ARTICLE IN PRESS

Atmospheric Pollution Research xxx (xxxx) xxx

Contents lists available at ScienceDirect

Atmospheric Pollution Research

journal homepage: www.elsevier.com/locate/apr

Effects of outdoor air pollution on hospital admissions from cardiovascular diseases in the capital city of Mongolia

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A R T I C L E I N F O

Keywords:
Air pollution
Hospital admission
Cardiovascular disease
Stroke
Case-crossover
Mongolia

A B S T R A C T

Cardiovascular diseases (CVD) are one of the primary causes of morbidity worldwide, while ambient air pollution (AAP) is a major contributor to CVD. This study is the first study that aimed to compare the differences in AAP concentrations and acute effects on the risk of admissions from CVD, ischaemic heart diseases (IHD), and stroke before and after introducing the new type of coal briquette in Ulaanbaatar, Mongolia. We collected daily hospital admission records, air quality and meteorology data between January 1, 2016 and December 31, 2022. The relative risks (RRs) of cause-specific hospitalisations associated with daily concentrations of AAP were estimated by a time-stratified case-crossover analysis with conditional Poisson distributed lag models. Overall, acute exposure to the pollutants, except for O_3, was positively associated with an increased risk of all admissions. For each interquartile range (IQR) increase in $PM_{2.5}$, PM_{10}, SO_2, NO_2 and CO, the risk of CVD admissions increased by 0.5% (RR = 1.005; 95% CI: 0.998, 1.012) at lag0, 2.9% (RR = 1.029; 95% CI: 1.014, 1.044), 2.5% (RR = 1.025; 95% CI: 1.010, 1.040), 4.1% (RR = 1.041; 95% CI: 1.016, 1.068) and 0.3% (RR = 1.003; 95% CI: 0.995, 1.012) at lag01, respectively. Subgroup analyses showed greater risks of CVD admissions for women and people aged <65 years, in the cold season, and after the raw coal ban period. During the cold winter season, Ulaanbaatar's AAP levels remained higher than the World Health Organization's guidelines, regardless of consuming the new coal briquettes. Adopting alternative efficient methods to improve air quality and associated health outcomes is necessary.

1. Introduction

According to the Global Burden of Disease report, the morbidity rate of cardiovascular diseases (CVD) has increased from 271 million in 1990 to 523 million in 2019, resulting in 360 million disability-adjusted life years (DALYs) globally (Cohen et al., 2017). The World Health Organization (WHO) reported that CVDs, including ischemic heart diseases (IHD) and strokes, are one of the primary causes of morbidity and mortality worldwide, accounting for 17.9 million deaths, with over three-quarters of these fatalities occurring in low- and middle-income countries (LMICs) (WHO, 2021a; World Heart Federation, 2023). Meanwhile, ambient air pollution has emerged as a serious public health threat, responsible for 4.2 million premature deaths globally, 89% of which occurred in LMICs (WHO, 2019). Several epidemiological and systematic review studies have examined associations between short-term exposure to outdoor air pollution and the risk of hospital

Peer review under responsibility of Turkish National Committee for Air Pollution Research and Control.
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https://doi.org/10.1016/j.apr.2024.102338
Received 23 March 2024; Received in revised form 19 October 2024; Accepted 23 October 2024
Available online 28 October 2024

Please cite this article as: Nandin-Erdene Bayart et al., *Atmospheric Pollution Research,* https://doi.org/10.1016/j.apr.2024.102338

admissions from CVDs; some studies have found positive associations (Cai et al., 2018; Wu et al., 2022; Zhong et al., 2018), but others did not (Barnett et al., 2006; Xu et al., 2021). The existing body of research on the acute effects of air pollution on CVD hospitalisations has been mainly conducted in high-income nations, with limited research available from LMICs despite the significantly elevated levels of air pollution in these regions (Lee et al., 2020; Zou et al., 2021). Thus, scientific evidence from developing countries like Mongolia is needed due to its poor air quality, and differences in population characteristics, socioeconomic status, housing types and weather conditions.

The capital city of Mongolia, Ulaanbaatar (UB), is one of the most polluted cities in the world (ADB, 2022b), and during cold, windless days, particle pollutant levels could reach up to 1000 μg/m^3, which might be found in the underground mining environment (Warburton et al., 2018). On the other hand, CVD is the first leading cause of mortality and the third leading cause of morbidity (MDoH, 2022) in this country. Among CVD mortality, IHD and stroke were identified as the most common causes of death in Mongolia, accounting for 44% and 22.8%, respectively (MDoH, 2022). The Mongolian population reached 3.5 million in 2023; however, about 50% of the people reside in the capital city, with the majority of UB's residents living in traditional round-shaped houses known as "ger" (Warburton et al., 2018). During the cold winter season, these ger households consume raw or processed coal briquettes for cooking and heating purposes, using a traditional stove connected to chimneys without any pollution control devices, which releases significant amounts of pollutants into the surrounding air, causing the main source of outdoor air pollution in UB (Allen et al., 2013; Enkhbat et al., 2016; Enkhjargal et al., 2020). Another major source of the city's air pollution is related to three major coal-fired combined heat and power plants, which burn raw coal and supply central heating to the apartment buildings in UB (Huang et al., 2013; Jun 2021). Furthermore, the number of vehicles in UB has grown rapidly in recent years, with most of these vehicles being second-hand (more than ten years old), contributing a substantial amount of pollution (Barn et al., 2018; Huang et al., 2013).

In response to the urgent need, the Government of Mongolia has implemented several political and practical actions to reduce outdoor air pollution in UB, such as providing low-emission stoves, extending heating networks, and introducing new types of processed coal briquettes to the city's residents. Accordingly, on May 15, 2019, the Government of Mongolia banned raw coal consumption in the capital city, and any transportation of raw coal into the city has been prohibited (ADB, 2022a). To ensure its implementation, "Tavan Tolgoi Fuel" LLC, a government-owned fuel company, was established to manufacture and distribute refined coal briquettes to the ger households in the six central districts of the capital city since 2019. However, no study has been conducted to examine if this intervention has improved the air quality and any associated reduction in health outcomes such as CVD admissions or mortality, which has been associated with high levels of ambient air pollution elsewhere (Chen et al., 2018; Orellano et al., 2020; Stieb et al., 2020; Wu et al., 2022).

A few studies have been conducted to evaluate UB's ambient air pollution levels on respiratory and cardiovascular morbidity and mortality. A recent study (Enkhjargal et al., 2020) results showed that daily mean concentrations of $PM_{2.5}$, PM_{10}, SO_2, NO_2, O_3, and CO in UB were 85.7 μg/m^3, 182.7 μg/m^3, 24.6 μg/m^3, 45.4 μg/m^3, 29.4 μg/m^3 and 1.0 mg/m^3, which were significantly higher than the WHO Air Quality Guidelines. Another study conducted by Allen and colleagues found that ambient air pollution caused 29% of CVD mortality and 40% of lung cancer deaths, accounting for 10% of the all-cause mortality rate in UB, Mongolia (Allen et al., 2013). Enkhjargal et al., reported positive associations between ambient air pollution and CVD admissions in the cold season (using data from 2008 to 2017). However, these study findings have been inconsistent, and the data analysis methods were not clearly explained. Moreover, to the best of our knowledge, no study has been conducted to assess the impacts of the new type of coal briquettes on air quality and its effects on CVD morbidity in UB. The main purposes of this study were therefore a) to compare outdoor air pollution levels before and after consuming the new type of coal briquettes; b) to assess the acute effects of ambient air pollution on hospital admissions from CVD, IHD and stroke in the capital city of Mongolia and compare before and after the raw coal ban.

2. Methods

2.1. Study area and population

The study areas are shown in Fig. 1. Mongolia is located between Russia and China, and is classified as a lower-middle-income country based on the World Bank's Country Classification by income level (World Bank, 2023). The capital city spans a total land area of 4704 square km and is situated in the Tuul River valley at an elevation of approximately 1300 m from sea level, surrounded by four big mountains. UB has nine districts; however, due to the availability of substantial datasets, health data from the nine public hospitals and air quality data from the seven monitoring stations in the six central districts – Bayangol (BGD), Bayanzurkh (BZD), Khan-Uul (HUD), Sukhbaatar (SBD), Chingeltei (CHD), and Songinokhairkhan (SHD) were utilised in our study. Therefore, the traditional household areas, three major coal-fired power plants, and the main roads were identified as the primary sources of outdoor air pollution in the city (Fig. 1).

2.2. Air pollution and meteorological data

In our study, daily mean concentrations of six criteria air pollutants and meteorological data were collected between January 1, 2016 and December 31, 2022 from the National Centre for Environmental Monitoring in UB. The six criteria air pollutants included particulate matter ≤2.5 μm ($PM_{2.5}$) and ≤10 μm (PM_{10}) in diameter, sulphur dioxide (SO_2), nitrogen dioxide (NO_2), ozone (O_3) in micrograms per cubic meter (μg/m^3) and carbon monoxide (CO) in milligram per cubic meter (mg/m^3) as the indicators of air quality suggested by the WHO (WHO, 2021b). There are 15 air quality monitoring stations in UB, but our research used air quality data from seven stations, which had less than 25% of missing data. Daily (24-h) mean concentrations of $PM_{2.5}$, PM_{10}, SO_2, NO_2 and 8-h mean concentrations of CO and O_3 across the monitoring stations were employed. Daily mean atmospheric temperature and relative humidity were gathered from the selected monitoring stations (Fig. 1).

2.3. Hospital admission data

The hospital admission data from all-cause and cause-specific records between January 1, 2016 and December 31, 2022 were obtained from the National Centre for Health Development at the Ministry of Health in UB, Mongolia. A total of nine public hospitals, which included six secondary and three tertiary level, provided the required health data for this study (Fig. 1). Each patient record includes a national identity card number, age, gender, date of birth, dates of admission and discharge, main cause of hospitalisation, home address and name of the hospital. The hospitalisation data were classified based on the International Statistical Classification of Diseases and Related Health Problems 10th Revision (ICD-10) coding (WHO, 2016). We aggregated the number of cases of inpatients admitted on the same day and used the aggregated daily time series of the cases in the analysis. The primary outcomes included daily hospital admissions from all-cause (ICD10: A00-Z99), CVDs (ICD10: I00-I99), IHDs (ICD10: I20-I25) and cerebrovascular diseases, defined as total strokes (ICD10: I60-I69). These nine public hospitals provide reliable diagnoses based on medical examinations, pathology test results, and computed tomography or magnetic resonance imaging. This study was approved by the Human Research Ethics Committee of Curtin University (Approval No: HRE2021-0062) and classified as a low-risk study.

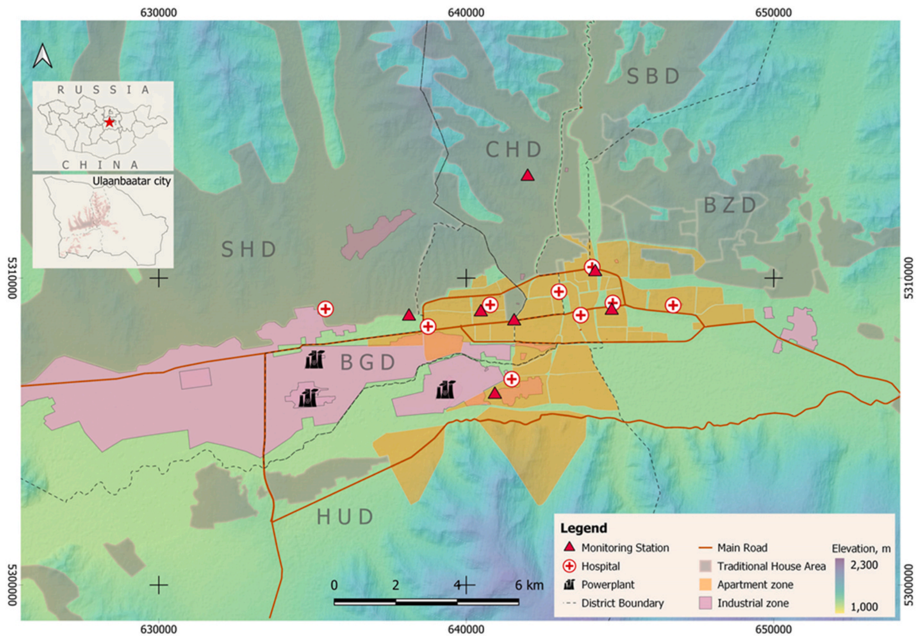


Fig. 1. Study area map of Ulaanbaatar city, Mongolia (air quality monitoring stations, nine hospitals in the six central districts and other areas).

2.4. Statistical analysis

In this study, a time-stratified case-crossover analysis was conducted to estimate the effect of air pollution for five preceding days (including the day of admission) on hospital admissions from CVD, IHD and stroke. In the case-crossover design, aggregated daily counts of hospital admissions were time-stratified by matching case and control days. The date of admission was defined as the case day and compared with control days as the same day of the week (DOW) in the same month of the same year. A conditional Poisson model was applied because it gave more precise confidence intervals compared to the quasi-Poisson regression in our preliminary analysis. The conditional Poisson regression incorporating distributed lag model (DLM) was used to estimate the exposure-lag response association between air pollution exposure and cause-specific hospital admissions. The DLM model allowed us to simultaneously model linear exposure-response relationships and account for the delayed (lagged) effects of the air pollutants through a flexible 'cross-basis' function to describe exposure-lag-response associations (Gasparrini et al., 2010). The modelling framework was specified as follows:

$$\log\,[E(Y_t)] = \alpha + cb(AP) + ns(Temp, 3dfs) + ns(RH, 3dfs), eliminate = factor(stratum)$$

where α is the intercept; $[EY_t]$ is the observed number of daily hospital admission counts at day t; *cb (AP)* is the cross-basis function specified using R package 'dlnm' (Gasparrini, 2011) for daily air pollution exposure level; *ns()* is the natural cubic splines for nonlinear variable adjustment of meteorological factors, including temperature *(Temp)* and relative humidity *(RH)*; *dfs* represent the degrees of freedom. To construct the *cb(AP)*, an optimal 3dfs for the lag scale of all pollutants were selected based on minimum Akaike Information Criterion (AIC) after varying 2–7 dfs and using a maximum lag of 5 days (Gasparrini, 2011; Gasparrini et al., 2010). Similarly, the 3dfs for the non-linear adjustment of *Temp* and *RH* were chosen based on the minimum AIC. The conditional factor variable *stratum* specified the same DOW in the same month of the same year (defined as interaction terms among the variables DOW, month, and year) to effectively control for the influence of the DOW, seasonal and long-term trends (Armstrong et al., 2014; Mostofsky et al., 2018). Single-pollutant conditional Poisson regressions were performed using the R package 'gnm' (Turner and Firth, 2007) and the eliminate function was applied to include the *stratum* factor variable (Armstrong et al., 2014). To minimize inaccurate results caused by collinearity in single-lag estimates in distributed lag models, we applied cumulative effect estimates rather than individual lag days (Basagaña and Barrera-Gómez, 2022).

The relative risk (RR) and 95% confidence intervals (CI) of hospital admissions from CVD, IHD and stroke were estimated as per interquartile range (IQR) increase in all pollutants (53.5 μg/m^3 for $PM_{2.5}$, 78.0 μg/m^3 for PM_{10}, 47.7 μg/m^3 for SO_2, 28.9 μg/m^3 for NO_2, 1.3 mg/m^3 for CO and 19.5 μg/m^3 for O_3). Subgroup analyses were performed by age (<65 years vs. ≥65 years), sex (male vs. female), two seasons (Kim et al., 2021; Liu et al., 2024), and before/after the periods of the raw coal ban. The two seasons were defined as warm (April–September) and cold season (October–March) based on weather conditions and coal consumption for heating and cooking purposes in UB, Mongolia. We also included lag effects in the model because the effects of air pollutants might be delayed (Orellano et al., 2020). We evaluated the immediate (same day: Lag0) and delayed (up to 5 days: Lag01-Lag05) effects of air pollution on cause-specific hospital admissions for overall and all subgroups. All analyses were performed with the R statistical software program (version 4.1.1) (R., 2021). The results were reported and interpreted without consideration of arbitrary P-value threshold or statistical significance following the recent recommendations by the American Statistical Association (Wasserstein et al., 2019).

3. Results

A total of 861,995 people were hospitalised during the study period, of which 151,644 (17.6%) patients were admitted due to CVDs. The average age for CVD patients was 59.4 (SD 14.1) years, and the length of hospital stay was 7.2 (SD 2.5) days. There were 55.8% female patients diagnosed with CVDs and 64.4% of patients aged <65 years. Of those, 36,918 (24.3%) patients with an average age of 59.0 (SD 12.8) years were admitted due to stroke, while 34,742 (22.9%) patients were admitted from IHD, with an average age of 61.7 (SD 13.3) years. More than half of the patients were female diagnosed with CVD and stroke, but 50.7% of male patients admitted to the hospitals were due to IHD. Among CVDs, there was a higher number of hospitalisations during the cold season, and more patients were hospitalised after the raw coal ban

Table 1
Demographic characteristics of cause-specific hospitalisations in Ulaanbaatar, Mongolia (2016–2022).

Characteristics		CVD	Stroke	IHD
		N (%)	N (%)	N (%)
		151,644 (100)	36,918 (24.3)	34,742 (22.9)
Age in years, mean (SD)		59.4 (14.1)	59.0 (12.8)	61.7 (13.3)
Length of stay, mean (SD)		7.2 (2.5)	7.6 (3.2)	6.8 (2.5)
Age subgroup	<65	97,595 (64.4)	24,878 (67.4)	20,437 (58.9)
	≥65	54,049 (35.6)	12,040 (32.6)	14,287 (41.1)
Sex	Female	84,603 (55.8)	19,319 (52.3)	17,125 (49.3)
	Male	67,041 (44.2)	17,599 (47.7)	17,599 (50.7)
Season	Warm (Apr–Sep)	72,843 (48)	17,841 (48.3)	16,999 (49.0)
	Cold (Oct–Mar)	78,801 (52)	19,077 (51.7)	17,725 (51.0)
The raw coal ban	Before	74,306 (49.0)	18,016 (48.8)	16,155 (46.5)
	After	77,338 (51.0)	18,902 (51.2)	18,587 (53.5)

Abbreviations: SD, standard deviation; Apr–April; Sep–September; Oct–October; Mar–March.

(Table 1).

The annual mean (SD) concentrations of $PM_{2.5}$, PM_{10}, SO_2, NO_2, CO and O_3 were 52.2 (57.8) μg/m^3, 118.1 (71.8) μg/m^3, 41.0 (51.7) μg/m^3, 51.4 (22.5) μg/m^3, 1.3 (1.1) mg/m^3 and 29.4 (14.8) μg/m^3, respectively. During the study period, UB's daily mean temperature and relative humidity were 0.9^{0}C (ranging from −30.4^{0}C to 29.3^{0}C) and 53.0% (11.4%–85.0%), respectively. On average, the cold season (October–March) had higher air pollutant levels, lower temperatures, and higher relative humidity than the warm season (Table 2).

Fig. 2 shows the comparison of daily mean concentrations of air pollutants during the study period. After consuming the new coal briquettes, there was a decline in the daily concentrations of $PM_{2.5}$ and PM_{10} during the cold season. For instance, the highest concentration of daily $PM_{2.5}$ was 527.0 μg/m^3 before the raw coal ban, which declined to 286.3 μg/m^3 after using the new coal briquettes. For PM_{10}, the daily mean concentrations of the pollutant decreased after banning raw coal consumption; however, its levels rose again in 2021 and then fluctuated in 2022. In contrast, SO_2 concentrations increased two-to three-fold after using the new types of coal briquettes, and its concentration peaked highest (387.7 μg/m^3) in 2021. The daily mean concentrations of CO began to rise in 2020 and peaked in January 2022 (27.2 mg/m^3), which was 4.1 times higher than the peak concentration before the raw coal ban (6.2 mg/m^3). The daily mean concentrations of O_3 declined marginally and remained lower than the WHO Air Quality guideline limit of 100 μg/m^3 throughout the study period. Overall, after consuming the new types of coal briquettes, outdoor air pollutants in UB, except O_3, remained considerably higher compared to the WHO Air Quality Guidelines and the Mongolian Air Quality Standards, particularly during the cold season (MASM, 2021; WHO, 2021b).

The levels of $PM_{2.5}$, PM_{10}, SO_2, NO_2 and CO were positively correlated with each other (correlation coefficient = 0.45–0.87, P-value <0.05), while O_3 was negatively correlated with other pollutants. The correlation between $PM_{2.5}$ and PM_{10} was the strongest, with a Spearman correlation coefficient of 0.87, followed by the correlation between SO_2 versus CO and NO_2 versus CO. Most pollutants, except O_3, showed negative correlations with daily average temperature; however, the correlations were negligible between air pollutants and relative humidity (Table S1).

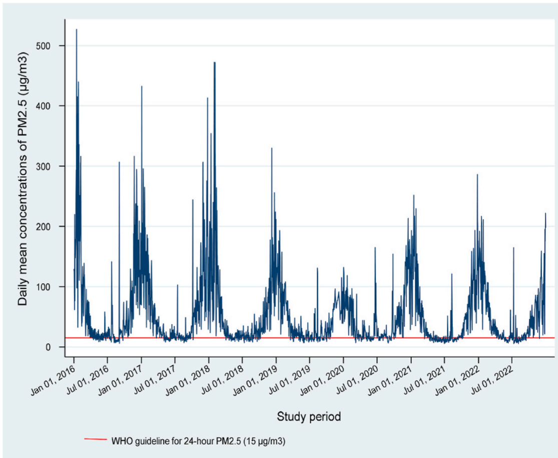
The adjusted and unadjusted RRs of air pollution on hospital admissions from CVD, IHD and stroke in cumulative lag days are shown in Table 3 and Table S2. The risk of these three CVD admissions was positively associated with all pollutants except O_3. The highest RRs of air pollution on CVD, IHD and stroke hospitalisations occurred on the same day (Lag0) for $PM_{2.5}$ and CO, whereas PM_{10}, SO_2 and NO_2 were at the two-day average (Lag01). For each IQR increase in $PM_{2.5}$, PM_{10}, SO_2, NO_2 and CO, the risk of CVD admissions increased by 0.5 % (RR = 1.005; 95% CI: 0.998, 1.012), 2.9 % (RR = 1.029; 95% CI: 1.014, 1.044), 2.5 % (RR = 1.025; 95% CI: 1.010, 1.040), 4.1 % (RR = 1.041; 95% CI: 1.016, 1.068) and 0.3 % (RR = 1.003; 95% CI: 0.995, 1.012), respectively. The RRs of stroke admissions increased by 1.4 % (RR = 1.014; 95% CI: 1.000, 1.028), 4.6 % (RR = 1.046; 95% CI: 1.015, 1.078), 5.3 % (RR = 1.053; 95% CI: 1.021, 1.085), 10.8 % (RR = 1.108; 95% CI: 1.053, 1.167) and 1.1 % (RR = 1.011; 95% CI: 0.991, 1.031) for each IQR increase in $PM_{2.5}$, PM_{10}, SO_2, NO_2 and CO, respectively. For each IQR increase in $PM_{2.5}$, PM_{10}, SO_2, NO_2 and CO, the RRs of IHD admissions increased by 0.8 % (RR = 1.008; 95% CI: 0.994, 1.022), 1.0 % (RR = 1.010; 95% CI: 0.980, 1.041), 3.0 % (RR = 1.030; 95% CI: 1.000, 1.060), 1.7 % (RR = 1.017; 95% CI: 0.968, 1.069) and 0.2 % (RR = 1.002 95% CI: 0.985, 1.019), respectively. Evidence of associations was observed between all pollutants, except for O_3, and hospital admissions only for CVD and stroke (Fig. 3 and Fig. S1; Table S3).

Subgroup analyses of CVD admissions associated with the air pollutants for Lag01 is shown in Table 4. When comparing the subgroups, women had a greater risk of CVD hospitalisations compared to men, and those under the age of 65 had a higher risk than those aged 65 and older. Comparing the two seasons, the RRs of air pollutants on CVD admissions were higher in the cold season compared to the warm season, except for O_3. When comparing these two different types of coal consumption, the RRs of CVD admissions associated with gaseous pollutants, including NO_2, SO_2 and CO, were higher after using the new coal briquettes (Table 4).

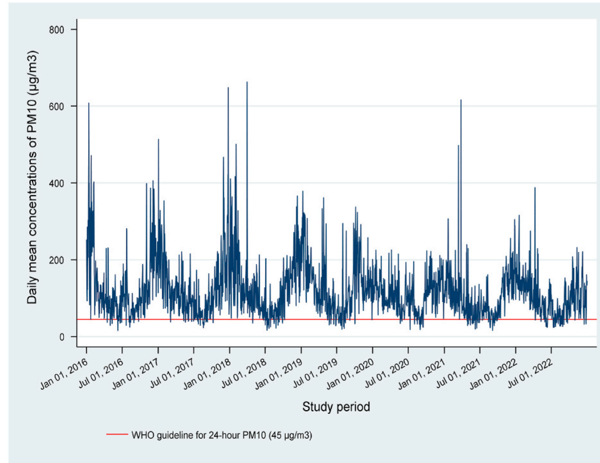
Table 2
Summary statistics[b] of air pollutant concentrations and meteorological factors in Ulaanbaatar, Mongolia (2016–2022).

Variables	Mean	SD	Min	Percentile			IQR	Max
				P25	P50	P75		
$PM_{2.5}$ (μg/m^3)[c]	52.2	57.8	5.5	16.0	27.7	69.5	53.5	527.0
PM_{10} (μg/m^3)[c]	118.1	71.8	16	69.2	101.3	147.2	78	663.2
SO_2 (μg/m^3)[c]	41.0	51.7	1.0	7.7	19.8	55.3	47.7	387.7
NO_2 (μg/m^3)[c]	51.4	22.5	11.9	35.6	46.2	64.5	28.9	309.0
CO (μg/m^3)[a]	1.3	1.1	0.2	0.5	0.9	1.8	1.3	27.2
O_3 (mg/m^3)[a]	29.4	14.8	3.0	18.5	27.5	38.0	19.5	89.0
Temperature (^{0}C)[c]	0.9	14.4	−30.4	−12.6	2.6	13.9	26.6	29.3
Relative humidity (%)[c]	53.2	13.3	11.4	44.3	55.6	63.6	19.4	85.0

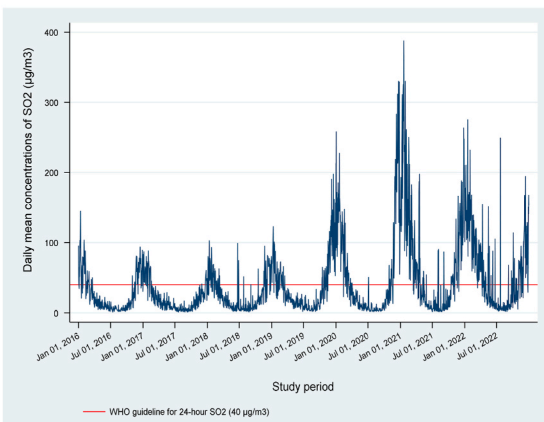
[a] 8-h average concentration.
[b] Statistics were generated from daily (24-h) mean levels of air pollutants from seven monitoring stations; Abbreviations: IQR, interquartile range = P75-P25.
[c] 24-h average concentration.



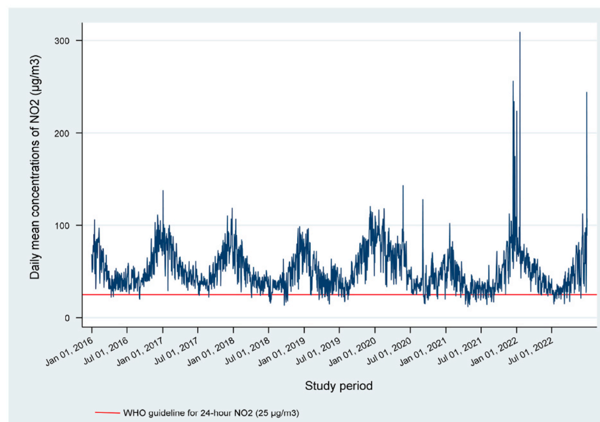
($PM_{2.5}$)



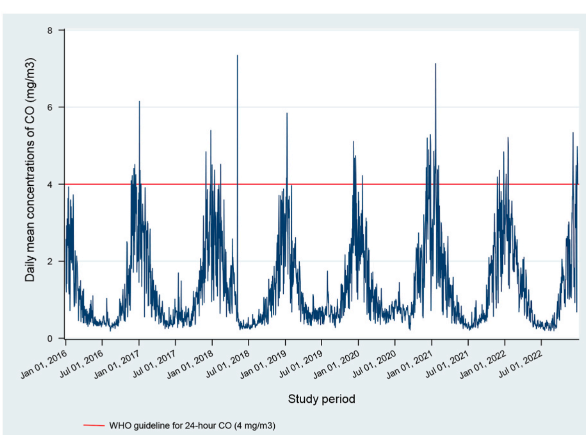
(PM_{10})



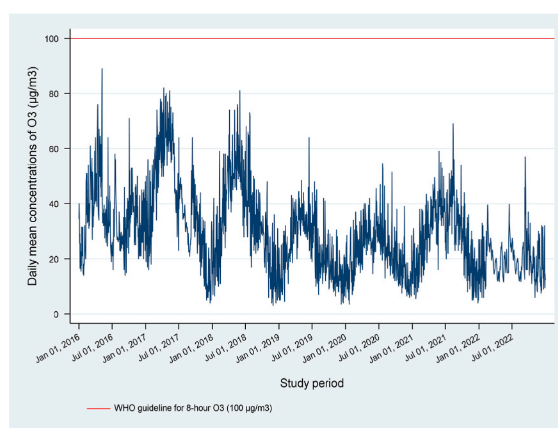
(SO_2)



(NO_2)



(CO)



(O_3)

Fig. 2. Daily mean concentrations of ambient air pollutants compared with the WHO guidelines (2016–2022).

4. Discussion

To the best of our knowledge, this is the first study that provides a pioneering effort in assessing the effects of outdoor air pollution on CVD, IHD and stroke hospitalizations before and after raw coal was banned by introducing a new type of coal briquettes in the capital city of Mongolia. Following the adoption of new coal briquettes since May 2019, there was a reduction in daily particle concentrations, yet gaseous pollutants experienced an upward trend, excluding O_3. Notably, these pollutant levels consistently exceeded both the WHO Air Quality Guidelines (WHO, 2021b) and the Mongolian National Standard levels (MASM, 2021), especially during the cold winter season. Overall, our study found

Table 3
Adjusted RRs of CVD, IHD and stroke admissions associated with air pollutants per IQR increase at Lag0-Lag01 in single pollutant models.

	RR (95% CI) for $PM_{2.5}$	RR (95% CI) for PM_{10}	RR (95% CI) for SO_2	RR (95% CI) for NO_2	RR (95% CI) for CO	RR (95% CI) for O_3
CVD admissions						
Lag0	1.005 (0.998, 1.012)	1.023 (1.012, 1.033)	1.022 (1.011, 1.033)	1.037 (1.018, 1.055)	1.003 (0.995, 1.012)	0.958 (0.942, 0.975)
Lag01	1.000 (0.991, 1.010)	1.029 (1.014, 1.044)	1.025 (1.010, 1.040)	1.041 (1.016, 1.068)	0.998 (0.986, 1.011)	0.944 (0.922, 0.966)
Stroke admissions						
Lag0	1.014 (1.000, 1.028)	1.031 (1.009, 1.054)	1.041 (1.019, 1.064)	1.076 (1.038, 1.116)	1.011 (0.991, 1.031)	0.932 (0.900, 0.966)
Lag01	1.012 (0.993, 1.032)	1.046 (1.015, 1.078)	1.053 (1.021, 1.085)	1.108 (1.053, 1.167)	1.006 (0.979, 1.033)	0.911 (0.868, 0.956)
IHD admissions						
Lag0	1.008 (0.994, 1.022)	1.008 (0.986, 1.030)	1.021 (1.001, 1.041)	1.014 (0.979, 1.050)	1.002 (0.985, 1.019)	0.932 (0.900, 0.966)
Lag01	1.004 (0.985, 1.024)	1.010 (0.980, 1.041)	1.030 (1.000, 1.060)	1.017 (0.968, 1.069)	0.982 (0.958, 1.007)	0.911 (0.868, 0.956)

that transient increases in $PM_{2.5}$, PM_{10}, SO_2, NO_2 and CO were positively associated with an increased risk of hospital admissions from CVD, stroke and IHD. Although with small magnitudes, evidence of associations without null in the confidence intervals was observed between all pollutants, except O_3, and hospitalisations only for CVD and total stroke. Three pollutants (PM_{10}, SO_2 and NO_2) consistently showed positive associations with the health outcomes investigated, and NO_2 particularly showed the most elevated effects on all admissions and strongest for stroke.

A time-series study on 309,561 CVD admission cases from China reported that the RRs of CVD admissions were increased by 0.1 % (RR = 1.001; 95% CI: 1.000, 1.002), 0.3 % (RR = 1.003; 95% CI: 1.001, 1.006) and 0.4 % (RR = 1.004; 95% CI: 1.002, 1.006) when $PM_{2.5}$, SO_2, and NO_2 concentrations were increased by 10 μg/m^3, respectively (Yu et al., 2024). Another time-series study conducted in China revealed that an increase of 10 μg/m^3 in $PM_{2.5}$ and PM_{10} concentrations resulted in RRs by 0.3 % (RR = 1.003; 95% CI: 1.001, 1.004) and 0.6 % (RR = 1.006; 95% CI: 1.005, 1.007) for IHD admissions, respectively (Xu et al., 2017). According to the findings of a systematic review and meta-analysis, the odds ratios (OR) for hospital admissions related to stroke were increased by 0.8 % (RR = 1.008; 95% CI: 1.005, 1.0011), 0.4 % (RR = 1.004; 95% CI: 1.001, 1.006), 1.3 % (RR = 1.013; 95% CI: 1.007, 1.020) and 2.3 % (RR = 1.023; 95% CI: 1.015, 1.030) per 10 μg/m^3 increase in $PM_{2.5}$, PM_{10}, SO_2, and NO_2, respectively (Niu et al., 2021). These findings are similar to our study and prior research undertaken in both developed and developing countries, including the USA, Australia, Vietnam and Thailand (Danesh Yazdi et al., 2022; Hasnain et al., 2023; Nhung et al., 2020; Phosri et al., 2019). Biological mechanisms linking air pollution to cardiovascular illnesses include changes in heart rate, increased oxidative stress, blood coagulation, and the development of thrombosis (Routledge et al., 2006). However, further animal and clinical research is required to explore the biological mechanisms associated with the adverse health effects of air pollution.

In subgroup analysis, the risk of CVD hospital admissions was larger in women than men, higher in people aged <65 years than those aged ≥65 and greater in the cold season (October–March) than in the warm season (April–September). There was a notifiable difference between the two periods of coal consumption, with processed coal briquettes having a greater relative risk of total CVD admissions linked with PM_{10}, NO_2, SO_2 and CO exposures compared to raw coal burning. However, the higher number of hospital admissions might be associated with the COVID-19 pandemic, so further studies need to investigate the association between CVD hospitalisations and air pollution during this period. A stronger association among females than males aligns with the prior research results (Dahlquist et al., 2023; Nuvolone et al., 2011); however, this finding contradicted the earlier study conducted in Mongolia (Enkhjargal et al., 2020). According to the seasonal pattern, the highest incidence of CVD admissions occurred during the cold season, which is consistent with the previous study undertaken in Mongolia (Enkhjargal et al., 2020) and other countries (Ballester et al., 2001; Xu et al., 2017). The RRs of outdoor air pollution on total CVD admissions were greater in the young age group (<65 years) than those aged ≥65 years, which was consistent with the findings of previous research (Chuang et al., 2007). Therefore, our recent study on the relationship between air pollution and CVD mortality observed the opposite: a higher risk of death occurred for males and in the elderly (≥65 years) (Bayart et al., 2024). One potential explanation for these discrepancies could be related to the unrestricted access to public hospitals in Mongolia, including secondary and tertiary-level clinics, without the need for referral letters (Bayarsaikhan et al., 2015), which may cause unnecessary hospitalisations among women and younger adults. Another possible reason might be that the primary source of outdoor air pollution in the capital city of Mongolia is traditional houses, where women are more likely to be exposed to air pollution while burning raw or processed coal for cooking and heating. Other possible reasons might be that younger people (<65 years) go to work every day and spend more time outside. As a result, they are more exposed to outdoor air pollution than older people, who are retired and spend the majority of their time inside.

There are some limitations in this research. The study employed secondary data from air quality monitoring stations in UB, which may not be representative of personal exposures. It may lead to misclassification of personal exposure and underestimation of the effects of outdoor air pollution on the general population. While this cannot eliminate the problem completely, the use of satellite-derived space-time varying exposure assessment could reduce exposure misclassification. Furthermore, the majority of UB's ambient air quality monitoring stations were set up in less polluted areas, which might not accurately represent the actual air pollution of the traditional household suburbs and the industrial areas. In this study, we linked pollutant concentrations to CVD, IHD and stroke events based on the date of hospitalisation rather than the date of onset, which could result in a non-differential error in exposure measurement (Goldman et al., 2011). Future research could enhance its accuracy and representativeness by incorporating primary data related to individual exposure to outdoor air pollution or air quality data obtained from the extremely polluted areas in UB.

This study also has several strengths. It is the first and, as of right now, the only study carried out in Mongolia to evaluate the outdoor air quality and the relationship with CVD hospital admissions before and after the consumption of new coal briquettes. We applied a time-stratified case cross-over study design with distributed lag models, which allows for controlling potential confounding factors, including long-term and seasonal trends and day of the week, and we also adjusted for atmospheric temperature and relative humidity. Finally, this robust data analysis method suggested more valid and reliable effect estimates of short-term exposure to ambient air pollution on CVD admissions.

5. Conclusion

Even though new processed coal briquettes have been manufactured and consumed in the capital city of Mongolia, outdoor air pollutant levels continue to exceed the exposure limits recommended by the World Health Organization and the Mongolian National Standards, especially during the winter season. Our findings indicated that short-term exposures to the six criteria air pollutants, except for O_3, were positively associated with elevated risk of admissions from CVDs, IHDs and total strokes. The strongest positive associations were found between exposures to PM_{10}, NO_2 and SO_2 and admissions from CVD and

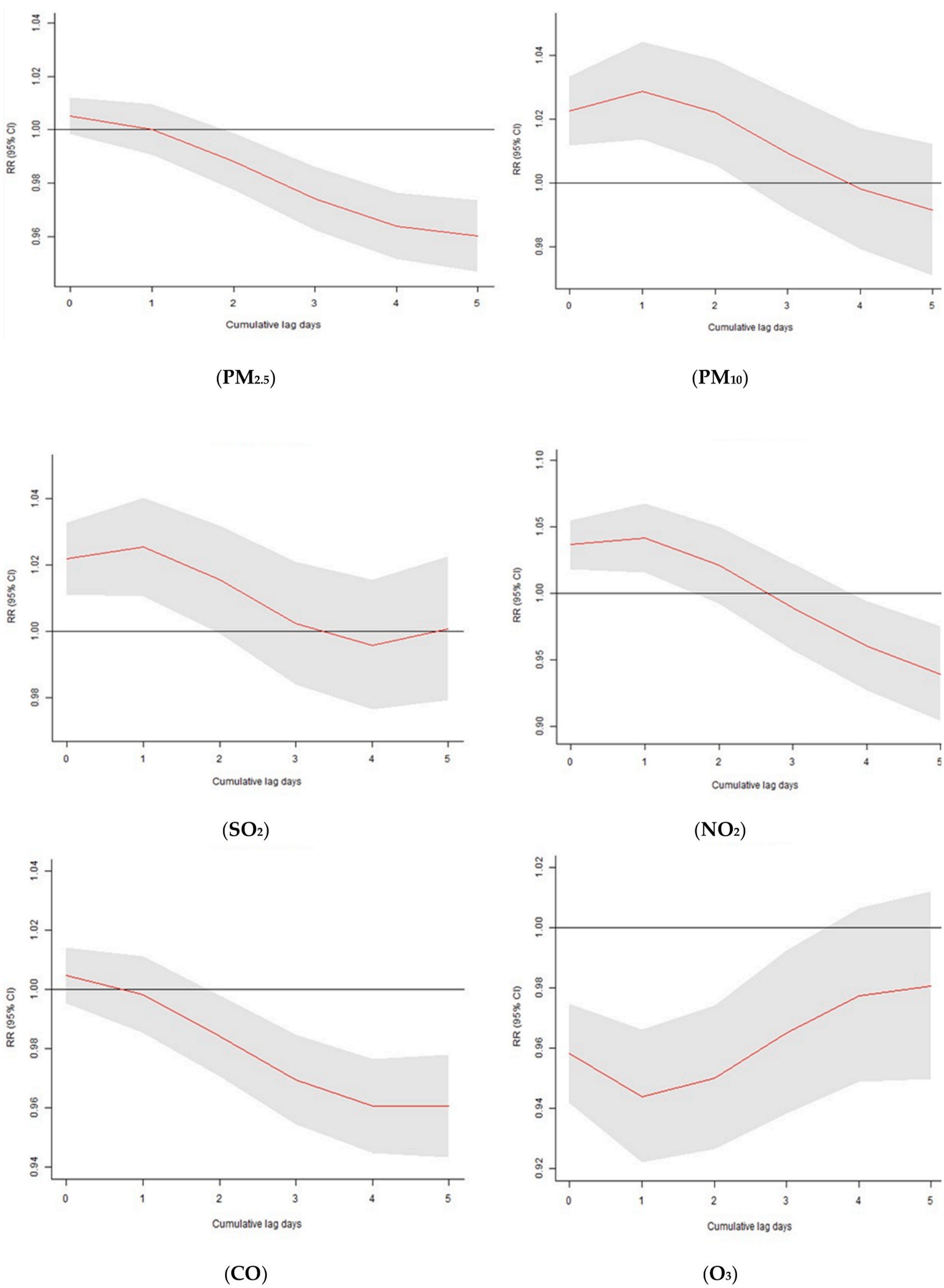


Fig. 3. Relative risks of CVD admissions associated with air pollutants per IQR increase at Lag0-Lag05 days.

Table 4
RRs of CVD admissions associated with air pollutants per IQR increase at lag01 by subgroups.

Subgroups		RR (95% CI) for $PM_{2.5}$	RR (95% CI) for PM_{10}	RR (95% CI) for SO_2	RR (95% CI) for NO_2	RR (95% CI) for CO	RR (95% CI) for O_3
Age	<65	1.008 (1.002, 1.013)	1.039 (1.020, 1.058)	1.024 (1.010, 1.037)	1.061 (1.028, 1.094)	1.012 (0.999, 1.024)	0.957 (0.936, 0.977)
	≥65	1.005 (0.990, 1.020)	1.011 (0.986, 1.036)	1.018 (1.002, 1.035)	1.052 (1.020, 1.084)	0.993 (0.976, 1.009)	1.002 (0.998, 1.006)
Sex	Female	1.006 (0.996, 1.016)	1.017 (1.002, 1.031)	1.030 (1.008, 1.052)	1.033 (1.006, 1.060)	1.003 (0.989, 1.017)	0.943 (0.922, 0.965)
	Male	1.005 (0.988, 1.022)	1.013 (1.006, 1.020)	1.020 (1.005, 1.035)	1.046 (1.010, 1.082)	1.007 (0.993, 1.020)	0.978 (0.952, 1.003)
Season	Warm	1.001 (0.983, 1.019)	1.008 (0.977, 1.039)	1.008 (0.986, 1.030)	1.016 (0.987, 1.045)	0.994 (0.974, 1.015)	0.986 (0.941, 1.030)
	Cold	1.017 (0.971, 1.063)	1.110 (1.043, 1.177)	1.032 (1.009, 1.055)	1.057 (1.045, 1.069)	1.037 (1.006, 1.068)	0.942 (0.883, 1.000)
Raw coal ban	Before	1.007 (0.990, 1.025)	1.017 (0.988, 1.047)	0.997 (0.986, 1.008)	1.034 (1.012, 1.056)	1.005 (0.983, 1.027)	0.991 (0.978, 1.004)
	After	0.991 (0.957, 1.024)	1.029 (1.003, 1.055)	1.021 (1.009, 1.033)	1.041 (1.023, 1.059)	1.017 (0.992, 1.042)	0.942 (0.824, 1.060)

stroke. Based on our study findings, we suggest that the Government of Mongolia should focus on evidence-based decision-making by adopting more efficient strategies to reduce the current ambient air pollution and associated adverse health effects in the capital city.

CRediT authorship contribution statement

Nandin-Erdene Bayart: Writing – original draft, Resources, Project administration, Methodology, Investigation, Funding acquisition, Formal analysis, Data curation. **Gavin Pereira:** Writing – review & editing, Supervision, Methodology, Funding acquisition. **Christopher M. Reid:** Writing – review & editing, Supervision. **Sylvester Dodzi Nyadanu:** Writing – review & editing, Validation, Methodology, Formal analysis. **Oyungoo Badamdorj:** Writing – review & editing, Supervision, Resources, Data curation. **Bazarzagd Lkhagvasuren:** Visualization, Software, Data curation. **Krassi Rumchev:** Writing – review & editing, Supervision, Methodology, Data curation.

Data availability

The air pollution and health data of this study are accessible upon request from any qualified investigator after approval of a protocol and signed data access agreement via Curtin University's Research Office.

Funding

This research received no external funding.

Declaration of Competing Interest

The authors declare that they have no known competing financial interests or personal relationships that could have appeared to influence the work reported in this paper.

Acknowledgments

The authors would like to thank the Centre for Health Development and the National Centre for Environmental Monitoring in Ulaanbaatar, Mongolia for providing data for our research. We also especially thank Dr. Amarzaya Jadambaa and Uranchimeg Dorj for their guidance and assistance with the data collection.

Appendix A. Supplementary data

Supplementary data to this article can be found online at https://doi.org/10.1016/j.apr.2024.102338.

References

ADB, 2022a. Asian development bank briefs: improving air quality in ulaanbaatar. Retrieved September 22, 2023 from. www.adb.org/publications/series/adb-briefs.

ADB, 2022b. Asian development bank briefs: improving air quality in ulaanbaatar, Mongolia. from chrome-extension://efaidnbmnnnibpcajpcglclefindmkaj/https://www.adb.org/sites/default/files/publication/842651/adb-brief-229-improving-air-quality-ulaanbaatar.pdf. . (Accessed 3 February 2024).

Allen, R.W., Gombojav, E., Barkhasragchaa, B., Byambaa, T., Lkhasuren, O., Amram, O., Takaro, T.K., Janes, C.R., 2013. An assessment of air pollution and its attributable mortality in Ulaanbaatar, Mongolia. Air Quality, Atmosphere and Health 6 (1), 137–150. https://doi.org/10.1007/s11869-011-0154-3 [Article].

Armstrong, B.G., Gasparrini, A., Tobias, A., 2014. Conditional Poisson models: a flexible alternative to conditional logistic case cross-over analysis. BMC Med. Res. Methodol. 14 (1), 122. https://doi.org/10.1186/1471-2288-14-122.

Ballester, F., Tenías, J.M., Pérez-Hoyos, S., 2001. Air pollution and emergency hospital admissions for cardiovascular diseases in Valencia, Spain. Journal of epidemiology and community health 55 (1), 57–65. https://doi.org/10.1136/jech.55.1.57, 1979.

Barn, P., Gombojav, E., Ochir, C., Laagan, B., Beejin, B., Naidan, G., Boldbaatar, B., Galsuren, J., Byambaa, T., Janes, C., Janssen, P.A., Lanphear, B.P., Takaro, T.K., Venners, S.A., Webster, G.M., Yuchi, W., Palmer, C.D., Parsons, P.J., Roh, Y.M., Allen, R.W., 2018. The effect of portable HEPA filter air cleaners on indoor PM2.5 concentrations and second hand tobacco smoke exposure among pregnant women in Ulaanbaatar, Mongolia: the UGAAR randomized controlled trial. The Science of the total environment 615, 1379–1389. https://doi.org/10.1016/j.scitotenv.2017.09.291.

Barnett, A.G., Williams, G.M., Schwartz, J., Best, T.L., Neller, A.H., Petroeschevsky, A.L., Simpson, R.W., 2006. The effects of air pollution on hospitalizations for cardiovascular disease in elderly people in Australian and New Zealand cities. Environmental Health Perspectives 114 (7), 1018–1023. https://doi.org/10.1289/ehp.8674.

Basagaña, X., Barrera-Gómez, J., 2022. Reflection on modern methods: visualizing the effects of collinearity in distributed lag models. Int. J. Epidemiol. 51 (1), 334–344. https://doi.org/10.1093/ije/dyab179.

Bayarsaikhan, D., Kwon, S., Chimeddagva, D., 2015. Social health insurance development in Mongolia: opportunities and challenges in moving towards Universal Health Coverage. Int. Soc. Secur Rev. 68 (4), 93–113.

Bayart, N.-E., Rumchev, K., Reid, C.M., Nyadanu, S.D., Pereira, G., 2024. Association between short-term exposure to ambient air pollution and mortality from cardiovascular diseases in ulaanbaatar, Mongolia. Atmosphere 15 (9), 1110.

Cai, J., Yu, S., Pei, Y., Peng, C., Liao, Y., Liu, N., Ji, J., Cheng, J., 2018. Association between airborne fine particulate matter and residents' cardiovascular diseases, ischemic heart disease and cerebral vascular disease mortality in areas with lighter air pollution in China [Article]. Int. J. Environ. Res. Publ. Health 15 (9). https://doi.org/10.3390/ijerph15091918. Article 1918.

Chen, C., Zhu, P., Lan, L., Zhou, L., Liu, R., Sun, Q., Ban, J., Wang, W., Xu, D., Li, T., 2018. Short-term exposures to PM2.5 and cause-specific mortality of cardiovascular health in China. Environ. Res. 161, 188–194. https://doi.org/10.1016/j.envres.2017.10.046.

Chuang, K.-J., Chan, C.-C., Su, T.-C., Lee, C.-T., Tang, C.-S., 2007. The effect of urban air pollution on inflammation, oxidative stress, coagulation, and autonomic dysfunction in young adults. Am. J. Respir. Crit. Care Med. 176 (4), 370–376. https://doi.org/10.1164/rccm.200611-1627OC.

Cohen, A.J.D., Brauer, M.P., Burnett, R.P., Anderson, H.R.P., Frostad, J.M.P.H., Estep, K. M.P.A., Balakrishnan, K.P., Brunekreef, B.P., Dandona, L.P., Dandona, R.P., Feigin, V.P., Freedman, G.M.P.H., Hubbell, B.P., Jobling, A.P., Kan, H.P., Knibbs, L. P., Liu, Y.P., Martin, R.P., Morawska, L.P., Forouzanfar, M.H.P., 2017. Estimates and 25-year trends of the global burden of disease attributable to ambient air pollution: an analysis of data from the Global Burden of Diseases Study 2015. Lancet 389 (10082), 1907–1918. https://doi.org/10.1016/S0140-6736(17)30505-6.

Dahlquist, M., Frykman, V., Hollenberg, J., Jonsson, M., Stafoggia, M., Wellenius, G.A., Ljungman, P.L.S., 2023. Short-term ambient air pollution exposure and risk of out-of-hospital cardiac arrest in Sweden: a nationwide case-crossover study. J. Am. Heart Assoc. 12 (21). https://doi.org/10.1161/JAHA.123.030456.

Danesh Yazdi, M., Wei, Y., Di, Q., Requia, W.J., Shi, L., Sabath, M.B., Dominici, F., Schwartz, J., 2022. The effect of long-term exposure to air pollution and seasonal temperature on hospital admissions with cardiovascular and respiratory disease in the United States: a difference-in-differences analysis. The Science of the total environment 843. https://doi.org/10.1016/j.scitotenv.2022.156855, 156855-156855.

Enkhbat, U., Rule, A.M., Resnick, C., Ochir, C., Olkhanud, P., Williams, D.L., 2016. Exposure to PM2.5 and blood lead level in two populations in ulaanbaatar, Mongolia. Int. J. Environ. Res. Publ. Health 13 (2). https://doi.org/10.3390/ijerph13020214 [Article].

Enkhjargal, A., Burmaajav, B., Tsegmed, S., Suvd, B., Norolkhoosuren, B., Unurbat, D., Batbayar, J., 2020. Impact of ambient air pollution and meteorological factors on hospital admission to the cardiovascular system disease on Ulaanbaatar City of Mongolia. Open J. Epidemiol. 10 (2), 100–114.

Gasparrini, A., 2011. Distributed lag linear and non-linear models in R: the package dlnm [Article]. J. Stat. Software 43 (8), 2–20. https://doi.org/10.18637/jss.v043.i08.

Gasparrini, A., Armstrong, B., Kenward, M.G., 2010. Distributed lag non-linear models. Stat. Med. 29 (21), 2224–2234. https://doi.org/10.1002/sim.3940.

Goldman, G.T., Mulholland, J.A., Russell, A.G., Strickland, M.J., Klein, M., Waller, L.A., Tolbert, P.E., 2011. Impact of exposure measurement error in air pollution epidemiology: effect of error type in time-series studies [Article]. Environmental Health: A Global Access Science Source 10 (1). https://doi.org/10.1186/1476-069X-10-61. Article 61.

Hasnain, M.G., Garcia-Esperon, C., Tomari, Y.K., Walker, R., Saluja, T., Rahman, M.M., Boyle, A., Levi, C.R., Naidu, R., Filippelli, G., Spratt, N.J., 2023. Effect of short-term exposure to air pollution on daily cardio- and cerebrovascular hospitalisations in areas with a low level of air pollution. Environ. Sci. Pollut. Res. Int. 30 (46), 102438–102445. https://doi.org/10.1007/s11356-023-29544-z.

Huang, Y.-K., Luvsan, M.-E., Gombojav, E., Ochir, C., Bulgan, J., Chan, C.-C., 2013. Land use patterns and SO2 and NO2 pollution in Ulaanbaatar, Mongolia. Environ. Res. 124, 1–6. https://doi.org/10.1016/j.envres.2013.02.006.

Jun, S, 2021. Is the raw coal ban a silver bullet to solving air pollution in Mongolia? A Study of the Mongolian Government's Air Pollution Reduction Policies and Recommendations in the Context of COVID-19. Journal of Public & International Affairs.

Kim, A., Jung, J., Hong, J., Yoon, S.-J., 2021. Time series analysis of meteorological factors and air pollutants and their association with hospital admissions for acute myocardial infarction in Korea. Int. J. Cardiol. 322, 220–226. https://doi.org/10.1016/j.ijcard.2020.08.060.

Lee, K.K., Bing, R., Kiang, J., Bashir, S., Spath, N., Stelzle, D., Mortimer, K., Bularga, A., Doudesis, D., Joshi, S.S., Strachan, F., Gumy, S., Adair-Rohani, H., Attia, E.F., Chung, M.H., Miller, M.R., Newby, D.E., Mills, N.L., McAllister, D.A., Shah, A.S.V., 2020. Adverse health effects associated with household air pollution: a systematic review, meta-analysis, and burden estimation study [Article]. Lancet Global Health 8 (11), e1427–e1434. https://doi.org/10.1016/S2214-109X(20)30343-0.

Liu, Y., Guo, M., Wang, J., Gong, Y., Huang, C., Wang, W., Liu, X., Liu, J., Ju, C., Ba, Y., Zhou, G., Wu, X., 2024. Effect of short-term exposure to air pollution on hospital admission for cardiovascular disease: a time-series study in Xiangyang, China. The Science of the total environment 918. https://doi.org/10.1016/j.scitotenv.2024.170735, 170735-170735.

MASM, 2021. Ambient Air Pollution Standards in Mongolia. *MNS 4585:2016)*.

MDoH, 2022. Mongolian department of health: annual report on health indicators. Retrieved December 10, 2023 from. http://hdc.gov.mn/media/files/2022.pdf.

Mostofsky, E., Coull, B.A., Mittleman, M.A., 2018. Analysis of observational self-matched data to examine acute triggers of outcome events with abrupt onset. Epidemiology 29 (6). https://journals.lww.com/epidem/fulltext/2018/11000/analysis_of_observational_self_matched_data_to.8.aspx.

Nhung, N.T.T., Schindler, C., Chau, N.Q., Hanh, P.T., Hoang, L.T., Dien, T.M., Thanh, N. T.N., Künzli, N., 2020. Exposure to air pollution and risk of hospitalization for cardiovascular diseases amongst Vietnamese adults: case-crossover study. The Science of the total environment 703. https://doi.org/10.1016/j.scitotenv.2019.134637, 134637-134637.

Niu, Z., Liu, F., Yu, H., Wu, S., Xiang, H., 2021. Association between exposure to ambient air pollution and hospital admission, incidence, and mortality of stroke: an updated systematic review and meta-analysis of more than 23 million participants. Environ. Health Prev. Med. 26 (1), 15. https://doi.org/10.1186/s12199-021-00937-1.

Nuvolone, D., Balzi, D., Chini, M., Scala, D., Giovannini, F., Barchielli, A., 2011. Short-term association between ambient air pollution and risk of hospitalization for acute myocardial infarction: results of the cardiovascular risk and air pollution in tuscany (RISCAT) study. Am. J. Epidemiol. 174 (1), 63–71. https://doi.org/10.1093/aje/kwr046.

Orellano, P., Reynoso, J., Quaranta, N., Bardach, A., Ciapponi, A., 2020. Short-term exposure to particulate matter (PM(10) and PM(2.5)), nitrogen dioxide (NO(2)), and ozone (O(3)) and all-cause and cause-specific mortality: systematic review and meta-analysis. Environ. Int. 142, 105876. https://doi.org/10.1016/j.envint.2020.105876.

Phosri, A., Ueda, K., Phung, V.L.H., Tawatsupa, B., Honda, A., Takano, H., 2019. Effects of ambient air pollution on daily hospital admissions for respiratory and cardiovascular diseases in Bangkok, Thailand. The Science of the total environment 651 (Pt 1), 1144–1153. https://doi.org/10.1016/j.scitotenv.2018.09.183.

R, 2021. Core Team. R (Version 4.1.1): A Language and Environment for Statistical Computing. R Foundation for Statistical Computing, Vienna, Austria. https://www.r-project.org/.

Routledge, H.C., Manney, S., Harrison, R.M., Ayres, J.G., Townend, J.N., 2006. Effect of inhaled sulphur dioxide and carbon particles on heart rate variability and markers of inflammation and coagulation in human subjects. Heart (British Cardiac Society) 92 (2), 220–227. https://doi.org/10.1136/hrt.2004.051672.

Stieb, D.M., Zheng, C., Salama, D., BerjawI, R., Emode, M., Hocking, R., Lyrette, N., Matz, C., Lavigne, E., Shin, H.H., 2020. Systematic review and meta-analysis of case-crossover and time-series studies of short term outdoor nitrogen dioxide exposure and ischemic heart disease morbidity. Environmental Health 19, 1–19. https://doi.org/10.1186/s12940-020-00601-1.

Turner, H., Firth, D., 2007. Generalized Nonlinear Models in R: an Overview of the Gnm Package.

Warburton, D., Warburton, N., Wigfall, C., Chimedsuren, O., Lodoisamba, D., Lodoysamba, S., Jargalsaikhan, B., 2018. Impact of seasonal winter air pollution on health across the lifespan in Mongolia and some putative solutions [Conference Paper]. Annals of the American Thoracic Society 15, S86–S90. https://doi.org/10.1513/AnnalsATS.201710-758MG.

Wasserstein, R.L., Schirm, A.L., Lazar, N.A., 2019. Moving to a world beyond "$p < 0.05$" [editorial]. Am. Statistician 73 (Suppl. 1), 1–19. https://doi.org/10.1080/00031305.2019.1583913.

WHO, 2016. International statistical classification of diseases and related health problems 10th revision (ICD-10)-WHO version for 2016. https://icd.who.int/browse10/2016/en#/IX.

WHO, 2019. Ambient (outdoor) air pollution. Retrieved April 17, 2024 from. https://www.who.int/news-room/fact-sheets/detail/ambient-(outdoor)-air-quality-and-health.

WHO, 2021a. Cardiovascular diseases (CVDs): key facts. Retrieved March 10, 2024 from. https://www.who.int/news-room/fact-sheets/detail/cardiovascular-diseases-(cvds.

WHO, 2021b. WHO global air quality guidelines: particulate matter (PM2.5 and PM10), ozone, nitrogen dioxide, sulfur dioxide and carbon monoxide. Retrieved May 17, 2023 from. https://www.who.int/publications/i/item/9789240034228.

World Bank, 2023. New World Bank country classifications by income level. Retrieved September 23, 2023 from. https://blogs.worldbank.org/opendata/new-world-bank-country-classifications-income-level-2022-2023.

World Heart Federation, 2023. World heart report 2023: confronting the world's number one killer. from. https://world-heart-federation.org/resource/world-heart-report-2023/. (Accessed 16 February 2024).

Wu, H., Zhang, B., Wei, J., Lu, Z., Zhao, M., Liu, W., Bovet, P., Guo, X., Xi, B., 2022. Short-term effects of exposure to ambient PM(1), PM(2.5), and PM(10) on ischemic and hemorrhagic stroke incidence in Shandong Province, China. Environ. Res. 212 (Pt C), 113350. https://doi.org/10.1016/j.envres.2022.113350.

Xu, A., Mu, Z., Jiang, B., Wang, W., Yu, H., Zhang, L., Li, J., 2017. Acute effects of particulate air pollution on ischemic heart disease hospitalizations in Shanghai, China. Int. J. Environ. Res. Publ. Health 14 (2), 168. https://doi.org/10.3390/ijerph14020168.

Xu, Z., Xiong, L., Jin, D., Tan, J., 2021. Association between short-term exposure to sulfur dioxide and carbon monoxide and ischemic heart disease and non-accidental death in Changsha city, China [Article]. PLoS One 16 (5 May). https://doi.org/10.1371/journal.pone.0251108. Article e0251108.

Yu, J., Zhu, A., Liu, M., Dong, J., Chen, R., Tian, T., Liu, T., Ma, L., Ruan, Y., 2024. Association between air pollution and cardiovascular disease hospitalizations in lanzhou city, 2013-2020: a time series analysis. Geohealth 8 (1). https://doi.org/10.1029/2022GH000780.

Zhong, H., Shu, Z., Zhou, Y., Lu, Y., Yi, B., Tang, X., Liu, C., Deng, Q., Yuan, H., Huang, Z., 2018. Seasonal effect on association between atmospheric pollutants and hospital emergency room visit for stroke [article]. J. Stroke Cerebrovasc. Dis. 27 (1), 169–176. https://doi.org/10.1016/j.jstrokecerebrovasdis.2017.08.014.

Zou, L., Zong, Q., Fu, W., Zhang, Z., Xu, H., Yan, S., Mao, J., Zhang, Y., Cao, S., Lv, C., 2021. Long-term exposure to ambient air pollution and myocardial infarction: a systematic review and meta-analysis [systematic review]. Front. Med. 8. https://www.frontiersin.org/article/10.3389/fmed.2021.616355.