Malins, 2021 [73]** | Sweden | 2006–2012 | Total cases 1981 | All | Nested case-control | Temperature | Monitors | Hospital visits | ICD-10: X60-X64 | 1 unit | Previous suicide attempt, county, sex, age, year and season when the antidepressant treatment was initiated |
| **Maas, 1994 [74]** | Belgium | 1979–1987 | NR | All | Cross-sectional | Weekly average temperature | One monitoring station in each region | Mortality | ICD-9: E950–E958 (victims), E953–E957 (non-victims), E950–E952 & E958 | 1 unit | Relative humidity, air pressure, hours of sunlight and precipitation per day, wind speed, geomagnetic index |
| **Merrill, 2019 [75]** | US | 2011–2015 | 182,140 | All | Cross-sectional | Average maximum daily temperature, average PM$_{2.5}$ | Monitors | Mortality rate | NR | NA | Age, sex, race, average daily sunlight, altitude, average PM$_{2.5}$, average daily precipitation, percent living in poverty, percent of adults who smoke cigarettes, percent urban residents, percent obese, percent low-income physical inactivity |
| **Muller, 2011 [76]** | Mitte franken, Germany | 1996–2005 | 2987 | All | Cross-sectional | Ecologic study | Temperature, radiation | Monitors | Mortality | NR | Season |
### Table 2. Cont.

| First Author, Publication Year | Location | Study Timeframe | Suicide Deaths: Number or Rate (100,000 Population) | Age Range (Years) | Study Design | Exposure Variables for Air Pollution and/or Temperature | Exposure Methods | Health Outcome | ICD Codes (If Applicable) | Increment of Exposure for Estimates of the Association | Considered Confounders |
|--------------------------------|----------|-----------------|----------------------------------------------------|-------------------|--------------|--------------------------------------------------------|------------------|---------------|--------------------------|-----------------------------------------------------|---------------------|
| Ng, 2016 [76]                  | Tokyo, Japan | 2003–2011     | 29,059                                             | All                | Case-crossover | PM$_{2.5}$, suspended particulate matter (SPM), SO$_2$, NO$_2$ | Monitors         | Mortality      | ICD-10: X60-X84            | IQR increase                                      | Holidays, new year holiday season, temperature, relative humidity |
| Nguyen, 2021 [77]              | California, US | 2005–2013   | 195,530                                            | All                | Time-series   | O$_3$, PM$_{2.5}$                                       | Nearest monitor  | Emergency room visits | ICD-9: E950-959 | 10 ppb increase in O$_3$ and 10 µg/m$^3$ increase in PM$_{2.5}$ | No$_2$, apparent temperature, seasonal/long-term trends, public holiday |
| Page, 2007 [78]                | England and Wales | 1995–2003  | 53,625                                             | All                | Time-series   | Daily mean temperature, suspended high temperature days | Monitors         | Daily suicide counts |                         | 1 unit                                             | Month, day of the week, holidays, daylight duration |
| Salih, 1997 [79]               | North Cheshire, England | 1989–1993  | 197                                                | All                | Case-crossover | Maximum temperature, minimum temperature                | One monitoring station | Mortality      | ICD-9: E950-959, ICD-10: E960-969 | 1 unit                                             | Total rainfall, sunshine hours, maximum relative humidity |
| Santurtun, 2021 [80]           | Madrid and Lisbon, Spain | 2002–2012  | Average daily suicide rate: 3.30/100,000 inhabitants in Madrid and 7.87/100,000 inhabitants in Lisbon | All                | Time-series   | Apparent Temperature (AT)                               | Monitors         | Mortality      | ICD-10: X60-X84           | 17.4 difference between maximum AT and the median AT | NO$_2$, the day of the week, and time |
| Schneider, 2020 [81]           | 4 Bavarian cities and 11 Bavarian counties, Germany | 1990–2006  | 10,395                                             | All                | Case-crossover | Temperature                                              | Monitors         | Mortality rate | ICD-9: E950-959, ICD-10: E960-969 | 1 unit                                             | Long-term time trend, precipitation, cloud cover |
| Sim, 2020 [82]                 | 47 prefectures, Japan | 1972–2015   | Average prefecture-specific annual count of suicide: 516.2 | ≥15                | Case-crossover | Temperature                                              | One monitoring station | Mortality      | ICD-10: E950-959 for ICD-8 and 9; X60-X84 for ICD-10 | 21.5: difference between the maximum suicide temperature versus 5th temperature percentile | Calendar year, month, and day-of-week, humidity |
| Szyszkowicz, 2010 [83]         | Vancouver, Canada | 1999–2003   | 1605                                               | All                | Case-crossover | NO$_2$, SO$_2$, O$_3$, CO, PM$_{10}$, PM$_{2.5}$ | Monitors         | Hospital admissions | NR                                      | IQR increase | Temperature, relative humidity, date (day, month, year), day of the week |
| Thilakaratne, 2020 [84]        | California, US | 2005–2013   | 63,108                                             | All                | Time-series   | NO$_2$, CO                                              | Monitors         | Hospital admissions | ICD-9: E950-959 | IQR increase | Daily mean apparent temperature, holidays, day of the week, seasonal/long-term trends, population |
| Williams, 2016 [85]            | New Zealand | 1995–2009   | 47,265                                             | All                | Time-series   | Temperature                                              | Interpolation     | Hospital admissions | ICD-9: E950-959 | 1 unit | Season, population |
| Yang, 2019a [86]               | Taipei, Taiwan | 2004–2008   | 2011                                               | All                | Case-crossover | O$_3$                                                   | Monitors         | Daily mortality  | ICD-9: E950-959 | IQR increase | Month, day of the week, temperature (lag 0), humidity (lag 0), pollutants (lag 0-2). In two-pollutants models, PM$_{10}$, NO$_2$, SO$_2$, and U were adjusted |
| Yang, 2019b [87]               | Taipei, Taiwan | 2008–2012   | 4752                                               | All                | Case-crossover | O$_3$                                                   | Monitors         | Hospital admissions | NR                                      | IQR increase | Temperature (lag 0), humidity, day of the week, and mood |
| Yarza, 2020 [88]               | Southern Israel | 2002–2017   | 2558 (age 15–99 years) | 16–90              | Case-crossover | Daily average temperature                                | One monitoring station | Hospital admissions | NR                                      | IQR increase | Day of the week, mood, relative humidity, age, sex, ethnicity, psychiatric diagnosis, SES |
| Zerboni, 2018 [89]             | Sao Paulo, Brazil | 2006–2007   | NR                                                 | NR                 | Cross-sectional | Perceived temperature                                    | One monitoring station | Mortality      | NR                                      | 1 unit | None |

NR = not reported, NA = not applicable, ICD = International Classification of Diseases, IQR = interquartile range, SES = socioeconomic status. Time-series studies are based on daily analysis unless otherwise specified.
Three studies addressed possible interactions between temperature and air pollution for suicide risks. Thilakaratne et al. [84] estimated hospitalization risks from SA associated with short-term CO and NO\textsubscript{2} separately for warm and cold seasons, finding higher associations in warm seasons in California, US. Yang et al. [13,86] estimated associations between O\textsubscript{3} and daily suicide rates separately for warm and cold days (mean temperature \( \geq \) or \(< 23 \, ^\circ\text{C} \)), finding higher associations on cold days in Taipei, Taiwan.

3.2. Risk Summarization

The 50 studies were classified into three summary groups based on direction and statistical significance of effect estimates (Table S3). No studies reported significantly negative associations. Studies for temperature generally reported positive associations between suicide and temperature.

For PM, 35.3\% \((n = 6)\) of the 11 studies for PM\textsubscript{10} and six studies for PM\textsubscript{2.5} suggested positive and significant associations between short-term PM exposure and suicide. For O\textsubscript{3} 37.5\% \((n = 3)\) of the eight studies found significantly positive associations with suicide. No significant associations were observed for SO\textsubscript{2} or NO\textsubscript{2}. Of the five studies for CO, two showed positive and significant associations. The number of studies for CO was limited, hindering assessment of the direction or presence of associations.

Meta-analysis included 31 eligible studies based on time-series analysis and case-crossover designs, with 18 for temperature and 13 for air pollution (Table 3). Including multiple risk estimates for different regions, 25 results of risk estimation for temperature were combined in meta-analysis. RR of daily suicide rates per IQR increase in daily temperature \((7.1 \, ^\circ\text{C})\) was 1.09 \((95\% \text{ CI: 1.06, 1.13})\). Heterogeneity among studies for the temperature-suicide association was high (96.9\%). The RR for an IQR PM\textsubscript{10} increase \((7.3 \, \mu\text{g/m}^3)\) was 1.01 \((95\% \text{ CI: 1.00, 1.03})\) and borderline significant \((p < 0.10)\). PM\textsubscript{2.5} also exhibited a borderline significant RR at 1.02 \((95\% \text{ CI: 1.00, 1.05})\) for an IQR increase \((13.1 \, \mu\text{g/m}^3)\). An IQR \((17.7 \, \text{ppm})\) increase in daily NO\textsubscript{2} was significantly associated with increased suicide risks \((RR = 1.03, 95\% \text{ CI: 1.00, 1.07})\), while O\textsubscript{3}, SO\textsubscript{2}, and CO did not exhibit associations with suicide risks. Substantial heterogeneity in associations was found for PM, O\textsubscript{3}, SO\textsubscript{2}, NO\textsubscript{2}, and CO \((I^2 54.1\%–71.5\%)\).

Table 3. Results of meta-analysis for the relative risk of suicide for an interquartile range (IQR) increase in temperature, PM\textsubscript{2.5}, PM\textsubscript{10}, O\textsubscript{3}, SO\textsubscript{2}, NO\textsubscript{2}, and CO.

| Variable          | Number of Included Results | RR     | 95\% CI       | p-Value     | I\(^2\) |
|-------------------|---------------------------|--------|---------------|-------------|---------|
| Temperature (\(^\circ\text{C}\)) | 25                     | 1.09   | (1.06, 1.13)  | <0.0001     | 96.9\%  |
| PM\textsubscript{2.5} (\(\mu\text{g/m}^3\)) | 7                      | 1.02   | (1.00, 1.05)  | 0.098       | 61.5\%  |
| PM\textsubscript{10} (\(\mu\text{g/m}^3\)) | 7                      | 1.01   | (1.00, 1.03)  | 0.054       | 62.3\%  |
| O\textsubscript{3} (ppb) | 5                      | 1.02   | (0.96, 1.10)  | 0.491       | 54.1\%  |
| SO\textsubscript{2} (ppb) | 5                      | 1.02   | (1.00, 1.04)  | 0.222       | 71.5\%  |
| NO\textsubscript{2} (ppb) | 6                      | 1.03   | (1.00, 1.07)  | 0.041       | 64.1\%  |
| CO (ppm) | 4                      | 1.02   | (0.95, 1.08)  | 0.631       | 61.5\%  |

IQR increase: 7.1 \(^\circ\text{C}\) for temperature, 7.3 \(\mu\text{g/m}^3\) for PM\textsubscript{10}, 13.1 \(\mu\text{g/m}^3\) for PM\textsubscript{2.5}, 21.3 ppb for O\textsubscript{3}, 3.7 ppb for SO\textsubscript{2}, and 1.4 ppm for CO.

Funnel plots for exposure–outcome combinations are shown in Figure 3. Based on the Egger’s test, there was significant publication bias for PM\textsubscript{10}–suicide associations \((p\text{-value 0.008 for PM}_{10})\), whereas publication bias was not found for the other air pollutants or temperature. Publication bias-adjusted RR for PM\textsubscript{10} \((RR = 1.01, 95\% \text{ CI: 1.00, 1.03}; I^2 = 61.5\%)\) did not change from the RR estimate without such adjustment.
The results of meta-regression analyses for GNI (US$) per capita, national suicide rates, and average exposure levels are shown in Table 4. Only GNI (US$) per capita was a significant effect modifier for the temperature–suicide association. RR of suicide risks associated with an IQR increase in daily temperature in regions with low GNI (US$) per capita (RR = 1.20, 95% CI: 1.14, 1.26) was significantly higher than in regions with higher GNI (US$) per capita (RR = 1.09, 95% CI: 1.07, 1.11). Suicide risks associated with air pollution were not modified by national suicide rates or average air pollution levels. Robust results were found using GDP per capita and PPP per capita (Table 5).
Table 4. Relative risks (RRs) of suicide associated with an interquartile range increase in temperature, PM$_{2.5}$, PM$_{10}$, and O$_3$, SO$_2$, NO$_2$, and CO by GNI per capita, national suicide rates, and average exposure levels.

| Exposure and Effect Modifier | N  | RR (95% CI)   | p-Value |
|------------------------------|----|---------------|---------|
| Temperature                  |    |               |         |
| GNI (US$) per capita         |    |               |         |
| Higher ($\geq$12,375)        | 31 | 1.09 (1.07, 1.11) | 0.001   |
| Lower (<$12,375)             | 9  | 1.20 (1.14, 1.26) |         |
| National suicide rates (per 100,000 population) |    |               |         |
| High ($\geq$16)              | 5  | 1.11 (1.06, 1.16) | 0.964   |
| Medium (14–15.9)             | 12 | 1.10 (1.07, 1.13) |         |
| Low (<14)                    | 23 | 1.11 (1.08, 1.14) |         |
| Average exposure level a     |    |               |         |
| High                         | 17 | 1.18 (1.13, 1.23) | 0.235   |
| Low                          | 18 | 1.14 (1.10, 1.18) |         |
| GNI (US$) per capita         |    |               |         |
| Higher ($\geq$12,375)        | 5  | 1.01 (1.00, 1.03) | 0.519   |
| Lower (<$12,375)             | 4  | 1.03 (1.00, 1.06) |         |
| National suicide rates (per 100,000 population) |    |               |         |
| High ($\geq$16)              | 2  | 1.02 (0.97, 1.06) | 0.830   |
| Medium (14–15.9)             | 0  | -              |         |
| Low (<14)                    | 6  | 1.02 (0.99, 1.05) |         |
| Average exposure level a     |    |               |         |
| High                         | 4  | 1.01 (0.98, 1.05) | 0.864   |
| Low                          | 4  | 1.02 (0.98, 1.05) |         |
| GNI (US$) per capita         |    |               |         |
| Higher ($\geq$12,375)        | 10 | 1.01 (0.99, 1.03) | 0.386   |
| Lower (<$12,375)             | 6  | 1.01 (0.99, 1.03) |         |
| National suicide rates (per 100,000 population) |    |               |         |
| High ($\geq$16)              | 6  | 1.01 (1.00, 1.01) | 0.680   |
| Medium (14–15.9)             | 3  | 1.00 (0.99, 1.01) |         |
| Low (<14)                    | 7  | 1.00 (0.99, 1.01) |         |
| Average exposure level a     |    |               |         |
| High                         | 7  | 1.00 (1.00, 1.01) | 0.893   |
| Low                          | 8  | 1.00 (1.00, 1.01) |         |
| O$_3$                        |    |               |         |
| GNI (US$) per capita         |    |               |         |
| Higher ($\geq$12,375)        | 2  | 1.01 (0.91, 1.29) | 0.417   |
| Lower (<$12,375)             | 3  | 0.99 (0.86, 1.13) |         |
| National suicide rates (per 100,000 population) |    |               |         |
| High ($\geq$16)              | 1  | 1.37 (0.93, 2.03) | 0.138   |
| Medium (14–15.9)             | 0  | -              |         |
| Low (<14)                    | 4  | 1.02 (0.96, 1.08) | 0.129   |
| Average exposure level a     |    |               |         |
| High                         | 2  | 0.94 (0.83, 1.08) | 0.129   |
| Low                          | 3  | 1.07 (0.97, 1.18) |         |
| SO$_2$                       |    |               |         |
| GNI (US$) per capita         |    |               |         |
| Higher ($\geq$12,375)        | 9  | 1.02 (1.00, 1.04) | 0.139   |
| Lower (<$12,375)             | 4  | 0.99 (0.96, 1.03) |         |
| National suicide rates (per 100,000 population) |    |               |         |
| High ($\geq$16)              | 5  | 1.02 (0.99, 1.06) | 0.357   |
| Medium (14–15.9)             | 4  | 1.02 (1.00, 1.04) |         |
| Low (<14)                    | 4  | 0.99 (0.96, 1.03) |         |
| Average exposure level a     |    |               |         |
| High                         | 6  | 1.03 (0.97, 1.10) | 0.908   |
| Low                          | 7  | 1.04 (0.97, 1.11) |         |
Table 4. Cont.

| Exposure and Effect Modifier | N  | RR (95% CI) | p-Value |
|------------------------------|----|-------------|---------|
| NO₂ GNI (US$) per capita     |    |             |         |
| Higher (≥$12,375)            | 10 | 1.03 (1.01, 1.05) | 0.938   |
| Lower (<$12,375)             | 5  | 1.03 (0.97, 1.09) |         |
| National suicide rates (per 100,000 population) | | | |
| High (≥16)                   | 5  | 1.03 (0.99, 1.06) | 0.871   |
| Medium (14–15.9)             | 4  | 1.03 (0.99, 1.06) |         |
| Low (<14)                    | 6  | 1.04 (0.99, 1.10) |         |
| Average exposure level a     |    |             |         |
| High                         | 6  | 1.02 (1.00, 1.05) | 0.015   |
| Low                          | 7  | 1.04 (1.01, 1.07) |         |
| GNI (US$) per capita         |    |             |         |
| Higher (≥$12,375)            | 4  | 1.02 (0.95, 1.08) |         |
| Lower (<$12,375)             | 0  | -           |         |
| National suicide rates (per 100,000 population) | | | |
| High (≥16)                   | 2  | 1.02 (0.94, 1.11) | 0.877   |
| Medium (14–15.9)             | 0  | 1.01 (0.87, 1.16) |         |
| Low (<14)                    | 2  | -           |         |
| Average exposure level a     |    |             |         |
| High                         | 2  | 1.02 (0.94, 1.11) | 0.877   |
| Low                          | 2  | 1.01 (0.87, 1.16) |         |

* Average exposure level for each exposure factor in the study region. The groups (high, low) were classified based on the median of the exposure factor.

Table 5. Relative risks (RRs) and 95% CIs of suicide associated with an interquartile range (IQR) increase in temperature, PM$_{2.5}$, PM$_{10}$, and O$_3$ by GDP per capita and PPP per capita (US$).

| Exposure | Group of GDP (US$) per Capita | RR (95% CI) | p-Value | Group of PPP (US$) per Capita | RR (95% CI) | p-Value |
|----------|--------------------------------|-------------|---------|--------------------------------|-------------|---------|
|          | Lower (≤$30,025) | Higher (>$30,025) |          | Lower (≤$37,058) | Higher (>$37,058) |          |
| Temperature (°C) | 9 1.20 (1.14, 1.26) | 31 0.92 (0.87, 0.98) | 0.005 | 9 1.23 (1.15, 1.31) | 29 1.11 (1.08, 1.14) | 0.003 |
| PM$_{2.5}$ (µg/m$^3$) | 4 1.01 (0.99, 1.03) | 4 1.01 (0.99, 1.03) | 0.839 | 4 1.01 (0.99, 1.03) | 4 1.01 (0.99, 1.03) | 0.839 |
| PM$_{10}$ (µg/m$^3$) | 6 1.00 (0.99, 1.01) | 10 1.01 (1.00, 1.01) | 0.386 | 6 1.00 (0.99, 1.01) | 10 1.01 (0.99, 1.02) | 0.386 |
| O$_3$ (ppb) | 3 0.99 (0.90, 1.10) | 1 1.28 (0.92, 1.78) | 0.144 | 3 0.90 (0.90, 1.10) | 1 1.28 (0.92, 1.78) | 0.144 |
| SO$_2$ (ppb) | 4 1.00 (0.98, 1.01) | 9 1.01 (1.00, 1.02) | 0.139 | 4 1.00 (0.98, 1.01) | 9 1.01 (1.00, 1.02) | 0.139 |
| CO (ppm) | 5 1.02 (0.98, 1.05) | 10 1.02 (1.00, 1.03) | 0.938 | 5 1.02 (0.98, 1.05) | 10 1.02 (1.00, 1.03) | 0.938 |

IQR increase was 7.1 °C for temperature, 7.3 µg/m$^3$ for PM$_{10}$, 13.1 µg/m$^3$ for PM$_{2.5}$, 21.3 ppb for O$_3$, 3.7 ppb for SO$_2$, and 1.4 ppm for CO.

Summaries of risk of bias are shown in Figure 4. We estimated “probably low risk” of bias for both temperature and air pollution. For air pollution, the risk of bias was relatively higher for detection bias, while more than 80% of the included studies showed definitely low risk of bias for the other five criteria of risk of bias. We concluded that overall risk of bias was definitely low for 50.0% (n = 9 of 18) of the air pollution studies and was probably low in the remaining air pollution studies (n = 9) (Table 6). For temperature, definitely high risk of bias was found for confounding bias (18.8% of included studies), detection bias (3.1%), and appropriateness of statistical analysis (6.3%) (Figure 4). Major reasons of higher risk of bias for temperature were estimating temperature from an insufficient number of monitoring stations (i.e., one monitoring station per city), lack of controlling for seasonality in statistical models, and using data of suicides from only one hospital within a city. About 25.0% (8 among 32) of included temperature studies was classified as probably high risk of bias, 68.8% (n = 22) as probably low risk of bias, and 6.3% (n = 2) had definitely low risk of bias (Table 6). Based on this assessment of bias, the true effect would lie close to the estimate effect from meta-analysis for the studied air pollutants except PM$_{10}$, for which we observed publication bias. For temperature, the true effect would likely be close to the estimate from meta-analysis.
Figure 4. Percent of the included studies by overall risk of bias (RoB) and levels of risk of bias for six criteria: (A) air pollution, (B) temperature.
4. Discussion

Several review studies, with a wide focus on mental health, examined risk of suicide associated with air pollution [7,26,28–30] and temperature [19,31]. Relatively fewer studies exist for suicide and air pollution compared to other health outcomes associated with air pollution (e.g., cardiovascular and respiratory diseases). Review studies for suicide risks include narrative, qualitative, and quantitative risk synthesis. We simultaneously focused on air pollution and temperature providing comprehensive information on quantitative and qualitative risk synthesis, the methodologies used, and studies examining exposures together as potential confounders or effect modifiers.

Our meta-analysis found significant associations between short-term temperature exposure and suicide. A previous meta-analysis found similar results, with slightly higher risks in tropical zones and regions with the middle national income (defined by the World Bank) [19]. We found significant associations with suicide for PM$_{2.5}$, PM$_{10}$, SO$_2$, and NO$_2$. Our findings on PM$_{10}$ and suicide are robust compared to a previous meta-analysis [29] that incorporated fewer studies. To our best knowledge, our meta-analyses is the first to quantitatively summarize evidence for suicide and O$_3$, SO$_2$, and NO$_2$. Relatively low number of studies for O$_3$ compared to other air pollutants highlights the need for further studies. Our findings for effect modification imply that a country’s suicide rates, air pollution levels, and climate do not explain heterogeneity across studies. While effect modification by GNI per capita was significant for the temperature–suicide relationships, future research is required to investigate effect modifications for associations between suicide and air pollution.

Interaction between air pollution and temperature in relation to health is critical for planning preventive measures. Public warning systems and surveillance systems for health outcomes associated with temperature can be reinforced during days with high air pollution. Driving factors of such interactions could vary by region. For example, Asian dust storms can become more frequent from acceleration of desertification by climate change [89]. Severe heatwaves in Mediterranean regions led to droughts and wildfires in 2000s, which elevated O$_3$ and PM during summers [90]. Climate models predict an overall drying of the land in the eastern Mediterranean and Middle East, which will influence air quality and health [91]. Many studies examined effect modification by season for associations between air pollution and mortality finding consistently higher risks in warmer seasons in North America and Europe [22]. Fewer studies used temperature as an effect modifier for mortality effects of air pollution [92,93]. For instance, a multicountry study in northeast Asia found that associations between several air pollutants and mortality (all cause, cardiovascular, respiratory) increased on days with high temperature, as did temperature-mortality associations on days with high air pollution [94]. Studies considered effect modifications by air pollution for temperature–health associations to a lesser extent [22]. We found only three studies addressing effect modifications by temperature for suicide risks of air pollution; these studies were conducted in California, USA and Taipei, Taiwan [13,84,86]. No included studies examined effect modification by air pollution on temperature-suicide relationships.

In terms of climate change, fossil-fuel-related emissions simultaneously elevate air pollution and temperature. Hyperthermia caused by failure of thermoregulation can increase intake of air pollutants, which can activate pathways related to SA through neurophysiological and stress response pathways. All 18 air pollution studies in our review adjusted for potential confounding by temperature and most studies adjusted for other meteorological factors (e.g., sunshine duration, relative humidity). However, confounding effects of air pollution were rarely controlled in temperature–suicide studies. Thus, assessment for risk of bias showed higher risk of confounding bias for temperature than air pollution in relation to suicide risks. Some studies argued that confounding by air pollution was small and it should not be considered for confounding of temperature–health associations [95,96]. However, the complex mechanisms of suicide risk suggest that air pollution and high temperature are both associated with neuroinflammation and central...
nervous system pathways (i.e., serotonin functions). Future temperature–suicide studies should consider potential confounding of air pollution and provide a clear rationale for air pollution’s role in this association.

Some studies were excluded from our meta-analysis due to different metrics for air pollution and temperature. This includes studies that examined temperature–suicide in associations stratified by quantile of PM$_{2.5}$ [74]; calculated differences of suicide rates between the 95th percentile of temperature and the minimum mortality temperature, which differed by city [71]; and used different temperature metrics such as heatwaves [45,56], diurnal temperature range [55], and perceived temperature [46]. Despite different approaches for exposure measurements, these studies generally supported the conclusion for associations between temperature and suicide risks.

Various terms for suicide outcomes have been used (e.g., suicide, suicidal behavior, SA, suicidal ideation, self-harm, self-injury, intentional deaths). Different sets of ICD codes were used to determine cases of specific outcomes (e.g., respiratory diseases) in epidemiological studies [97]. For this study, we found nine combinations of ICD codes used to identify suicide outcomes. In addition, other definitions of SA such as operational definitions or the lethality of SA have been used in recent studies (not meeting our inclusion criteria) to examine suicide risk [98]. The impact of these varying definitions lead on heterogeneity of risk estimations warrants future study.

Our findings suggest that more studies are needed on associations between air pollution and suicide, especially for O$_3$ and CO. Strengths of this study is that we summarized evidence both quantitatively and qualitatively, assessed risk of bias and provided subgroup analysis of meta-analysis to identify vulnerable populations.

With respect to limitations, we did not investigate the suicide risks by sex/gender subgroups. Men and women in different age groups may experience different suicide risks from air pollution. Many studies examined neuropsychological, neuroanatomical, and neurophysiological differences arising from interplay of sex hormones [99] such that ovarian steroids (e.g., estradiol, progesterone) affect the density of certain serotonin receptor sites [100]. Suicide risks may differ by income level of country as age-standardized suicide rates were three times higher in males than females in high-income countries; the male–female ratio for suicide rates was more equal in low- and middle-income countries [1]. Health disparities by sex/gender across countries should be studied further. Risks combined in this meta-analysis were based on varying lag structures. A previous meta-analysis [27] suggested that suicide risks differ between lag days and accumulate over the lag days. Future meta-analysis should be able to summarize evidence for the patterns of suicide risks over lag days. Our findings are based on results for a limited number of countries. In particular, future studies are needed for middle- and low-income southeast Asian countries in tropical zones as suicide risks associated with temperature are higher in tropical zones [19].

5. Conclusions

This systematic review and meta-analysis comprehensively summarized evidence for suicide risks associated with ambient temperature and air pollution. Significant and positive associations between daily high temperature and suicide were found from studies at probably low risk of bias. Results for associations between air pollution and suicide were based on studies that were determined to have definitely low risk of bias; there was suggestive evidence for associations between suicide and PM$_{2.5}$, PM$_{10}$, NO$_2$, and NO$_2$, with weak evidence for O$_3$, SO$_2$, and CO. Subgroup analysis showed higher suicide-temperature associations in high-income countries. As relatively less research has been conducted for air pollution, there is a need for future studies on pollution–suicide associations to better determine quality of evidence and effect modifications. Future studies are needed to verify confounding and interactions between air pollution and temperature in terms of the mechanisms of suicide behaviors. Our review also implies the importance of guidance for air quality and hot weather in clinical suicide prevention efforts.
Supplementary Materials: The following are available online at https://www.mdpi.com/article/10.3390/ijerph18147699/s1, Table S1: Search strategies, Table S2: MOOSE checklist, Table S3: Qualitative risk summary for the included studies, Text S1: Sensitivity analysis for meta-regression analysis. Reference [39] is referred to in Supplementary Materials.

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References
1. World Health Organization. Suicide Worldwide in 2019: Global Health Estimates; World Health Organization: Geneva, Switzerland, 2021; ISBN 978-92-4-002664-3.
2. Arensman, E.; Scott, V.; De Leo, D.; Pirkis, J. Suicide and Suicide Prevention from a Global Perspective. Crisis 2020. [CrossRef] [PubMed]
3. Hawton, K.; van Heeringen, K. Suicide. Lancet 2009, 373, 1372–1381. [CrossRef]
4. Mann, J.J.; Currier, D.M. Stress, Genetics and Epigenetic Effects on the Neurobiology of Suicidal Behavior and Depression. Eur. Psychiatry 2010, 25, 268–271. [CrossRef] [PubMed]
5. van Heeringen, K.; Mann, J.J. The Neurobiology of Suicide. Lancet Psychiatry 2014, 1, 63–72. [CrossRef]
6. Turecki, G.; Brent, D.A. Suicide and Suicidal Behaviour. Lancet 2016, 387, 1227–1239. [CrossRef] [PubMed]
7. Gladka, A.; Rymaszewska, J.; Zatorski, T. Impact of Air Pollution on Depression and Suicide. Int. J. Occup. Med. Environ. Health 2018, 31, 711–721. [CrossRef] [PubMed]
8. Raggweert, R.-M.; Cha, D.S.; Subramaniapillai, M.; Carmona, N.E.; Lee, Y.; Yuan, D.; Rong, C.; McIntyre, R.S. Air Pollution, Aeroallergens and Suicidality: A Review of the Effects of Air Pollution and Aeroallergens on Suicidal Behavior and an Exploration of Possible Mechanisms. Rev. Environ. Health 2017, 32. [CrossRef]
9. Turecki, G.; Brent, D.A.; Gunnell, D.; O’Connor, R.C.; Oquendo, M.A.; Pirkis, J.; Stanley, B.H. Suicide and Suicide Risk. Nat. Rev. Dis. Printers 2019, 5, 74. [CrossRef]
10. Costanza, A.; Amerio, A.; Aguglia, A.; Escelsior, A.; Serafini, G.; Berardelli, I.; Pompili, M.; Amore, M. When Sick Brain and Hopelessness Meet: Some Aspects of Suicidality in the Neurological Patient. CNS Neurol. Disord. Drug Targets 2020, 19, 257–263. [CrossRef]
11. Costanza, A.; Baertschi, M.; Weber, K.; Canuto, A. Neurological Diseases and Suicide: From Neurobiology to Hopelessness. Rev. Med. Suisse 2015, 11, 402–405. [CrossRef]
12. Chen, J.-C.; Samet, J.M. Air Pollution and Suicide Risk: Another Adverse Effect of Air Pollution? Eur. J. Epidemiol. 2017, 32, 943–946. [CrossRef]
13. Yang, C.-Y.; Huang, Y.-T.; Chiu, H.-F. Does Ambient Ozone Air Pollution Trigger Suicide Attempts? A Case Cross-over Analysis in Taipei. J. Toxicol. Environ. Health Part A 2019, 82, 638–644. [CrossRef]
14. Kim, Y.; Ng, C.F.S.; Chung, Y.; Kim, H.; Honda, Y.; Guo, Y.L.; Lim, Y.-H.; Chen, B.-Y.; Page, L.A.; Hashizume, M. Air Pollution and Suicide in 10 Cities in Northeast Asia: A Time-Stratified Case-Crossover Analysis. Environ. Health Perspect. 2018, 126, 037002. [CrossRef]
15. Li, Y.; Cheng, Y.; Cui, G.; Peng, C.; Xu, Y.; Wang, Y.; Liu, Y.; Liu, J.; Li, C.; Wu, Z. Association between High Temperature and Mortality in Metropolitan Areas of Four Cities in Various Climatic Zones in China: A Time-Series Study. Environ. Health 2014, 13, 65. [CrossRef] [PubMed]
16. Cianconi, P.; Betrò, S.; Janiri, L. The Impact of Climate Change on Mental Health: A Systematic Descriptive Review. *Front. Psychiatry* **2020**, *11*, 74. [CrossRef] [PubMed]

17. Bushman, B.J.; Wang, M.C.; Anderson, C.A. Is the Curve Relating Temperature to Aggression Linear or Curvilinear? Assaults and Temperature in Minneapolis Reexamined. *J. Personal. Soc. Psychol.* **2005**, *89*, 62–66. [CrossRef] [PubMed]

18. Hill, S.Y.; Jones, B.L.; Haas, G.L. Suicidal Ideation and Aggression in Childhood, Genetic Variation and Young Adult Depression. *J. Affect. Disord.* **2020**, *276*, 954–962. [CrossRef]

19. Gao, J.; Cheng, Q.; Duan, J.; Xu, Z.; Bai, L.; Zhang, Y.; Zhang, H.; Wang, S.; Zhang, Z.; Su, H. Ambient Temperature, Sunlight Duration, and Suicide: A Systematic Review and Meta-Analysis. *Sci. Total Environ.* **2019**, *646*, 1021–1029. [CrossRef]

20. Al Ahad, M.A.; Sullivan, F.; Demšar, U.; Melhem, M.; Kulu, H. The Effect of Air-Pollution and Weather Exposure on Mortality and Hospital Admission and Implications for Further Research: A Systematic Scoping Review. *PLoS ONE* **2020**, *15*, e0241415. [CrossRef]

21. Anenberg, S.C.; Haines, S.; Wang, E.; Nassikas, N.; Kinney, P.L. Synergistic Health Effects of Air Pollution, Temperature, and Pollen Exposure: A Systematic Review of Epidemiological Evidence. *Environ. Health* **2020**, *19*, 130. [CrossRef] [PubMed]

22. Stafoggia, M.; Schwartz, J.; Forastiere, F.; Perucci, C.A. Does Temperature Modify the Association between Air Pollution and Mortality? A Multicity Case-Crossover Analysis in Italy. *Am. J. Epidemiol.* **2008**, *167*, 1476–1485. [CrossRef] [PubMed]

23. Zhou, Y.; Xiao, H.; Guan, H.; Zheng, N.; Zhang, Z.; Tian, J.; Qu, L.; Zhao, J.; Xiao, H. Chemical Composition and Seasonal Variations of PM2.5 in an Urban Environment in Kunming, SW China: Importance of Prevailing Westerlies in Cold Season. *Atmos. Environ.* **2020**, *237*, 117704. [CrossRef]

24. Gordon, C.J. Role of Environmental Stress in the Physiological Response to Chemical Toxicants. *Environ. Res.* **2003**, *92*, 101. [CrossRef] [PubMed]

25. Ambient Temperature and Health in China: Chap 7. The Interaction of Ambient Temperature and Air Pollution in China. *Int. J. Environ. Res. Public Health* **2018**, 15, 276. [CrossRef] [PubMed]

26. Liu, Q.; Wang, W.; Gu, X.; Deng, F.; Wang, X.; Lin, H.; Guo, X.; Wu, S. Association between Particulate Matter Air Pollution and Ambient Temperature and Health in China: Chap 7. The Interaction of Ambient Temperature and Air Pollution in China. *Int. J. Environ. Res. Public Health* **2020**, 17, 74. [CrossRef] [PubMed]

27. Zhao, T.; Markevych, I.; Romanos, M.; Nowak, D.; Heinrich, J. Ambient Ozone Exposure and Mental Health: A Systematic Review of Epidemiological Studies. *Environ. Res.* **2018**, *165*, 459–472. [CrossRef] [PubMed]

28. Braithwaite, I.; Zhang, S.; Kirkbride, J.B.; Osborn, D.P.; Hayes, J.F. Air Pollution (Particulate Matter) Exposure and Associations with Depression, Anxiety, Bipolar, Psychosis and Suicide Risk: A Systematic Review and Meta-Analysis. *Environ. Health Perspect.* **2019**, *127*, 126002. [CrossRef]

29. Dickerson, A.S.; Wu, A.C.; Liew, Z.; Weisskopf, M. A Scoping Review of Non-Occupational Exposures to Environmental Pollutants and Adult Depression, Anxiety, and Suicide. *Curr. Environ. Health Rep.* **2020**, *7*, 256–271. [CrossRef] [PubMed]

30. Thompson, R.; Hornigold, R.; Page, L.; Waite, T. Associations between High Ambient Temperatures and Heat Waves with Mental Health Outcomes: A Systematic Review. *Public Health* **2018**, *161*, 171–191. [CrossRef]

31. Viswanathan, M.; Patnode, C.D.; Berkman, N.D.; Bass, E.B.; Chang, S.; Hartling, L.; Murad, M.H.; Treadwell, J.R.; Kane, R.L. Recommendations for Assessing the Risk of Bias in Systematic Reviews of Health Care Interventions. *J. Clin. Epidemiol.* **2017**, *79*, 26–34. [CrossRef]

32. Wells, K.; Littell, J.H. Study Quality Assessment in Systematic Reviews of Research on Intervention Effects. *Res. Soc. Work Pract.* **2009**, *19*, 52–62. [CrossRef]

33. Smith, V.; Devane, D.; Begley, C.M.; Clarke, M. Methodology in Conducting a Systematic Review of Systematic Reviews of Healthcare Interventions. *BMC Med. Res. Methodol.* **2011**, *11*, 15. [CrossRef] [PubMed]

34. Liberati, A.; Altman, D.G.; Tetzlaff, J.; Mulrow, C.; Gotzsche, P.C.; Ioannidis, J.P.A.; Clarke, M.; Devereaux, P.J.; Kleijnen, J.; Moher, D. The PRISMA Statement for Reporting Systematic Reviews and Meta-Analyses of Studies That Evaluate Healthcare Interventions: Explanation and Elaboration. *BMJ* **2009**, *339*, b2700. [CrossRef]

35. Stroup, D.F.; Berlin, J.A.; Morton, S.C.; Olkin, I.; Williamson, G.D.; Rennie, D.; Moher, D.; Becker, B.J.; Sipe, T.A.; Thacker, S.B. Meta-Analysis of Observational Studies in Epidemiology: A Proposal for Reporting. *JAMA* **2000**, *283*, 208–212. [CrossRef] [PubMed]

36. Egger, M.; Smith, G.D.; Schneider, M.; Minder, C. Bias in Meta-Analysis Detected by a Simple, Graphical Test. *BMJ* **1997**, *315*, 629–634. [CrossRef] [PubMed]

37. Shi, L.; Lin, L. The Trim-and-Fill Method for Publication Bias: Practical Guidelines and Recommendations Based on a Large Database of Meta-Analyses. *Medicine* **2019**, *98*, e15987. [CrossRef]

38. The World Bank. GNI per Capita, Atlas Method (Current US$) Data. Available online: https://data.worldbank.org/indicator/NY.GNP.PCAPCD (accessed on 16 July 2021).

39. *Handbook for Conducting a Literature-Based Health Assessment Using OHAT Approach for Systematic Review and Evidence Integration*; National Institute of Environmental Health Sciences: Triangle Park, NC, USA, 2019; p. 101.

40. Astudillo-García, C.J.; Rodríguez-Villamizar, L.A.; Cortez-Lugo, M.; Cruz-De la Cruz, J.C.; Fernández-Niño, J.A. Air Pollution and Suicide in Mexico City: A Time Series Analysis, 2000–2016. *Int. J. Environ. Res. Public Health* **2019**, *16*, 2971. [CrossRef]
42. Bakian, A.V.; Huber, R.S.; Coon, H.; Gray, D.; Wilson, P.; McMahon, W.M.; Renshaw, P.F. Acute Air Pollution Exposure and Risk of Suicide Completion. *Am. J. Epidemiol.* 2015, 181, 295–303. [CrossRef]
43. Bando, D.H.; Teng, C.T.; Volpe, F.M.; de Masi, E.; Pereira, L.A.; Braga, A.L. Suicide and Meteorological Factors in São Paulo, Brazil, 1996–2011: A Time Series Analysis. *Rev. Bras. Psiquiatr.* 2017, 39, 220–227. [CrossRef]
44. Barker, A.; Hawton, K.; Fagg, J.; Jennison, C. Seasonal and Weather Factors in Parasuicide. *Br. J. Psychiatry* 1994, 165, 375–380. [CrossRef]
45. Basagaña, X.; Sartini, C.; Barrera-Gómez, J.; Dadvand, P.; Cunillera, J.; Ostro, B.; Sunyer, J.; Medina-Ramón, M. Heat Waves and Cause-Specific Mortality at All Ages. *Epidemiology* 2011, 22, 765–772. [CrossRef] [PubMed]
46. Basu, R.; Gavin, L.; Pearson, D.; Ebsiu, K.; Malig, B. Examining the association between Apparent Temperature and Mental Health-Related Emergency Room Visits in California. *Am. J. Epidemiol.* 2018, 187, 726–735. [CrossRef] [PubMed]
47. Casas, L.; Cox, B.; Bauwelink, M.; Nemerly, B.; Deboosere, P.; Nawrot, T.S. Does Air Pollution Trigger Suicide? A Case-Crossover Analysis of Suicide Deaths over the Life Span. *Eur. J. Epidemiol.* 2017, 32, 973–981. [CrossRef] [PubMed]
48. Deisenhammer, E.A.; Kemmler, G.; Parson, P. Association of Meteorological Factors with Suicide. *Acta Psychiatr. Scand.* 2003, 108, 455–459. [CrossRef] [PubMed]
49. Dixon, P.G.; Kalkstein, A.J. Where Are Weather-Suicide Associations Valid? An Examination of Nine US Counties with Varying Seasonality. *Int. J. Biometeorol.* 2018, 62, 685–697. [CrossRef] [PubMed]
50. Fernández-Niño, J.A.; Astudillo-García, C.I.; Rodríguez-Villamizar, L.A.; Florez-García, V.A. Association between Air Pollution and Suicide: A Time Series Analysis in Four Colombian Cities. *Environ. Health* 2018, 17, 47. [CrossRef]
51. Fernández-Niño, J.; Florez-García, V.; Astudillo-García, C.; Rodríguez-Villamizar, L. Weather and Suicide: A Decade Analysis in the Five Largest Capital Cities of Colombia. *Environ. Health Prev. Med.* 2018, 15, 3133. [CrossRef]
52. Fountoulakis, K.N.; Chatzikosta, I.; Pastiadis, K.; Zanis, P.; Kawohl, W.; Kerkhof, A.J.F.M.; Navickas, A.; Höschl, C.; Lecic-Tosevski, D.; Sorel, E.; et al. Relationship of Suicide Rates with Climate and Economic Variables in Europe during 2000–2012. *Ann. Gen. Psychiatry* 2016, 15, 19. [CrossRef] [PubMed]
53. Grijbovskı, A.; Kozhakhmetova, G.; Kosbayeva, A.; Menne, B. Associations between Air Temperature and Daily Suicide Counts in Astana, Kazakhstan. *Medicina* 2013, 49, 59. [CrossRef] [PubMed]
54. Hiltunen, L.; Ruuhela, R.; Ostamo, A.; Lönnqvist, J.; Suominen, K.; Partonen, T. Atmospheric Pressure and Suicide Attempts in Finland. *Int. J. Biometeorol.* 2012, 56, 1045–1053. [CrossRef] [PubMed]
55. Hiltunen, L.; Haukka, J.; Ruuhela, R.; Suominen, K.; Partonen, T. Local Daily Temperatures, Thermal Seasons, and Suicide Rates in Finland from 1974 to 2010. *Environ. Health Prev. Med.* 2014, 19, 286–294. [CrossRef]
56. Hu, J.; Wen, Y.; Duan, Y.; Yan, S.; Liao, Y.; Pan, H.; Zhu, J.; Yin, P.; Cheng, J.; Jiang, H. The Impact of Extreme Heat and Heat Waves on Emergency Ambulance Dispatches due to External Caus in Shenzhen, China. *Environ. Pollut.* 2020, 261, 114156. [CrossRef] [PubMed]
57. Kayipmaz, S.; San, I.; Usul, E.; Korkut, S. The Effect of Meteorological Variables on Suicide. *Int. J. Biometeorol.* 2020, 64, 1593–1598. [CrossRef] [PubMed]
58. Kim, C.; Jung, S.H.; Kang, D.R.; Kim, H.C.; Moon, K.T.; Hur, N.W.; Shin, D.C.; Suh, I. Ambient Particulate Matter as a Risk Factor for Suicide. *AJP* 2010, 167, 1100–1107. [CrossRef]
59. Kim, Y.; Kim, H.; Kim, D.-S. Association between Daily Environmental Temperature and Suicide Mortality in Korea (2001–2005). *Psychiatry Res.* 2011, 186, 390–396. [CrossRef]
60. Kim, Y.; Myung, W.; Won, H.-H.; Shim, S.; Jeon, H.J.; Choi, J.; Carroll, B.J.; Kim, D.K. Association between Air Pollution and Suicide in South Korea: A Nationwide Study. *PloS ONE* 2015, 10, e0117929. [CrossRef]
61. Kim, Y.; Kim, H.; Honda, Y.; Guo, Y.L.; Chen, B.-Y.; Woo, J.-M.; Ebi, K.L. Suicide and Ambient Temperature in East Asian Countries: A Time-Stratified Case-Crossover Analysis. *Environ. Health Perspect.* 2016, 124, 75–80. [CrossRef]
62. Kim, Y.; Kim, H.; Gasparini, A.; Armstrong, B.; Honda, Y.; Chung, Y.; Ng, C.F.S.; Tobias, A.; Iñiguez, C.; Lavigne, E.; et al. Suicide and Ambient Temperature: A Multi-Country Multi-City Study. *Environ. Health Perspect.* 2019, 127, 117007. [CrossRef]
63. Kubo, R.; Ueda, K.; Saposo, X.; Honda, A.; Takano, H. Temperature: A Case-Crossover Analysis of Suicide Mortality in 26 South Korean Cities: Effect Modification by Demographic and Socioeconomic Factors. *Sci. Total Environ.* 2020, 639, 944–951. [CrossRef] [PubMed]
64. Kuk, H.; Jung, J.; Myung, W.; Baek, J.H.; Kang, J.M.; Kim, D.K.; Kim, H. Association between Dust Storm Occurrence and Risk of Suicide: A Case-Crossover Analysis of the Korean National Death Database. *Environ. Int.* 2019, 133, 105146. [CrossRef]
65. Lee, H.; Myung, W.; Kim, H.; Lee, E.-M.; Kim, H. Association between Ambient Temperature and Injury by Intentions and Mechanisms: A Case-Crossover Design with a Distributed Lag Nonlinear Model. *Sci. Total Environ.* 2020, 746, 141261. [CrossRef]
66. Lee, H.; Myung, W.; Kim, H.; Lee, E.-M.; Kim, H. Association between Ambient Temperature and Injury by Intentions and Mechanisms: A Case-Crossover Design with a Distributed Lag Nonlinear Model. *Sci. Total Environ.* 2020, 746, 141261. [CrossRef]
67. Li, T.; Yan, M.; Sun, Q.; Anderson, G.B. Mortality Risks from a Spectrum of Causes Associated with Wide-Ranging Exposure to Fine Particulate Matter: A Case-Crossover Study in Beijing, China. *Environ. Int.* 2018, 111, 52–59. [CrossRef]
68. Likhvar, V.; Honda, Y.; Ono, M. Relation between Temperature and Suicide Mortality in Japan in the Presence of Other Confounding Factors Using Time-Series Analysis with a Semiparametric Approach. *Environ. Health Prev. Med.* 2011, 16, 36–43. [CrossRef] [PubMed]
69. Lin, C.-Z.; Li, L.; Song, Y.-F.; Zhou, Y.-X.; Shen, S.-Q.; Ou, C.-Q. The Impact of Ambient Air Pollution on Suicide Mortality: A Case-Crossover Study in Guangzhou, China. *Environ. Health* 2016, 15, 90. [CrossRef]
70. Liu, J.J.; Wang, F.; Liu, H.; Wei, Y.B.; Li, H.; Yue, J.; Que, J.; Degenhardt, L.; Lappin, J.; Lu, L.; et al. Ambient Fine Particulate Matter Is Associated with Increased Emergency Ambulance Dispatches for Psychiatric Emergencies. *Environ. Res.* 2019, 177, 108611. [CrossRef]

71. Luan, G.; Yin, P.; Wang, L.; Zhou, M. Associations between Ambient High Temperatures and Suicide Mortality: A Multi-City Time-Series Study in China. *Environ. Sci. Pollut. Res.* 2019, 26, 20377–20385. [CrossRef] [PubMed]

72. Makris, G.D.; White, R.A.; Reutforts, J.; Ekstilts, L.; Andersen, M.; Papadopoulos, F.C. Sunshine, Temperature and Suicidal Behaviour in Patients Treated with Antidepressants: An Explorative Nested Case-Control Study. *Sci. Rep.* 2021, 11. [CrossRef] [PubMed]

73. Maes, M.; Meyer, F.; Thompson, P.; Peeters, D.; Cosyns, P. Synchronized Annual Rhythms in Violent Suicide Rate, Ambient Temperature and the Light-Dark Span. *Acta Psychiatr. Scand.* 1994, 90, 391–396. [CrossRef]

74. Merrill, R.M. Injury-Related Deaths According to Environmental, Demographic, and Lifestyle Factors. *J. Environ. Public Health* 2019, 2019. [CrossRef]

75. Müller, H.; Biemann, T.; Renk, S.; Reulbach, U.; Ströbel, A.; Kornhuber, J.; Sperling, W. Higher Environmental Temperature and Global Radiation Are Correlated with Increasing Suicidality—A Localized Data Analysis. *Chronobiol. Int.* 2011, 28, 949–957. [CrossRef]

76. Ng, C.F.S.; Stickley, A.; Konishi, S.; Watanabe, C. Ambient Air Pollution and Suicide in Tokyo, 2001–2011. *J. Affect. Disord.* 2016, 201, 194–202. [CrossRef]

77. Nguyen, A.-M.; Malig, B.J.; Basu, R. The Association between Ozone and Fine Particles and Mental Health-Related Emergency Department Visits in California, 2005–2013. *PloS ONE* 2021, 16, e0249675. [CrossRef] [PubMed]

78. Page, L.A.; Hajat, S.; Kovats, R.S. Relationship between Daily Suicide Counts and Temperature in England and Wales. *Br. J. Psychiatry* 2007, 191, 106–112. [CrossRef] [PubMed]

79. Salib, E.; Gray, N. Weather Conditions and Fatal Self-Harm in North Cheshire 1989–1993. *Br. J. Psychiatry* 1997, 171, 473–477. [CrossRef] [PubMed]

80. Santurtün, A.; Almendra, R.; Silva, G.L.; Fdez-Arroyabe, P.; Santurtün, M.; Santana, P. Suicide and Apparent Temperature in the Two Capitals Cities in the Iberian Peninsula. *Soc. Sci. Med.* 2020, 265, 113411. [CrossRef]

81. Schneider, A.; Hampil, R.; Ladwig, K.-H.; Baumert, J.; Lukaschek, K.; Peters, A.; Breitner, S. Impact of Meteorological Parameters on Suicide Mortality Rates: A Case-Crossover Analysis in Southern Germany (1990–2006). *Sci. Total Environ.* 2020, 707, 136053. [CrossRef]

82. Sim, K.; Kim, Y.; Hashizume, M.; Gasparini, A.; Armstrong, B.; Sera, F.; Ng, C.F.S.; Honda, Y.; Chung, Y. Nonlinear Temperature-Suicide Association in Japan from 1972 to 2015: Its Heterogeneity and the Role of Climate, Demographic, and Socioeconomic Factors. *Environ. Int.* 2020, 142, 105829. [CrossRef]

83. Szyzszkowicz, M.; Willey, J.B.; Grafstein, E.; Rowe, B.H.; Colman, I. Air Pollution and Emergency Department Visits for Suicide Attempts in Vancouver, Canada. *Environ. Health Insights* 2010, 4, EHI.55662. [CrossRef]

84. Thilakaratne, R.A.; Malig, B.J.; Basu, R. Examining the Relationship between Ambient Carbon Monoxide, Nitrogen Dioxide, and Mental Health-Related Emergency Department Visits in California, USA. *Sci. Total Environ.* 2020, 746, 140915. [CrossRef]

85. Williams, M.N.; Hill, S.R.; Spicer, J. Do Hotter Temperatures Increase the Incidence of Self-Harm Hospitalisations? *Psyclchol. Health Med.* 2016, 21, 226–235. [CrossRef] [PubMed]

86. Yang, C.-Y.; Weng, Y.-H.; Chiu, Y.-W. Relationship between Ozone Air Pollution and Daily Suicide Mortality: A Time-Stratified Case-Crossover Study in Taipei. *J. Toxicol. Environ. Health Part A* 2019, 82, 261–267. [CrossRef]

87. Yarza, S.; Vodonom, A.; Hassan, L.; Shaley, H.; Novack, V.; Novack, L. Suicide Behavior and Meteorological Characteristics in Hot and Arid Climate. *Environ. Res.* 2020, 184, 109314. [CrossRef]

88. Zerbini, T.; Gianvecchio, V.A.P.; Regina, D.; Tsujimoto, T.; Ritter, V.; Singer, J.M. Suicides by Hanging and Its Association with Meteorological Conditions in São Paulo. *J. Forensic Leg. Med.* 2018, 53, 22–24. [CrossRef]

89. Ma, C.-J.; Kasahara, M.; Höller, R.; Kamiya, T. Characteristics of Single Particles Sampled in Japan during the Asian Dust-Storm Period. *Atmos. Environ.* 2001, 35, 2707–2714. [CrossRef]

90. Hodnebreg, Ø.; Solberg, S.; Stordal, F.; Svendby, T.M.; Simpson, D.; Gauss, M.; Hilboll, A.; Pfister, G.G.; Turquet, S.; Richter, A. Impact of Forest Fires, Biogenic Emissions and High Temperatures on the Elevated Eastern Mediterranean Ozone Levels during the Hot Summer of 2007. *Atmos. Chem. Phys.* 2012, 12, 8727–8750. [CrossRef]

91. Lelieveld, J.; Hadjinicolaou, P.; Kostopoulou, E.; Chenoweth, J.; El Maayar, M.; Giannakopoulos, C.; Hannides, C.; Lange, M.A.; Tanarhte, M.; Tyrlis, E.; et al. Climate Change and Impacts in the Eastern Mediterranean and the Middle East. *Clim. Chang.* 2012, 114, 667–687. [CrossRef] [PubMed]

92. Kim, S.E.; Lim, Y.-H.; Kim, H. Temperature Modifies the Association between Particulate Air Pollution and Mortality: A Multi-City Study in South Korea. *Sci. Total Environ.* 2015, 524–525, 376–383. [CrossRef]

93. Chen, K.; Wolf, K.; Breitner, S.; Gasparini, A.; Stafoggia, M.; Samoli, E.; Andersen, Z.J.; Bero-Bedada, G.; Bellander, T.; Hennig, F.; et al. Two-Way Effect Modifications of Air Pollution and Air Temperature on Total Natural and Cardiovascular Mortality in Eight European Urban Areas. *Environ. Int.* 2018, 116, 186–196. [CrossRef] [PubMed]

94. Lee, W.; Choi, H.M.; Kim, D.; Honda, Y.; Leon Guo, Y.-L.; Kim, H. Synergic Effect between High Temperature and Air Pollution on Mortality in Northeast Asia. *Environ. Res.* 2019, 178, 108735. [CrossRef] [PubMed]
95. Hajat, S.; Gasparrini, A. The Excess Winter Deaths Measure: Why Its Use Is Misleading for Public Health Understanding of Cold-Related Health Impacts. *Epidemiology* **2016**, *27*, 486–491. [CrossRef]

96. Buckley, J.P.; Samet, J.M.; Richardson, D.B. Commentary: Does Air Pollution Confound Studies of Temperature? *Epidemiology* **2014**, *25*, 242–245. [CrossRef] [PubMed]

97. Ji, M.; Cohane, D.S.; Bell, M.L. Meta-Analysis of the Association between Short-Term Exposure to Ambient Ozone and Respiratory Hospital Admissions. *Environ. Res. Lett.* **2011**, *6*, 024006. [CrossRef]

98. Aguglia, A.; Giacomini, G.; Montagna, E.; Amerio, A.; Escelsior, A.; Capello, M.; Cutroneo, L.; Ferretti, G.; Scafidi, D.; Costanza, A. Meteorological Variables and Suicidal Behavior: Air Pollution and Apparent Temperature Are Associated with High-Lethality Suicide Attempts and Male Gender. *Front. Psychiatry* **2021**, *12*, 224. [CrossRef] [PubMed]

99. Leung, A.; Chue, P.; Psych, M.R.C. Sex Differences in Schizophrenia, a Review of the Literature. *Acta Psychiatr. Scand.* **2000**, *101*, 3–38. [CrossRef] [PubMed]

100. Strüber, D.; Lück, M.; Roth, G. Sex, Aggression and Impulse Control: An Integrative Account. *Neurocase* **2008**, *14*, 93–121. [CrossRef] [PubMed]