Clinical Neuroscience Research, 2024, Volume 2, Issue 3
http://ojs.bbwpublisher.com/index.php/CNR
Online ISSN: 2981-8133

High Ambient Temperatures Increase Outpatient Visits for Sleep Disorders in Hefei City, China

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Abstract: *Objective*: To analyze the impact of ambient temperature on the quantity of outpatient clinic visits for sleep disorders. *Methods*: Using data from sleep disorder outpatient visits in a large tertiary hospital in Hefei City, a distributional lag nonlinear model combined with a generalized Poisson regression model was used to analyze the relationship between ambient temperature and the number of outpatient visits for sleep disorders. *Results*: Ambient temperatures above 17.2℃ were found to be connected with a higher prevalence of sleep disorders visits, and that this relationship was most significant on day 8, which lasted for 7 days. For the single-day lagged impact, the maximum relative risk (RR) for moderate heat (75th percentile) was 1.077 (95% CI: 1.015–1.143). The cumulative lag effect was substantially greater than the single-day lag effect, with a maximum relative risk (RR) of 2.609 (95% CI: 1.306–5.212). The longest lag time was 14 days. The RR was similarly greater in women and those over 40. Outpatient visits for men with sleep disorders were not affected by ambient temperature in a statistically significant way. *Conclusion*: High ambient temperature raises the risk that patients will visit an outpatient facility and serves as a risk factor for sleep disorders. Patients who were 40 years of age or older and women were at vulnerability.

Keywords: Ambient temperature; Sleep disorders; Time-series analysis

Online publication: September 30, 2024

1. Introduction

Sleep disorders are characterized by insufficient sleep, excessive sleep, or irregular movements during sleep. Sleep disorders affect 0.047% to 50.5% of the population, with insomnia being the most prevalent type, followed by sleep breathing disorders, restless legs syndrome, nightmares, sleepwalking, and narcolepsy [1]. Sleep disorders can alter immune mechanisms like neuroendocrine thermoregulation, leading to a pathological process [2–3]. It not only raises the risk of hypertension, diabetes, heart disease, dementia, and stroke, but it also has significant psychological and economic effects [4].

Sleep quality is closely connected to ambient temperature and humidity [5]. High ambient temperatures have a negative impact on sleep quality [6]. Ambient temperature was the most important element influencing sleep quality, with relative humidity and lighting having negligible effects [7]. The global temperature rise will exceed 1.5°C between 2030 and 2052, according to the Intergovernmental Panel on Climate Change, and weather extremes will become more violent and frequent [8]. It is imperative to assess the detrimental effects of ambient temperature on health and adopt effective healthcare initiatives and laws to prevent and lessen these effects in light of the constantly changing environment. As a result, this study will statistically examine the association between ambient temperature and outpatient visits of sleep disorders in Hefei City from 2018 to 2020 to analyze the influence of short-term temperature variations on population health.

2. Materials and methods

2.1. Study area

Hefei, Anhui Province in China, is set in eastern China and the western end of the Yangtze River Delta. It has four distinct seasons, a pleasant environment, and moderate rainfall.

2.2. Date collection

Between January 1, 2018, and December 31, 2020, the study gathered information on daily outpatient attendances for sleep disorders at three campuses of a sizable tertiary care hospital. The age, gender, and dwelling address were among the basic details. To clarify the diagnosis, sleep disorders were described using the International Classification of Diseases (ICD-10), and diagnostic information was documented by an outpatient electronic healthcare record system. Individuals who (1) did not know when their symptoms started, (2) did not have a fixed address or did not live in Hefei, (3) had a questionable diagnosis, and (4) were not sure of their gender or age, were not included in the study.

The Hefei Meteorological Bureau provided meteorological data from 1 January 2018 to 31 December 2020. Meteorological monitoring procedures have been implemented to meet Chinese surface meteorological observation criteria. The study collected the daily mean temperature (Tmean), relative humidity (RH), wind speed (WS), sunshine hours (SH), and precipitation from the Meteorological Bureau's statistics. By deducting the daily highest temperature from the daily minimum temperature, the diurnal temperature range (DTR) was obtained. The Hefei Environmental Monitoring Centre provided air pollution statistics for the same period.

2.3. Statistical analysis

This study utilized a generalized Poisson regression model together with a distributional lag nonlinear model (DLNM) to quantitatively examine the impacts of ambient temperature on sleep disorder outpatient attendances owing to the "over-dispersed" distribution of sleep disorder outpatients. After compiling the consultation and meteorological data with SPSS 25.0, statistical analysis was completed using R software (version 4.2.2). Using a two-sided test, $\alpha = 0.05$. Spearman correlation studies were conducted for meteorological elements and air pollutants to prevent multicollinearity between variables. Correlation coefficients greater than 0.6 were excluded from the model. The model included rainfall, PM2.5, DTR, and SO2. To evaluate degrees of freedom and model fit, the specific model was constructed using residual analysis and the Akaike Information Criterion (AIC):

$$Yt \sim \text{quasi-Poisson}(\mu_t)$$

$$\text{Log}(\mu t) = \alpha + \beta T_{meant,l,3} + ns(DTR_{t,l,3}) + ns(SO2_{t,l,3}) + ns(PM2.5_{t,l,3}) + ns(Rainfall_{t,l,3}) + ns(Timet,7) + \gamma Dow_t + \delta Holiday_t$$

t and l stand for the visitation date and lag days, respectively; On day t, Yt is the anticipated total number of outpatient appointments for sleep disorders; The mean temperature's DLNM cross-base function is $T_{meant,l}$; Log() represents the link function, and α indicates intercepting. The T_{mean} index coefficient is represented by β, while the Dow and Holiday matrices factors, each representing weekday and holiday effects, are represented by γ and δ, respectively. The natural cubic spline function is indicated by ns; and DTR_t, with three degrees of freedom, stands for the daily comparative difference on day t; ($DTR_{t,l,3}$), ($SO2_{t,l,3}$), ($PM2.5_{t,l,3}$), (Rainfall t,l,3) with a degree of freedom of 3. $Timet_7$ indicates the time tendency with seven degrees of freedom. The study examined the lagged effect from 1 to 14 days with a mod_t lag date of 14 days. The relative risk (RR) and 95% confidence interval (CI) were used to analyze the relationship between T_{mean} and sleep disorders outpatient visits.

Using the median corresponding temperature of 17.2°C as a reference, the relative risk (RR) of mild hyperthermia (75th percentile) was calculated for this investigation. Potential impacts of heat correction resulting from certain patient characteristics were analyzed by age group (0–40 years, ≥40 years), as well as sex (male and female). Additionally, the study performed many analyses of sensitivity and adjusted the rainfall (df = 3-5), and SO2 (df = 3-5).

3. Results

3.1. Descriptive statistics

Table 1 displays daily data from sleep disorder clinic visits along with air pollution and weather information. For sleep disorders, there were 2796 outpatient consultations in total during the study interval. There were 1736 cases of females (62%) and 71.6% of the population is ≥40 years of age.

Table 1. Statistical characteristics of outpatient visits for weather variables and sleep disorders in Hefei, 2018–2020

Group	Sum	(Mean ± SD)	Min	P5	P25	P50	P75	P95	Max
All visits	2796	2.55 ± 2.46	0	0	1	2	4	8	14
Male	1060	0.97 ± 1.14	0	0	0	1	2	3	6
Female	1736	1.58 ± 1.79	0	0	0	1	2	5	10
< 40years	793	0.72 ± 1.01	0	0	0	1	3	5	11
≥40years	2003	1.83 ± 1.96	0	0	0	0	1	3	7
T_{mean} (°C)	-	16.55 ± 9.42	-5.3	1.4	8.2	17.2	24.5	30	33.3
DTR (°C)	-	9.24 ± 4.57	0.6	2.2	5.7	9.1	12.5	17	21.5
RH (%)	-	78.56 ± 11.80	35	58	71	80	87	96.3	99
WS (m/s)	-	2. 12 ± 0.88	0.4	1.0	1.5	2.0	2.6	3.8	6.2
SH (h)	-	5.19 ± 4.30	0	0	0	5.7	9.1	11.5	12.9
Rainfall (mm)	-	3.29 ± 11.55	0	0	0	0	0.7	18. 1	197.4
PM2.5 ($\mu g/m^3$)	-	42.92 ± 27.97	5	13	24	35	53	103	184
NO_2 ($\mu g/m^3$)	-	40.69 ± 17.82	10	18	27	37	52	74	102
SO_2 ($\mu g/m^3$)	-	6.67 ± 3.02	2	3	5	6	8	13	27
O_3 ($\mu g/m^3$)	-	112.9 ± 49.64	6	39.6	74	110	146	197	255

3.2. Analysis of the correlation of significant environmental elements

Figure 1 depicts the Spearman's correlation between the major environmental elements that are associated with sleep disorders. The mean ambient temperature was inversely associated with WS, PM2.5, NO_2, and SO_2, but positively related to DTR, sunshine hours, and rainfall.

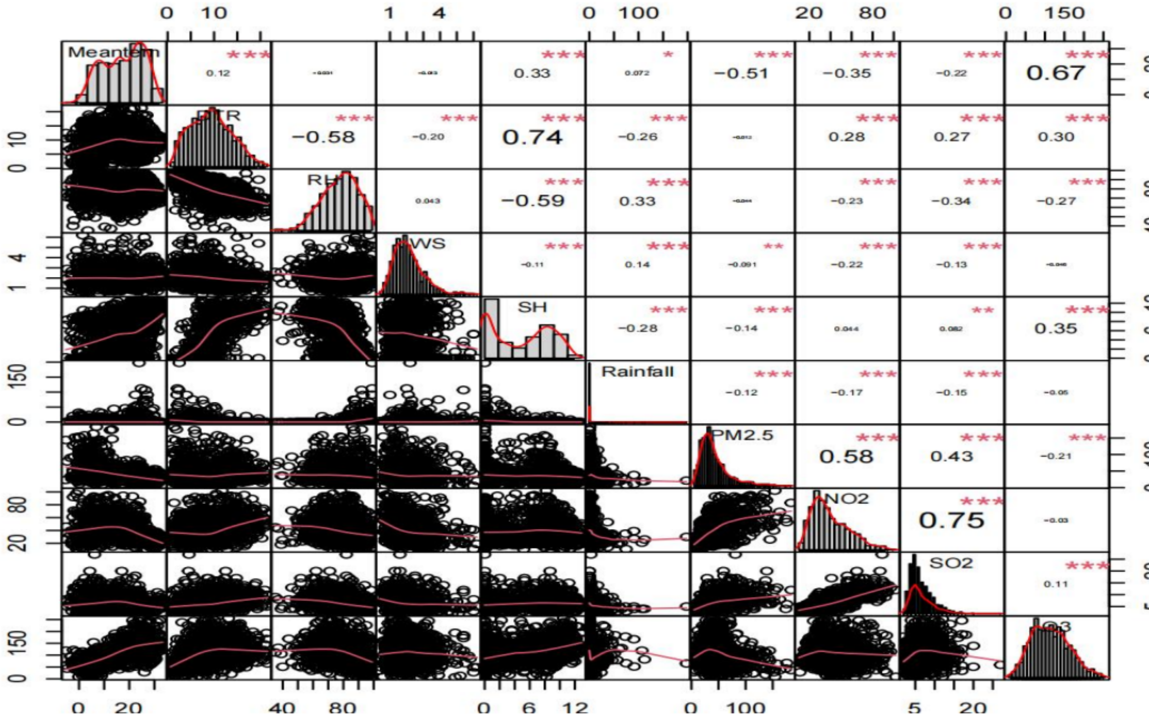

Figure 1. Shows the Spearman's correlation coefficients between main pollutants and meteorological conditions; *$P < 0.05$, with a scatterplot at the bottom and Spearman's correlation coefficients at the top

3.3. Mean temperature's effect on outpatient visits for sleep disorders

The entire exposure-response connection between mean temperature and sleep disorder clinic visits is depicted in **Figure 2**. The average temperature rose above 17.2℃, and a significant increase in patients visiting sleep disorder clinics occurred. It seems that lowering the temperature guards against insomnia. The delayed effect and the longest lag time of 14 days are shown in **Figure 2**.

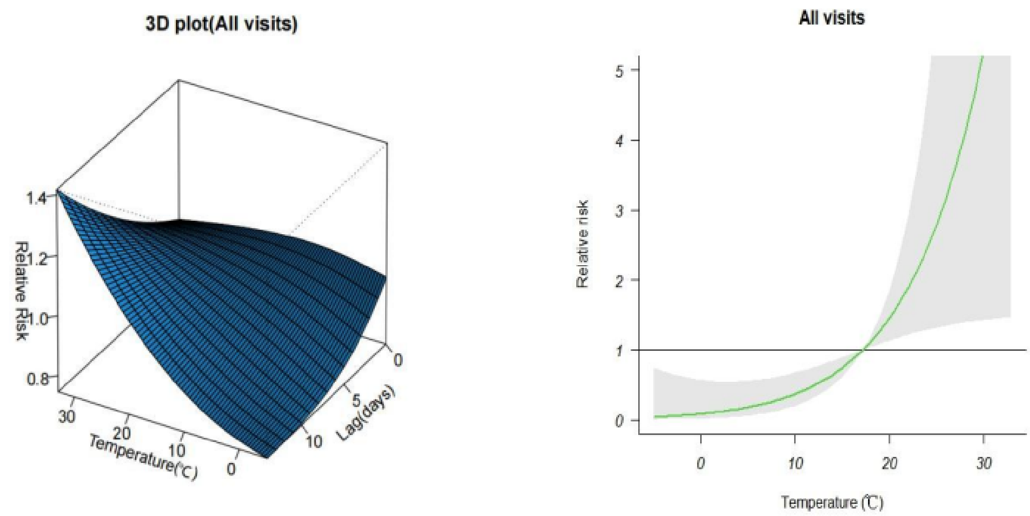

Figure 2. Exposure-response relationship between mean temperature and sleep disorder attendees in the Hefei

3.4. Lagged impacts of certain mean temperatures

Table 2 and **Table 3** (reference 17.2℃) present the single-day and cumulative lagged impacts of mean temperatures on outpatient visits related to sleep disorders. The impact of high temperatures on sleep disorder visits is significant. The impact of high temperatures on visits related to sleep disorders is noteworthy. The cumulative lag impact was substantially greater than the single-day lag impact, starting on day 12 with an RR of 1.943 (95% CI: 1.080–3.495) and lasting for 6 days to reach its maximum. The single-day lag influence started on the 8th day with an RR of 1.077 (95% CI: 1.015–1.143). The lagged impact for females began on the 8th day with an RR of 1.077 (95% CI: 1.002–1.158) and persisted for 6 days, whereas the cumulative lagged effect began on day 12 and lasted for 3 days, reaching a maximum with an RR of 2.937 (95% CI: 1.265–6.821). In men, the delayed effect began on day 11 and lasted for two days, with an RR of 1.105 (95% CI: 1.006–1.213). Age analysis revealed that the lag impact began on day 10 and continued only 3 days in patients <40 years with sleep difficulties, with an RR of 1.132 (95% CI: 1.001–1.280) and no significant cumulative lag impact. In contrast, patients older than 40 years had a lag effect that was comparable to that of the population in general (RR = 1.081, 95% CI: 1.009–1.158). Hypothermia dramatically reduced the probability of outpatient visits for sleep disturbances in women and people of ≥40 years. In men and the <40 years group, however, it was not statistically significant. The results are illustrated in **Figure 3**.

Table 2. The single-day lagged effect of high temperature on outpatient visits for sleep disorders, reference 17.2℃

Single-day (day(s))	Relative risk (95% confidence interval)				
	Total	**Male**	**Female**	**<40 years**	**≥40 years**
Lag0	0.979 (0.859– 1. 117)	0.929 (0.771– 1. 119)	1.011 (0.863– 1. 184)	0.961 (0.787– 1. 173)	0.983 (0.845– 1. 144)
Lag1	0.990 (0.901– 1.089)	0.949 (0.829– 1.086)	1.014 (0.905– 1. 137)	0.974 (0.843– 1. 125)	0.995 (0.891– 1. 110)
Lag2	1.001 (0.935– 1.073)	0.969 (0.879– 1.068)	1.018 (0.937 – 1. 107)	0.988 (0.890– 1. 109)	1.007 (0.929– 1.091)
Lag3	1.013 (0.956– 1.074)	0.987 (0.910– 1.072)	1.024 (0.954– 1.099)	1.001 (0.918– 1.093)	1.019 (0.952– 1.091)
Lag4	1.025 (0.966– 1.087)	1.005 (0.926– 1.091)	1.031 (0.960– 1. 108)	1.015 (0.930– 1. 108)	1.031 (0.962– 1. 105)
Lag5	1.037 (0.975– 1.004)	1.022 (0.937– 1. 114)	1.041 (0.964– 1. 123)	1.029 (0.938– 1. 129)	1.043 (0.970– 1. 122)
Lag6	1.050 (0.985– 1. 120)	1.037 (0.949– 1. 134)	1.051 (0.972– 1. 136)	1.044 (0.949– 1. 148)	1.056 (0.980– 1. 137)
Lag7	1.064 (0.999– 1. 132)	1.052 (0.964– 1. 149)	1.063 (0.985– 1. 148)	1.058 (0.963– 1. 162)	1.068 (0.993– 1. 149)
Lag8	1.077 (1.015– 1. 143)*	1.066 (0.980– 1. 160)	1.077 (1.002– 1. 158)*	1.072 (0.980– 1. 174)	1.081 (1.009– 1. 158)*
Lag9	1.091 (1.031– 1. 155)*	1.079 (0.995– 1. 171)	1.091 (1.019– 1. 169)*	1.087 (0.997– 1. 186)	1.093 (1.024– 1. 168)*
Lag10	1.037 (0.954-1. 126)*	1.092 (1.005– 1. 187)*	1. 107 (1.032– 1. 187)*	1. 102 (1.008– 1.205)*	1. 106 (1.035– 1. 183)*
Lag11	1. 120 (1.049– 1. 197)*	1. 105 (1.006– 1.213)*	1. 124 (1.037– 1.217)*	1. 117 (1.009– 1.236)*	1. 119 (1.037– 1.207)*
Lag12	1. 135 (1.048– 1.230)*	1. 117 (0.997– 1.250)	1. 141 (1.035– 1.258)*	1. 132 (1.001– 1.280)*	1. 132 (1.031– 1.243)*
Lag13	1. 151 (1.041– 1.272)*	1. 128 (0.981– 1.297)	1. 159 (1.026– 1.309)*	1. 147 (0.986– 1.336)	1. 145 (1.020– 1.286)*
Lag14	1. 166 (1.032– 1.318)*	1. 140 (0.962– 1.352)	1. 177 (1.014– 1.368)*	1. 163 (0.966– 1.400)	1. 159 (1.005– 1.336)*

*$P < 0.05$

Table 3. The cumulative lagged effect of high temperature on outpatient visits for sleep disorders, reference 17.2℃

Multi-day (day(s))	Relative risk (95% confidence interval)				
	Total	**Male**	**Female**	**<40 years**	**≥40 years**
Lag0-0	0.979 (0.859– 1. 117)	0.929 (0.771– 1. 119)	1.011 (0.863– 1. 184)	0.961 (0.787– 1. 173)	0.983 (0.845– 1. 144)
Lag0-1	0.970 (0.775– 1.215)	0.882 (0.641– 1.214)	1.026 (0.782– 1.345)	0.936 (0.665– 1.318)	0.978 (0.754– 1.269)
Lag0-2	0.972 (0.730– 1.296)	0.855 (0.568– 1.286)	1.045 (0.739 – 1.478)	0.925 (0.598– 1.432)	0.985 (0.707– 1.374)
Lag0-3	0.985 (0.709– 1.369)	0.845 (0.529– 1.347)	1.071 (0.720– 1.591)	0.927 (0.563– 1.527)	1.005 (0.687– 1.470)
Lag0-4	1.010 (0.706– 1.446)	0.849 (0.510– 1.413)	1. 105 (0.717– 1.703)	0.942 (0.547– 1.621)	1.036 (0.684– 1.571)
Lag0-5	1.049 (0.714– 1.540)	0.868 (0.504– 1.496)	1. 150 (0.722– 1.831)	0.970 (0.543– 1.733)	1.082 (0.692– 1.691)
Lag0-6	1. 102 (0.731– 1.662)	0.901 (0.504– 1.609)	1.210 (0.735– 1.991)	1.013 (0.546– 1.878)	1. 143 (0.708– 1.843)
Lag0-7	1. 173 (0.756– 1.818)	0.948 (0.511– 1.759)	1.287 (0.755–2. 193)	1.072 (0.555–2.069)	1.221 (0.732–2.036)
Lag0-8	1.264 (0.791–2.014)	1.012 (0.524– 1.951)	1.386 (0.784–2.450)	1. 150 (0.571–2.314)	1.320 (0.765–2.278)
Lag0-9	1.380 (0.839–2.267)	1.093 (0.544–2. 193)	1.514 (0.826–2.773)	1.251 (0596–2.626)	1.444 (0.809–2.578)
Lag0-10	1.526 (0.903–2.580)	1. 194 (0.572–2.493)	1.676 (0.884–3. 179)	1.379 (0.630–3.020)	1.599 (0.867–2.948)
Lag0-11	1.710 (0.983–2.977)	1.320 (0.606–2.871)	1.884 (0.959–3.702)	1.541 (0.673–3.527)	1.790 (0.939–3.413)
Lag0-12	1.943 (1.080–3.495)*	1.474 (0.646–3.363)	2. 151 (1.051–4.399)*	1.745 (0.724–4.208)	2.027 (1.023–4.015)*
Lag0-13	2.236 (1.190–4.202)*	1.664 (0.686–4.039)	2.494 (1.157–5.376)*	2.004 (0.776–5. 172)	2.323 (1.116–4.835)*
Lag0-14	2.609 (1.306–5.212)*	1.899 (0.718–5.023)	2.937 (1.265–6.821)*	2.332 (0.821–6.621)	2.693 (1.206–6.013)*

* $P < 0.05$

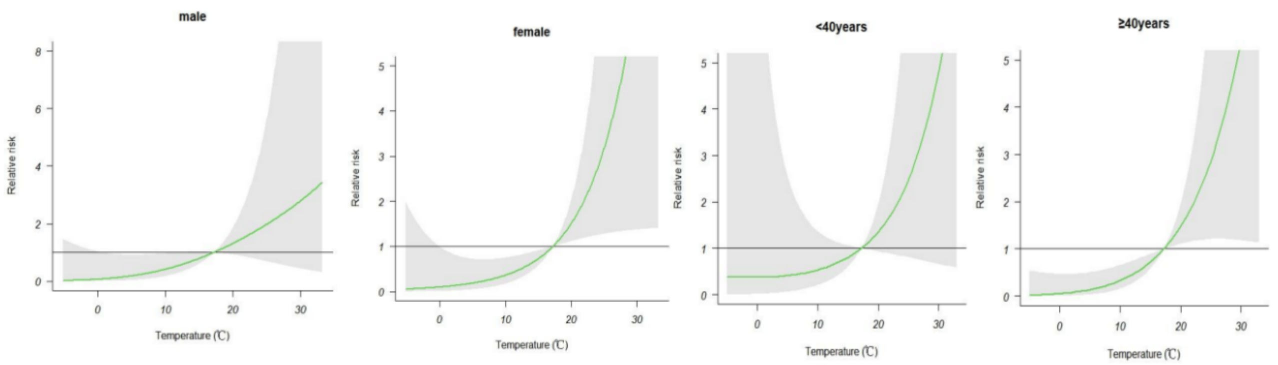

Figure 3. Exposure-response relationships between sleep disorders visit and mean temperature in a subgroup of patients, in Hefei City

3.5. Sensitivity analyses

The sensitivity analyses demonstrate that for the SO_2 (df = 3–5) and rainfall (df = 3–5), the exposure-response curves are consistent throughout degrees of freedom in the model. It indicates the stability of the model, as illustrated in **Figure 4** and **Figure 5**.

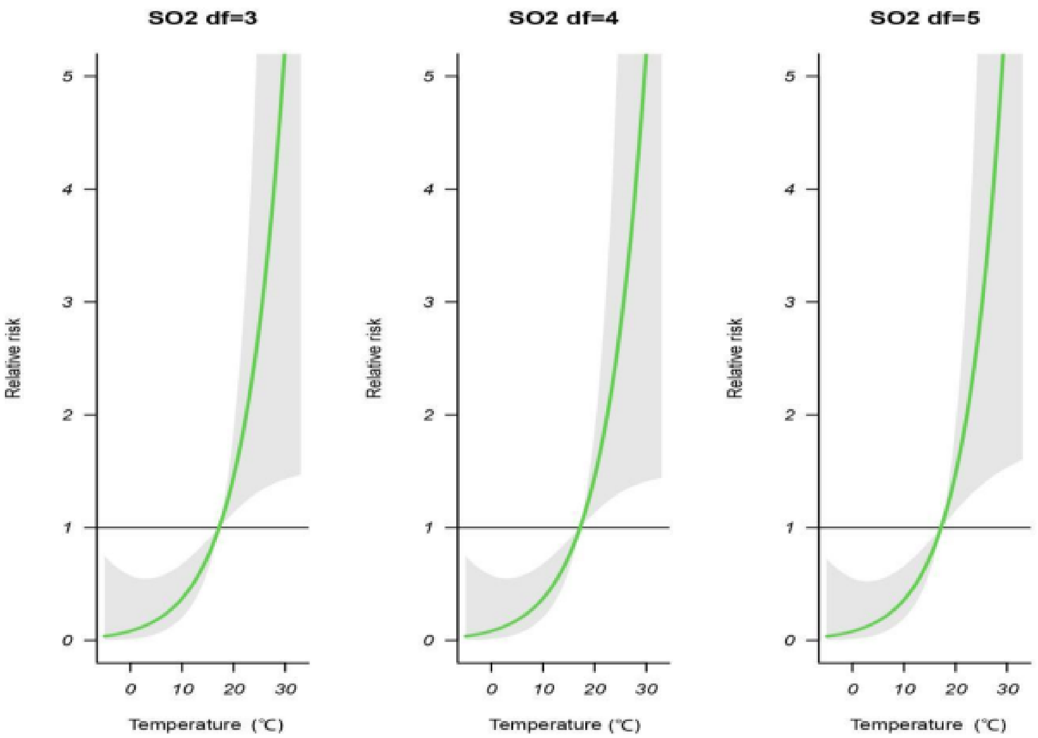

Figure 4. Sensitivity analysis when altering the degrees of freedom (df = 3–5) for SO_2 in the model

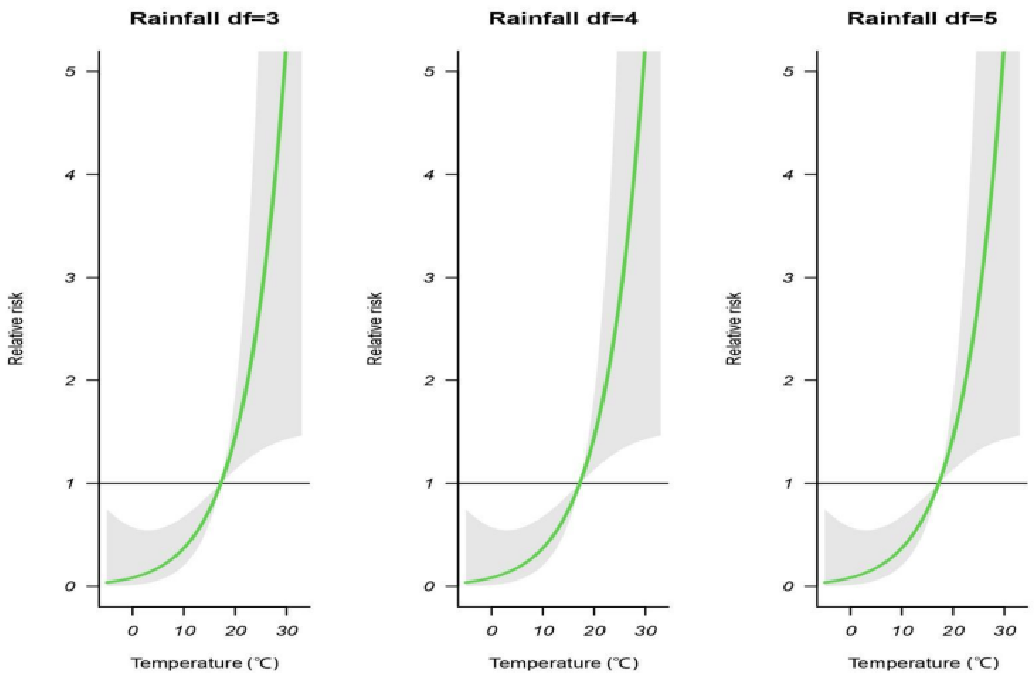

Figure 5. Sensitivity analysis when altering the degrees of freedom (df = 3–5) for rainfall in the model

4. Discussion

The research used a generalized Poisson regression model in conjunction with a distributional lag nonlinear model to examine the relationship between ambient temperature and sleep disorders. The study discovered a substantial positive relationship between the occurrence of outpatient visits for sleep disorders and ambient temperature above 17.2℃. This effect was significant starting at 8 days lag and lasting for 7 days. Low temperatures are protective against sleep disorders. The results show that elevated high temperature is associated with an increased risk of sleep disorders. Furthermore, the study discovered that women and people over the age of 40 were more vulnerable to the impacts of high temperatures.

A considerable amount of research supports the assumption that high temperatures are a favorable factor in the development of sleep disorders [9]. The prevalence of sleep deficit rises in high temperatures [10–11]. The precise mechanism by which temperature contributes to sleep disorders is unknown at this time, although the link seems biologically reasonable. The effects of direct exposure to hot surroundings during the day, such as heat stress, cardiovascular stress, or dehydration, may persist throughout the night [12]. As a result, being exposed to greater ambient temperatures may impair the body's capacity to regulate its own temperature and make falling asleep harder, leading to sleep disorders [13]. A 68-country research of ambient temperature on sleep measurements discovered that greater nighttime temperatures lowered sleep duration. This is congruent with the findings of the study, which discovered that high ambient temperatures increased outpatient visits for sleep disorders [14–16].

Based on age and gender, the research found differences in vulnerability to ambient temperature impacts on sleep disorders. High temperatures had a stronger impact on outpatient visits for sleep disturbances in people over 40 and women. A study conducted in the United States discovered a strong connection between overnight temperatures and sleep disorders, this correlation was most pronounced in the summer and among older adults and those with poor incomes [17]. Potential pathways include body skin temperature related to older persons and sleep outcomes, according to research conducted in Japan and China, with greater skin temperatures in older populations associated with poorer sleep quality [18]. Another study discovered that the higher the difference between daytime and nighttime temperatures, the greater the sleep loss, and the longer the cumulative lag impact of outside ambient temperature on sleep reduction, demonstrating that indoor environments might hold ambient heat and improve heat-related sleep deprivation [19]. As for gender differences, they might be connected to physiological elements (such as higher subcutaneous fat content, larger area of body surface-to-fat content ratios, and hormone adjustments) that make females more susceptible to high temperatures [20].

5. Conclusions

High ambient temperature may be a risk factor for sleep disorders, people ≥40 years, and women with sleep disorders are vulnerable to high ambient temperatures. When hot weather is forecast, vulnerable people should be reminded to take precautions as soon as possible and to remain watchful for 8 days after exposure. Furthermore, sleep problem clinics should boost physician scheduling during peak times to better allocate medical resources.

Disclosure statement

The authors declare no conflict of interest.

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