Environment International 183 (2024) 108356

Contents lists available at ScienceDirect

Environment International

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

Full length article

Using individual approach to examine the association between urban heat island and preterm birth: A nationwide cohort study in China

Xiang Xiao [a,1], Ruixia Liu [b,1], Zheng Zhang [b,1], Bin Jalaludin [c], Joachim Heinrich [d], Xiangqian Lao [e], Lidia Morawska [f], Shyamali C. Dharmage [g], Luke D. Knibbs [h,i], Guang-Hui Dong [j,*], Meng Gao [a,k,*], Chenghong Yin [b,*]

[a] Department of Geography, Hong Kong Baptist University, Hong Kong, China
[b] Beijing Obstetrics and Gynecology Hospital, Capital Medical University, Beijing 100026, China
[c] School of Public Health and Community Medicine, The University of New South Wales, Kensington 2052, Australia
[d] Institute and Clinic for Occupational, Social and Environmental Medicine, University Hospital, LMU Munich, Munich 80336, Germany
[e] Department of Biomedical Sciences, the City University of Hong Kong, Hong Kong, China
[f] International Laboratory for Air Quality and Health, Queensland University of Technology, Brisbane 4059, Australia
[g] Allergy and Lung Health Unit, Melbourne School of Population and Global Health, University of Melbourne, Melbourne, VIC 3052, Australia
[h] School of Public Health, The University of Sydney, NSW 2006, Australia
[i] Public Health Research Analytics and Methods for Evidence, Public Health Unit, Sydney Local Health District, Camperdown, NSW 2050, Australia
[j] Guangdong Provincial Engineering Technology Research Center of Environmental Pollution and Health Risk Assessment, Department of Occupational and Environmental Health, School of Public Health, Sun Yat-sen University, Guangzhou 510080, China
[k] Center for Ocean Research in Hong Kong and Macau (CORE), Hong Kong, China

ARTICLE INFO

Keywords:
Urban heat island
Heat exposure
Individual-level
Preterm birth

ABSTRACT

Background: Evidence suggests that maternal exposure to heat might increase the risk of preterm birth (PTB), but no study has investigated the effect from urban heat island (UHI) at individual level.
Aims: Our study aimed to investigate the association between individual UHI exposure and PTB.
Methods: We utilized data from the ongoing China Birth Cohort Study (CBCS), encompassing 103,040 birth records up to December 2020. UHI exposure was estimated for each participant using a novel individual assessment method based on temperature data and satellite-derived land cover data. We used generalized linear mixed-effects models to estimate the association between UHI exposure and PTB, adjusting for potential confounders including maternal characteristics and environmental factors.
Results: Consistent and statistically significant associations between UHI exposure and PTB were observed up to 21 days before birth. A 5 °C increment in UHI exposure was associated with 27 % higher risk (OR = 1.27, 95 % confident interval: 1.20, 1.34) of preterm birth in lagged day 1. Stratified analysis indicated that the associations were more pronounced in participants who were older, had higher pre-pregnancy body mass index level, of higher socioeconomic status and living in greener areas.
Conclusion: Maternal exposure to UHI was associated with increased risk of PTB. These findings have implications for developing targeted interventions for susceptible subgroups of pregnant women. More research is needed to validate our findings of increased risk of preterm birth due to UHI exposure among pregnant women.

Abbreviations: API, application programming interface; BMI, body mass index; CI, confidence interval; GIS, geographical information system; GLMER, generalized linear mixed-effects model; HIV, human immunodeficiency virus; MODIS, moderate resolution imaging spectroradiometer; NDVI, normalized difference vegetation index; OR, odds ratio; $PM_{2.5}$, particulate matter ≤ 2.5 μm in diameter; PTB, preterm births; SD, standard deviation; SES, socioeconomic status; UHI, urban heat island.

* Corresponding authors at: Beijing Obstetrics and Gynecology Hospital, Capital Medical University, 251 Yaojia Yuan Road, Chaoyang District, Beijing 100026, China (C. Yin), Guangdong Provincial Engineering Technology Research Center of Environmental Pollution and Health Risk Assessment, Guangzhou Key Laboratory of Environmental Pollution and Health Risk Assessment, Department of Preventive Medicine, School of Public Health, Sun Yat-sen University, 74 Zhongshan 2nd Road, Yuexiu District, Guangzhou 510080, China (G.-H. Dong), Department of Geography, Hong Kong Baptist University, Hong Kong SAR, China. 1222 Academic and Administration Building, Baptist University Road Campus, Hong Kong Baptist University, Hong Kong, China (M. Gao).
E-mail addresses: donggh5@mail.sysu.edu.cn (G.-H. Dong), mmgao2@hkbu.edu.hk (M. Gao), yinchh@ccmu.edu.cn (C. Yin).

[1] These authors contributed equally to this work and should be listed as the first author.

https://doi.org/10.1016/j.envint.2023.108356
Received 5 July 2023; Received in revised form 22 October 2023; Accepted 26 November 2023
Available online 28 November 2023

1. Introduction

The urban population has grown rapidly during the past decades and approximately 68 % of the total population is projected to lead their lives in urban areas worldwide by 2050 (United Nations, 2018). Rapid urbanization has inevitably altered the urban environment, including loss of vegetation and the increase of concrete and roads, which leads to the urban heat island (UHI) effect (Seto et al., 2012). The term urban heat island (UHI) refers to the higher temperatures of cities compared with surrounding areas. In a warming, urbanizing world, the UHI effect could exacerbate extreme heat exposure by increasing the intensity and duration of heat waves, especially among urban dwellers (Ward et al., 2016). The UHI can pose potential health risks by altering the meteorology, air pollutant emission rates, pollutant transport, and photochemistry (Ulpiani, 2021).

Previously published literature, including several national and multi-country studies, has suggested associations between heat exposure and morbidity and mortality (Gasparrini et al., 2015; Gronlund et al., 2014; Ma et al., 2015; Son et al., 2016; Ye et al., 2012). However, pregnant women, who might be more vulnerable to temperature extremes (i.e., cold and heat extremes) (Bekkar et al., 2020), have received comparatively less attention (He et al., 2016; Son et al., 2022). More recent studies have revealed that exposure to temperature extremes during pregnancy could trigger the occurrence of preterm birth (PTB; defined as less than 37 complete weeks of gestation), which is a well-documented risk factor for both acute infant morbidity and mortality, and long-term physical, behavioral and cognitive development problem (Saigal and Doyle, 2008).

Despite the potential health risk due to UHIs, very few studies have investigated the associations between UHI effects and health outcomes. The UHI effect is typically measured by the temperature difference between urban and rural areas, known as UHI intensity (i.e., the excess temperature exposure). The UHI effect leads to excess temperature increase in urban areas, resulting in higher intensity and longer duration of heatwaves in cities (Ward et al., 2016). The UHI can affect almost every urban area (Stewart and Oke, 2012), and furthermore, recent studies also demonstrated that UHI varies within cities due to differences in land use pattern and population density (Ho et al., 2023; Shi et al., 2018). However, it can be challenging to accurately measure individual-level exposure to UHIs within a city. The lack of intra-city exposure assessment can pose difficulties for epidemiological studies attempting to identify potential associations, particularly in small studies involving a limited number of cities, partially due to an insufficient exposure gradient and a potentially high possibility of exposure misclassification and confounding.

To date, numerous studies have employed sophisticated techniques to create high spatiotemporal resolution (e.g., 0.5 ~ 1 km) grid temperature data (Zhang et al., 2022) and land use data (Sulla-Menashe et al., 2019). These datasets enable researchers to quantify the temperature differential between residential addresses at individual level within cities. In addition, using individual-level UHI exposure could be of great importance and will advance our understanding of the adverse impacts of UHIs on human health at a more granular level. The information can be helpful in identifying vulnerable populations within cities and informing targeted urban policies and public health interventions to adapt to those risks. To date, to the best of our knowledge, no such study investigating individual UHI exposure and PTB has been conducted.

In this study, we aimed to develop standardized methods to assess individual-level UHI intensity and further explore the potential association between UHI intensity and PTB using a nationwide birth cohort database in China.

2. Methods

2.1. Study population

The nationwide prospective birth cohort, China Birth Cohort Study (CBCS), aimed at investigating risk factors for birth defects and developing strategies for their reduction. (Supplementary Materials, Figure S1). Detailed information has been published elsewhere (Yue et al., 2022). Briefly, pregnant women who visited the hospitals were invited to this study, and those who agreed to participate provided informed consent and completed questionnaires on demographic characteristics, socioeconomic status (education and income level), lifestyle, living environments, housing, and neighborhood information (including residential address). After recruitment to the study, the participants had at least one additional follow-up during the remaining period of their pregnancy. After delivery of the newborns, trained investigators conducted the final follow-up to obtain the most recent information related to residential surrounding environments and reproductive history. Birth records were obtained through the registry systems. The study was conducted in accordance with the Declaration of Helsinki and in accordance with local statutory requirements. The cohort study protocol was approved by the Ethics Committee of Beijing Obstetrics and Gynecology Hospital, Capital Medical University (Approval no.: 2018-KY-003–02). Details about the recruitment process are presented in Figure S2 (Supplementary Materials).

2.2. Address geocoding

Residential addresses in this study were organized based on the official administrative divisions established by the government. Prior to admission to the hospital, participants were required to provide detailed and properly formatted residential addresses for the hospital registration system. During pregnancy, residential addresses were obtained at each follow-up visit and then confirmed at the time of delivery. We utilized an Application Programming Interface (API) provided by Auto Navi Map, which is equivalent to Google Maps in China, to geocode addresses. The geocodes of these addresses (i.e., geographical coordinates) were further used as point locations in the assessment of UHI intensity.

2.3. PTB definition

PTB was defined as $<$ 37 completed gestational weeks (WHO, 2012). Gestational age was measured in days using the date of the last menstrual period in combination with confirmatory ultrasound examinations.

2.4. Temperature and land cover datasets

We retrieved temperature and land use datasets for the entire study period of 2017 to 2020. The daily temperature data at a resolution of 1 km were obtained from Zhang et al. (2022), who used a spatiotemporal gap-filling framework to generate a seamless global 1 km daily land surface temperature dataset (mid-daytime and mid-nighttime) from 2003 to 2020. This dataset was based on standard MODIS products such as MOD11A1 and MYD11A1. The details have been previously described elsewhere (Zhang et al., 2022). This globally seamless temperature data were available at two time points (namely, 1:30 AM and 1:30 PM local time), and we used mid-daytime temperature data (i.e., 1:30 PM local time) for our analysis.

Land cover data at a resolution of 500 m from 2017 to 2020 were retrieved from MODIS land use products (MCD12Q1) (Sulla-Menashe and Friedl, 2018), using the online Data Pool tool at the NASA Land Processes Distributed Active Archive Center. We adopted the IGBP (International Geosphere Biosphere Program) global vegetation classification scheme, which defined urban areas as those with at least 30 %

impervious surface area, including building materials, asphalt, and vehicles. The land cover data were pre-processed (e.g., reprojection and resampling) using the nearest-neighbor method (Raptis et al., 2003) to ensure consistency in grid size and spatial reference across all the retrieved datasets.

2.5. UHI assessment

According to its definition, UHI effect can be quantified by the temperature difference between central urban areas and surrounding suburban or rural areas. In this study, we have taken a pioneering step by introducing an individual-level UHI assessment approach. This unique method involves quantifying the individual-specific temperature variance between a participant's urban residence and the adjacent suburban or rural areas. To further detect the UHI effect at individual level, we implemented a novel framework by using the Geographical Information System (GIS) tools in R and ArcPy. The algorithm framework is shown in Fig. 1.

Briefly, we geocoded the residential addresses of study participants and classified them as urban or non-urban based on land cover data from MODIS. We then created two separate circular buffers (initially, within 1.5 km radius and 15 km radius, respectively) to represent the actual temperature that affects people and its surrounding temperature, and labeled all temperature data grids as either urban or non-urban. If the number of identified grids within each buffer was less than 9 and 81 (i.e., 3 × 3 and 9 × 9 grids), respectively, an iteration program was applied to enlarge the radius by the step of 0.1 km and 1 km, respectively, at one time until a sufficient number of labeled grids were identified. This was done to ensure that the data used to calculate the results was not dominated by just a few temperature grids. Within the urban buffer, we used only temperature data grids that fell into the 'urban' class to calculate the average temperature, and similarly within the non-urban buffer, only 'non-urban' temperature data grids were used to calculate the average non-urban temperature.

For an urban address, the average temperature in the smaller buffer was considered as urban temperature (T_u), and that in the larger buffer was considered as corresponding surrounding non-urban temperature (T_n). A similar procedure was followed for non-urban addresses, except that T_n was calculated using the smaller buffer and T_u was calculated using the larger buffer. Finally, the individual-level UHI intensity was

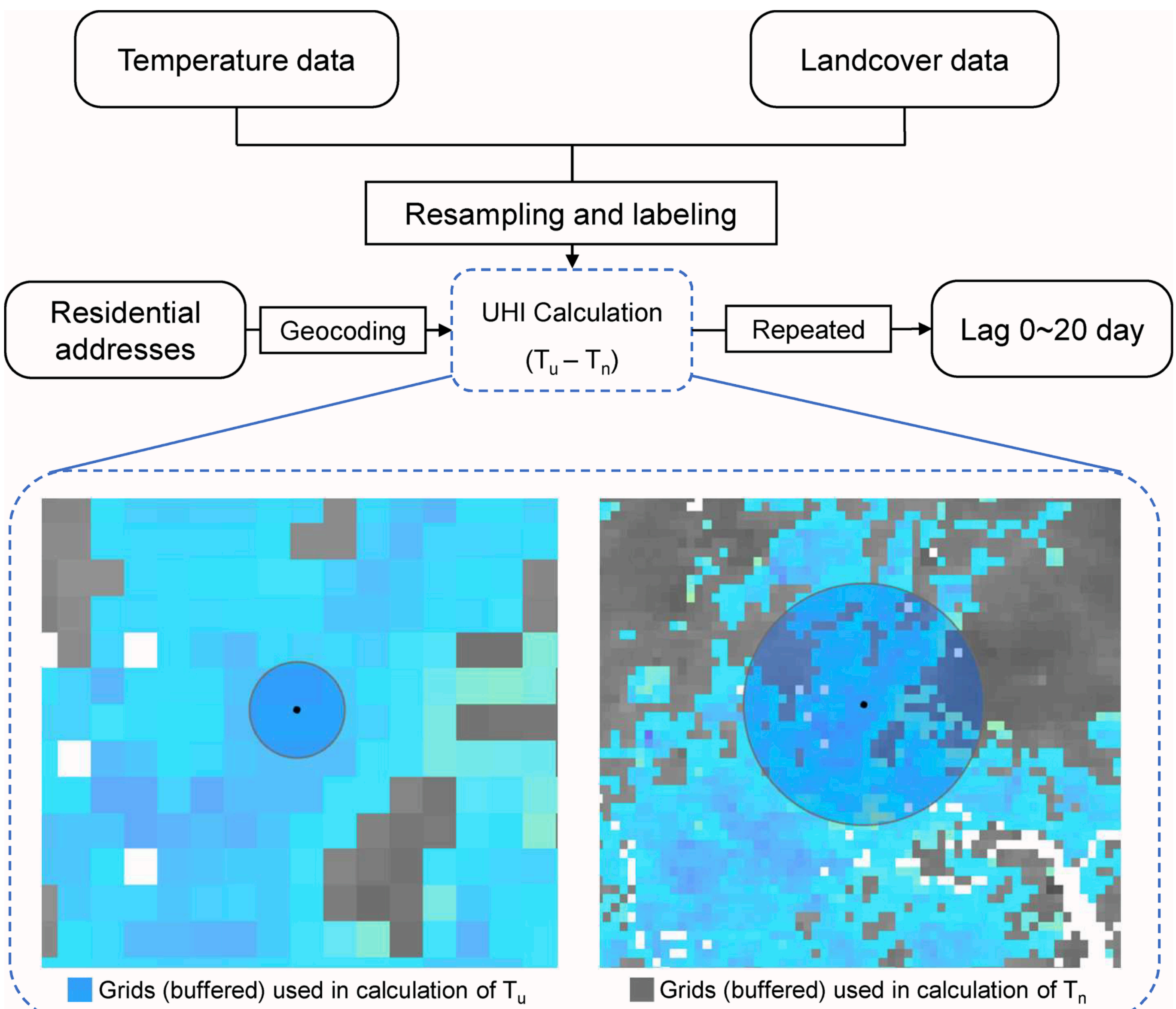

Fig. 1. Flowchart of individual Urban Heat Island exposure assessment.

calculated as the difference between T_u and T_n. Each individual's exposure to UHI was meticulously calculated through the labeling of temperature grids, precise geo-referencing using land cover datasets, and potentially additional iterations to ensure a sufficient number of temperature grids were available for a robust assessment. For each recorded birth, the UHI intensity was computed using the aforementioned procedure for every day leading up to the onset date of birth, with a retrospective window of 21 days (i.e., lag 0d to lag 20d), which was limited by the substantial computational overhead associated with the calculation of UHI intensity. The average level of UHI during one, two and three weeks prior to birth (i.e., lag 1w to lag 3w) was also calculated.

2.6. Statistical analyses

We estimated the association between PTB and UHI intensity using generalized linear mixed-effects models (GLMER). To account for potential unmeasured clustering in our data, province was used as the random effect term in the GLMER models. For the dichotomous birth outcome PTB, we used logit link functions in the model, as done in previous studies (Bravo and Miranda, 2022; Cai et al., 2020; Luo et al., 2022; Xiao et al., 2022).

To adjust for potential confounding variables, we included a range of covariates in the models, such as: 1) maternal characteristics, including age (years), pre-pregnancy body mass index (pre-BMI) (kg/m^2), income level (CNY per year), education level (High school or lower vs, higher education), ethnicity (Hans vs. others), environmental tobacco smoke exposure (Yes vs. No); 2) sex of the child (male or female) and month of birth; 3) residential neighborhood variables, including residential type (urban vs. non-urban), living within 100 m of main roads (proximity to main roads; yes vs. no), household use of air purifier (yes vs. no), self-reported residential noise disturbance (yes vs. no); 4) average normalized difference vegetation index in 500 m radius buffer ($NDVI_{\text{-}500m}$), temperature (°C) and particulate matter ≤ 2.5 μm in diameter ($PM_{2.5}$) levels ($\mu g/m^3$) during the third trimester of pregnancy. We adjusted for temperature and $PM_{2.5}$ exposure during the third trimester because our previous findings (Xiao et al., 2023) suggested significant associations between exposure to temperature and air pollutants during the third trimester of pregnancy. By adjusting for these variables, our intention was to isolate the specific effect of UHI exposure on PTB and minimize the potential confounding.

We first built the base model, which only included UHI exposure, residential type and province-level random effects term. Furthermore, we fitted a fully adjusted model in which all the confounders were included. Residential greenness, which potentially modifies the exposure to UHI, was further used as an effect modifier in the stratified analysis, and effect modification was tested by including an interaction term with UHI in the model. We also examined the confounding effect of each covariate in the models by adding sets of covariates at a time until reaching the fully adjusted model. To investigate whether UHI effects may vary by season, we also stratified our analysis by cold/warm season.

All statistical analyses in this study were conducted in R software (version 4.2.2), using the "lmer" package for generalized mixed-effect regression. All statistical tests were two-sided, and P-values < 0.05 were considered statistically significant. We present effect estimates as odds ratios (OR) with 95 % confidence intervals (CIs) for PTB associated with a 5-degree Celsius increase in UHI intensity.

3. Results

3.1. Characteristics of participants

A total of 103,040 birth records were included in the analysis. Table 1 summarizes the maternal covariates, including birth outcomes and environmental exposures, stratified by PTB. The average gestational age at delivery was 274.6 days (39.2 weeks), with 6.2 % (n = 6388) of newborns born preterm. Compared with term births, women who delivered preterm were slightly older ($P < 0.001$), had higher pre-pregnancy BMI ($P < 0.001$), and belonged to a lower socioeconomic status (SES), such as income ($P < 0.001$) and education level ($P < 0.001$). Women who delivered preterm also had a slightly higher rate of environmental tobacco exposure ($P = 0.037$). No significant differences were observed in ethnicity ($P = 0.160$), self-reported proximity to main road ($P = 0.764$) or self-reported noise disturbance ($P = 0.966$) between the two groups of women.

Table 1
Characteristics of participants in the study.

Variable	Mean ± SD, *n* (%)			P[*]
	Total	Term birth	Preterm birth	
	(*n* = 103040)	(*n* = 96652)	(*n* = 6388)	
Mothers				
Age (years)	30.7 ± 5.0	30.7 ± 5.0	31.2 ± 4.9	< 0.001
Pre-pregnancy BMI (kg/m^2)	21.8 ± 3.6	21.8 ± 3.6	22.1 ± 3.7	< 0.001
Gestational age (days)	274.6 ± 11.8	276.6 ± 7.9	243.7 ± 16.5	< 0.001
Ethnicity (Han)	85,943 (83.4 %)	80,574 (83.4 %)	5369 (84.0 %)	0.16
Education level				< 0.001
Middle High school or lower	56,125 (54.5 %)	52,416 (54.2 %)	3709 (58.1 %)	
Higher education	46,915 (45.5 %)	44,236 (45.8 %)	2679 (41.9 %)	
Annual family income (CNY)				< 0.001
≤ 100,000	31,415 (30.5 %)	29,275 (30.3 %)	2140 (33.5 %)	
100000 ~ 400000	61,352 (59.5 %)	57,673 (59.7 %)	3679 (57.6 %)	
≥ 400,000	10,273 (10.0 %)	9704 (10.0 %)	569 (8.9 %)	
Environmental tobacco exposure	41,270 (40.1 %)	38,632 (40.0 %)	2638 (41.3 %)	0.037
Sex of newborn (boys)	53,650 (52.1 %)	50,085 (51.8 %)	3565 (55.8 %)	< 0.001
Environmental factors				
Residential type (Urban)	90,504 (87.8 %)	85,119 (88.1 %)	5385 (84.3 %)	< 0.001
Use of air purifier (yes)	23,132 (22.4 %)	21,821 (22.6 %)	1311 (20.5 %)	< 0.001
Proximity to main road (yes)	32,685 (31.7 %)	30,670 (31.7 %)	2015 (31.5 %)	0.764
Noise disturbance (yes)	5924 (5.7 %)	5558 (5.8 %)	366 (5.7 %)	0.966
$NDVI_{\text{-}500m}$	0.31 ± 0.12	0.31 ± 0.12	0.30 ± 0.12	0.026
$PM_{2.5}$ ($\mu g/m^3$)[a]	37.7 ± 17.9	37.8 ± 17.7	36.2 ± 20.6	< 0.001
Temperature (°C)[a]	16.4 ± 9.4	16.4 ± 9.4	16.7 ± 9.7	0.001

Abbreviations: BMI, body mass index; CNY, Chinese yuan; NDVI, normalized difference vegetation index; $PM_{2.5}$, particulate matter ≤ 2.5 μm; SD, standard deviation.

[*] P-values were derived using two-sample t-tests for continuous variables and chi-squared test for categorical variables.

[a] Exposure level in the third trimester of pregnancy.

3.2. Exposure to UHI and associated risks for PTB

Participants residing in urban areas were exposed to an average of 2.8 °C (standard deviation, [SD]: 2.6 °C) higher temperature than participants living in non-urban areas (Table 2), and this pattern was similar across different lagged days and lagged windows (Fig. 2). UHI exposure was associated with vegetation index ($NDVI_{\text{-}500m}$) (Supplementary Material, Figure S3), socioeconomic status (income and

Table 2
Results of UHI intensity stratified by residential type.

UHI intensity (°C) mean (SD)	Overall	Non-urban	Urban	*P*-test*
lag 1w	2.58 (2.61)	−3.54 (2.54)	2.80 (2.33)	< 0.001
lag 2w	2.58 (2.58)	−3.54 (2.51)	2.80 (2.30)	< 0.001
lag 3w	2.59 (2.57)	−3.55 (2.48)	2.81 (2.28)	< 0.001
lag 1 ~ 2w	2.59 (2.60)	−3.54 (2.53)	2.81 (2.32)	< 0.001
lag 2 ~ 3w	2.60 (2.60)	−3.58 (2.52)	2.82 (2.31)	< 0.001
lag 0d	2.61 (2.83)	−3.56 (2.84)	2.83 (2.57)	< 0.001
lag 1d	2.61 (2.83)	−3.61 (2.81)	2.84 (2.56)	< 0.001
lag 2d	2.61 (2.83)	−3.58 (2.86)	2.83 (2.56)	< 0.001
lag 3d	2.61 (2.81)	−3.61 (2.83)	2.83 (2.54)	< 0.001
lag 4d	2.61 (2.81)	−3.58 (2.78)	2.83 (2.54)	< 0.001
lag 5d	2.61 (2.83)	−3.61 (2.85)	2.83 (2.56)	< 0.001
lag 6d	2.62 (2.82)	−3.60 (2.76)	2.84 (2.55)	< 0.001
lag 7d	2.61 (2.82)	−3.62 (2.80)	2.84 (2.55)	< 0.001
lag 8d	2.62 (2.81)	−3.54 (2.79)	2.84 (2.54)	< 0.001
lag 9d	2.62 (2.80)	−3.56 (2.80)	2.84 (2.54)	< 0.001
lag 10d	2.62 (2.80)	−3.59 (2.78)	2.85 (2.53)	< 0.001
lag 11d	2.60 (2.82)	−3.55 (2.82)	2.82 (2.56)	< 0.001
lag 12d	2.60 (2.82)	−3.51 (2.91)	2.82 (2.56)	< 0.001
lag 13d	2.60 (2.81)	−3.58 (2.84)	2.82 (2.55)	< 0.001
lag 14d	2.59 (2.81)	−3.57 (2.83)	2.81 (2.55)	< 0.001
lag 15d	2.61 (2.81)	−3.55 (2.88)	2.83 (2.54)	< 0.001
lag 16d	2.60 (2.80)	−3.60 (2.82)	2.82 (2.53)	< 0.001
lag 17d	2.60 (2.79)	−3.54 (2.73)	2.82 (2.53)	< 0.001
lag 18d	2.60 (2.80)	−3.61 (2.78)	2.82 (2.53)	< 0.001
lag 19d	2.59 (2.80)	−3.61 (2.79)	2.82 (2.53)	< 0.001
lag 20d	2.61 (2.81)	−3.59 (2.79)	2.83 (2.54)	< 0.001

* *P*-tests were derived using two-sample t-tests.
ˆ**Abbreviations:** SD, standard deviation; UHI, urban heat island.

education level), and self-report neighborhood variables, i.e., proximity to main roads, residential noise disturbance and domestic use of air purifier (Supplementary Material, Table S1). The associations between UHI and PTB are shown in Fig. 3. UHI exposure in the 21 days leading up to birth was associated with increased odds of PTB. Specifically, we found that each 5-degree increment in UHI intensity was associated with adjusted OR of 1.06 (95 % CI: 0.99, 1.14), 1.27 (95 % CI: 1.20, 1.34), and 1.23 (95 % CI: 1.15, 1.32) for lagged 0 day, lagged 1 day and lagged 1 week, respectively. We did not find a significant association for the day of birth (lag 0).

3.3. *Sensitivity analysis*

We excluded the non-urban dwellers (approximately 12 percent of the participants resided in non-urban areas) in the sensitivity analysis (Table S2 and Figure S4). The effect estimates from the adjusted models attenuated slightly whereas the OR reached statistical significance for the base model. When we included births in warm seasons only (i.e., May to October), we found that the associations observed in main analysis were mainly driven by births in warm seasons, but we did not find evidence of UHI mitigating the risk during colder periods. (Supplementary Material, Table S3). In addition, we also used incremental models to examine how the associations between UHI and PTB changed with the inclusion of the other variables. Fig. 4 illustrates that the inclusion of maternal factors narrowed the confident interval significantly, compared to the inclusion of residential factors, $PM_{2.5}$ and temperature in third trimester.

3.4. *Stratified analysis*

The interaction of UHI exposure with maternal age, maternal education and pre-pregnancy BMI were consistently statistically significant. The results for lag 1 day are presented in Fig. 5, with the results of the other lagged days in Supplementary Files (Figure S5-S11). We found higher effect estimates of UHI exposure for mothers who were older, with higher pre-pregnancy BMI level, higher education level and resided in areas with higher vegetation index.

4. Discussion

In the study of a nationwide birth cohort with 103,040 participants in China, we used standardized methods to assess individual-level exposure to UHI and examined the association between UHI exposure and the risk of PTB. We found that urban residents were exposed to an average of 2.8 °C higher temperature than non-urban residents. A 5-degree increment in UHI (lag 1d) was associated with a 27 % increased risk for PTB. Higher effects were observed for mothers older than 30 years of age, of higher SES and living in areas with higher $NDVI_{-500m}$ (greener areas).

To the best of our knowledge, this is the first study that utilized individual exposure assessment approach to study the association between UHI exposure and PTB. We performed additional analyses to investigate the relationship between UHI exposure and urban and non-urban residence, as well as self-reported residential variables. Urban residents had overall positive UHI values, while non-urban residents had negative UHI values, indicating that our method was able to accurately identify the UHI exposure among urban and non-urban participants. Additionally, we found that UHI exposure was positively correlated with proximity to main traffic roads and self-reported noise disturbance (Supplementary File, Table S1). Specifically, participants living within 100 m of main traffic roads had an average UHI exposure 0.4 degrees Celsius higher, while those reporting noise disturbance tended to have an average UHI exposure 0.5 degrees Celsius higher. Many health studies have also used proximity to major roads as a proxy for urban environment (Cakmak et al., 2019; Willis et al., 2021; Yao et al., 2021; Yu et al., 2021), and noise exposure might also be associated with living in urban areas (Rudolph et al., 2019). These findings suggest that UHI is associated with these urban environment variables, further supporting the validity of our individual exposure assessment method.

Numerous previous studies in China (Ren et al., 2022), the United States (Son et al., 2022; Sun et al., 2020), Korea (Son et al., 2019) and Italy (Asta et al., 2019) have suggested strong associations between exposure to heat extremes during pregnancy and risk for PTB. Such associations have also been replicated in a global analysis of 14 low- and middle-income countries (McElroy et al., 2022). A recent systematic review from the United States reported that 4 studies in the US identified increased risk (OR ranging from 1.086 to 1.21) of PTB (Bekkar et al., 2020), and a *meta*-analysis of data from 27 countries concluded that a 1 °C increment in temperature was associated with an increased odds of PTB (OR:1.05, 95 % CI: 1.03 to 1.07) (Chersich et al., 2020). Previous studies also suggested that heat stress during pregnancy can lead to an

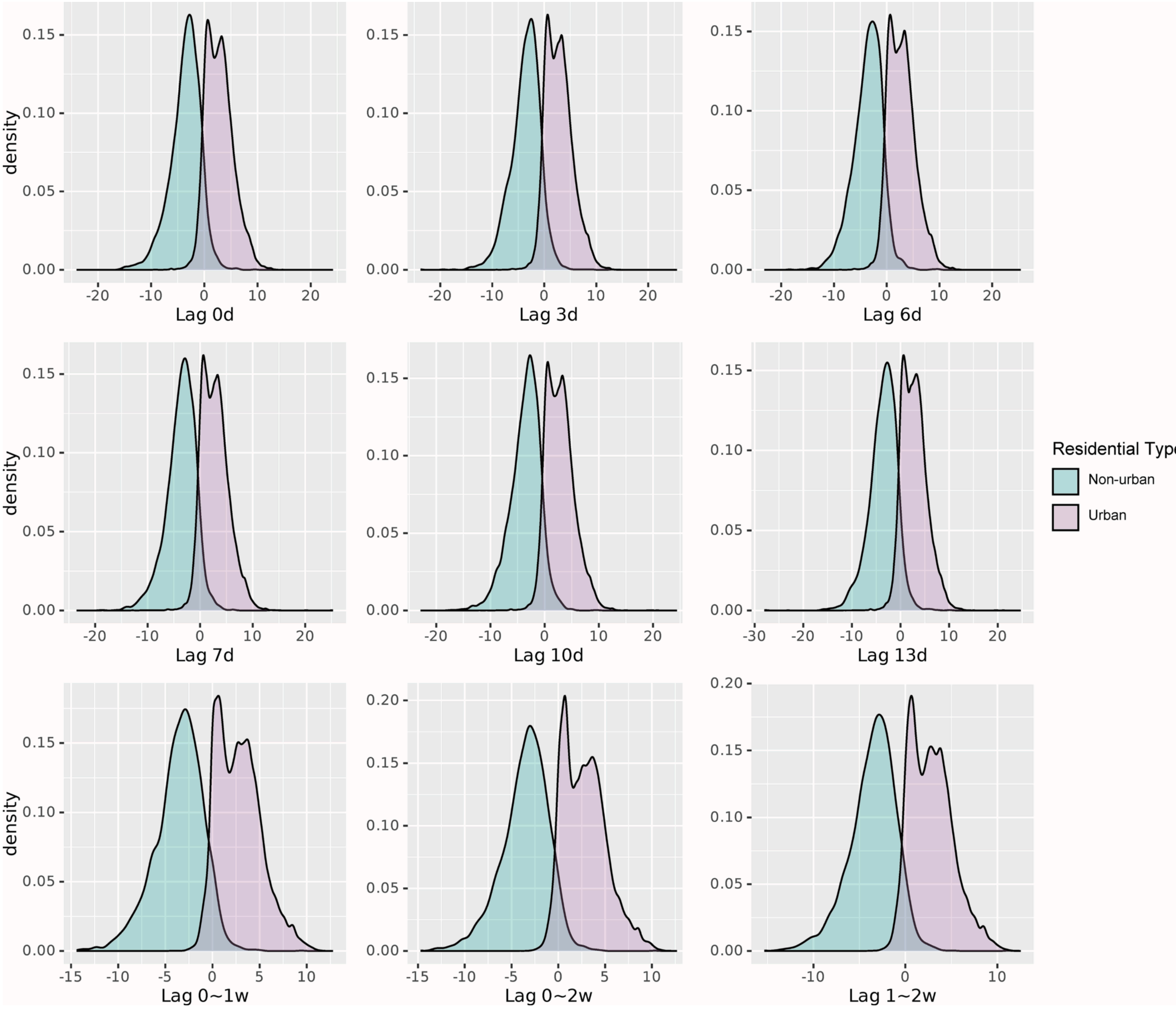

Fig. 2. Distribution of lagged individual UHI exposure in urban and non-urban participants.

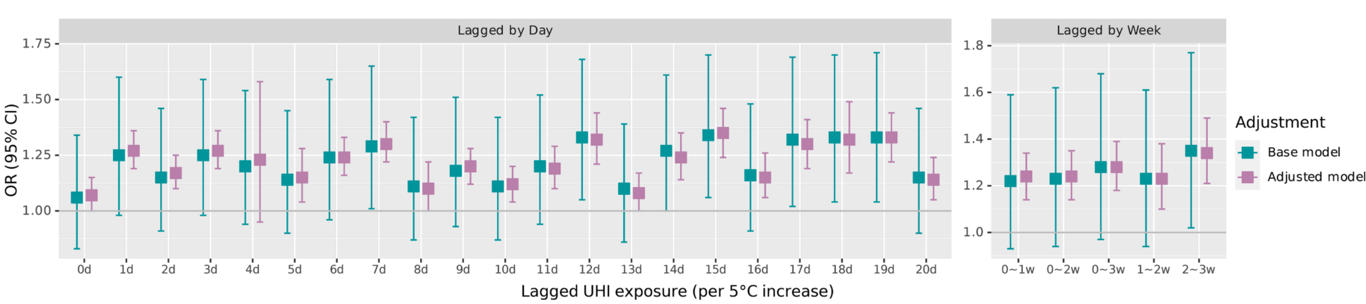

Fig. 3. Associations between lagged individual UHI exposure and preterm birth. Footnote: Base model: Model was only adjusted for residential type and random effect term (province). Adjusted model: Additionally adjusted for maternal age, pre-pregnancy BMI, month of birth, education level, ethnicity, environmental tobacco exposure, residential NDVI, noise disturbance, proximity to main roads, home use of air purifier, average $PM_{2.5}$ and temperature during the third trimester of pregnancy.

increase in the production of antidiuretic hormone (ADH) and oxytocin (OT), as well as dehydration (Dreiling et al., 1991; Stan et al., 2013). These physiological responses may contribute to a reduction in uterine blood flow and a shift in fetal metabolic pathways from anabolic to catabolic states, potentially leading to an increased risk of PTB (Wang et al., 2020). Although not all of these studies used similar heat exposure metrics, collectively, the literature suggests a higher risk of PTB due to heat exposure. Moreover, it has been suggested that UHIs might

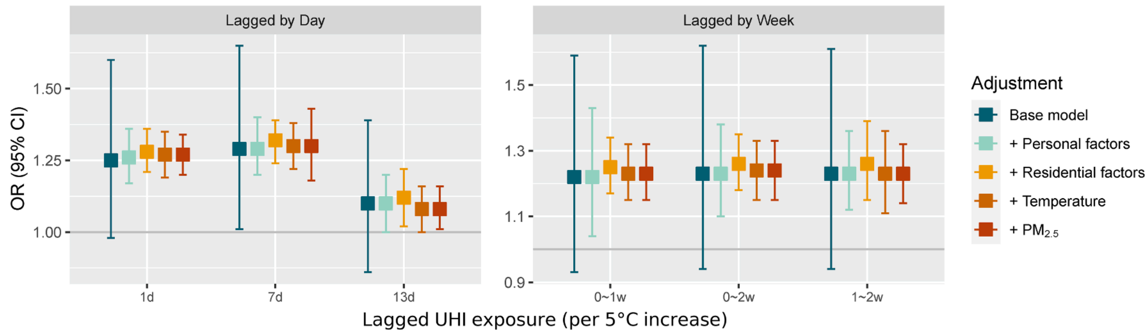

Fig. 4. Associations between individual UHI exposure and preterm birth in accumulating adjusted models. Footnote: Personal factors include maternal age, pre-pregnancy BMI, ethnicity, income, education level, environmental tobacco exposure and birth of month; Residential factors include residential NDVI, home use of air purifier, proximity to main roads and noise disturbance; $PM_{2.5}$ and temperature: average values in the third trimester of pregnancy.

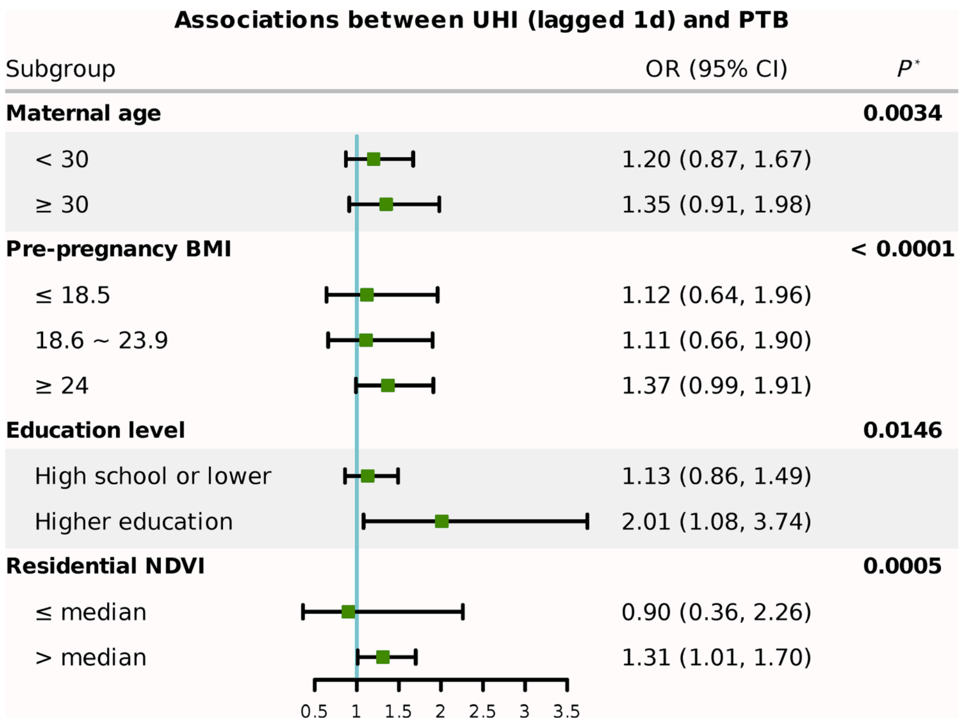

Fig. 5. Stratified associations between individual UHI exposure (lagged 1 day) and preterm birth. Footnote: *P-value for the interaction term. OR adjusted for residential type and random effect term (province), maternal age, pre-pregnancy BMI, month of birth, education level, ethnicity, environmental tobacco exposure, residential NDVI, noise disturbance, proximity to main roads, home use of air purifier, average $PM_{2.5}$ and temperature during the third trimester of pregnancy.

intensify the adverse effects of high temperatures on health, thereby increasing health risks in vulnerable populations (Iungman et al., 2023), but to the best of our knowledge, no available literature has studied and reported the risk directly associated with UHI.

Our study brought to attention the potential alleviated risk of preterm birth resulted from UHI exposure. We found approximately 1.2-fold odd of preterm birth per 5 °C increment in the assessed UHI intensity. The effect was slightly attenuated but still statistically robust, after we further excluded 12,891 participants living in non-urban areas. The current climate crisis is projected to increase the global temperature by around 4 – 4.5 °C by the end of this century (Masson-Delmotte et al., 2018), and the UHI effect will exacerbate the impact of climate change in urban settings (Chapman et al., 2017; Estrada and Perron, 2021), potentially posing greater risks to human health in cities. By adjusting our models with average temperature exposure during pregnancy, we still observed association between UHI and PTB, which partially indicates that the excess temperature increase due to UHI might even pose additional risks to human health.

In line with previous research indicating associations between temperature and PTB (He et al., 2016; Li et al., 2018; Zheng et al., 2018), our study found that births occurring in warm seasons exhibited stronger associations with PTB compared to the overall analysis. This observation suggests that the effects we observed in our main analysis may be dominated by births in warm seasons. One possible explanation for this pattern is that UHI in warm seasons can exacerbate temperature conditions, pushing them towards more extreme levels that have been associated with adverse birth outcomes. In contrast, UHI in cold seasons may modify temperatures towards more comfortable conditions, potentially mitigating the risks of PTB. However, it is worth acknowledging that neither the results for warm seasons nor cold seasons reached statistical significance in our study, potentially due to the limited statistical power resulting from dividing the dataset into subgroups, so that the aforementioned explanation is highly speculative. One previous study found similar warm/cold season pattern (Zhong et al., 2018), which is in line with our explanations. In addition, limited by the computational overhead, we were unable to conduct the UHI assessment throughout the whole pregnancy, but some previous studies have suggested that PTB might be associated with ambient temperature during conception month and the third trimester (Zheng et al., 2018). Therefore, further research with larger sample sizes and a specific focus on seasonal variations and exposure window is needed to better understand the relationship between UHI, temperature extremes, and preterm birth outcomes.

We also found that the risk for PTB was higher for mothers older than 30 years of age. Advanced maternal age has been identified as a risk factor for increased incidence of gestational diabetes mellitus (GDM) (Lao et al., 2006; Lee et al., 2023; Li et al., 2020), hypertension (Carpenter, 2007) and placental dysfunction (Lean et al., 2017). These factors could increase pregnant women's susceptibility to the adverse effects of UHI exposure. However, in contrast to previous studies that found low SES could exacerbate poor pregnancy outcomes (Noelke et al., 2019; Son et al., 2019), we found that higher SES participants might be at higher risk pf PTB from UHI exposure. This discrepancy could be partially explained by the fact that urban/rural status is highly correlated with SES in China (Wang et al., 2012), and that people in higher SES tend to live closer to prosperous areas of inner cities (Chen et al., 2016). In this context, it could be anticipated that UHI as well as other urban related health stressors could result in more adverse health outcomes, especially in rapidly urbanized, low- and middle-income countries.

We also found a stronger association between UHI for PTB in participants living in greener areas. The current literature is inconsistent regarding the ability of greener areas to modify the association between UHI and PTB. Some studies have suggested that residential greenness may contribute to lower associations between heat and preterm birth (Sun et al., 2020), however, a study in Rome reported higher risk of preterm birth from heat exposure in women living within 100 m from green spaces compared to women living beyond 500 m (Asta et al., 2019). A study in South Korea did not find significant difference of the heat effect on PTB by residential greenness (Son et al., 2019). Although it was suggested that greenness can influence ambient temperature through cooling effects by transpiration, shading, and convection (Kloog, 2019) and thus may mitigate the urban heat island, other complex factors, such as the actual use of the green space in cities, and behaviors (e.g., green space may relate with higher maternal outdoor activities resulting in increased exposure to heat) could also underline the observed differences (Son et al., 2022). As we did not collect information on the actual use pattern of green spaces, we were unable to test the proposed hypothesis. Future studies that collect the behavior patterns related to green space in urban areas are warranted.

Our study has several strengths. It is the first study to utilize an individual exposure assessment approach to study the association between UHI exposure and PTB. We developed and used standardized methods to assess individual UHI by combining residential addresses and temperature datasets, which may have implications for future studies. In addition, the comparison of UHI effect was performed at individual level, which could also minimize the likelihood of exposure misclassification. This approach is also promising for conducting analysis within a single city. However, the limitations of the study include the fact that, although we adjusted for many covariates that may affect the observed association between UHI and preterm birth, other unmeasured confounding factors may remain. Second, even though we adjusted the models for temperature exposure to minimize the potential confounding by temperature, the observed associations between UHI and PTB might still be affected, due to the uncontrolled residuals. Third, our analysis was unable to account for the potential influence of multiple births within the same pregnancy, as the information indicating singleton or multiple births is lacking. It is important to note, however, that multiple births constitute a relatively small proportion of all births, estimated at less than 5 % (Collins, 2007).Therefore, we believe its potential impact on our results may be relatively limited. Forth, we were unable to perform additional analysis to evaluate the critical exposure window throughout the whole pregnancy due to the vast data and computation overhead. Future studies in smaller regions could consider the investigation of the exposure window. In addition, we evaluated the association between PTB and each lag separately, which might not adequately account for potential non-linear exposure–response associations or relationships between lag days.

5. Conclusion

In this nationwide cohort study, we employed an innovative individual-level approach to assess UHI exposure and investigate its associated risks for PTB. This study provides evidence that maternal exposure to urban heat island effect in cities is associated with an increased risk of preterm birth. Stronger effects were observed for mothers older than 30 years of age, with higher SES and living in greener areas. These findings have implications for developing targeted interventions for susceptible subgroups of urban mothers. Better understandings of underlying mechanisms linking urban environment structure to urban heat island is essential for adaptation. More research is needed to validate our findings of the increased risk of preterm birth due to UHI exposure among pregnant women.

Funding

This study was supported by the National Natural Science Foundation of China (81872582, 81872583, M-0420), Guangdong Provincial Natural Science Foundation Team Project (2018B030312005), Natural Science Foundation of Guangdong Province (2021A1515011754, 2021B1515020015, 2020A1515011131), UGC CRF Young Collaborative Research Grant (C2002-22Y), UGC General Research Fund (12202021) and UGC Early Career Scheme (22201820) of the Hong Kong Special Administrative Region, China.

CRediT authorship contribution statement

Xiang Xiao: Methodology, Software, Validation, Formal analysis, Writing – original draft, Writing – review & editing. **Ruixia Liu:** Writing – review & editing. **Zheng Zhang:** Writing – review & editing. **Bin Jalaludin:** Writing – review & editing. **Joachim Heinrich:** Writing – review & editing. **Xiangqian Lao:** Writing – review & editing. **Lidia Morawska:** Writing – review & editing. **Shyamali C. Dharmage:** Writing – review & editing. **Luke D. Knibbs:** Writing – review & editing. **Guang-Hui Dong:** . **Meng Gao:** Conceptualization, Validation, Methodology. **Chenghong Yin:** Funding acquisition, Resources, Supervision, Project administration.

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.

Data availability

Data will be made available on request.

Acknowledgements

We appreciate the cooperation of all participating subjects in this study who have been very generous with their time and assistance. We also thank all contributors to the R projects. Finally, we acknowledge the efforts of all who did the fieldwork.

Appendix A. Supplementary Tables and Figures

Supplementary data to this article can be found online at https://doi.

org/10.1016/j.envint.2023.108356.

References

Asta, F., Michelozzi, P., Cesaroni, G., De Sario, M., Badaloni, C., Davoli, M., et al., 2019. The modifying role of socioeconomic position and greenness on the short-term effect of heat and air pollution on preterm births in rome, 2001–2013. Int. J. Environ. Res. Public Health 16, 2497.

Bekkar, B., Pacheco, S., Basu, R., DeNicola, N., 2020. Association of air pollution and heat exposure with preterm birth, low birth weight, and stillbirth in the us: A systematic review. JAMA Netw. Open 3, e208243.

Bravo, M.A., Miranda, M.L., 2022. A longitudinal study of exposure to fine particulate matter during pregnancy, small-for-gestational age births, and birthweight percentile for gestational age in a statewide birth cohort. Environ. Health 21, 9.

Cai, J., Zhao, Y., Kan, J., Chen, R., Martin, R., van Donkelaar, A., et al., 2020. Prenatal exposure to specific pm2.5 chemical constituents and preterm birth in china: A nationwide cohort study. Environ. Sci. Tech. 54, 14494–14501.

Cakmak, S., Hebbern, C., Vanos, J., Crouse, D.L., Tjepkema, M., 2019. Exposure to traffic and mortality risk in the 1991–2011 canadian census health and environment cohort (canchec). Environ. Int. 124, 16–24.

Carpenter MW. 2007. Gestational diabetes, pregnancy hypertension, and late vascular disease. Diabetes care 30:S246-S250.

Chapman, S., Watson, J.E.M., Salazar, A., Thatcher, M., McAlpine, C.A., 2017. The impact of urbanization and climate change on urban temperatures: A systematic review. Landsc. Ecol. 32 (10), 1921–1935.

Chen H, Zhu Z, Sun D, Wang X. 2016. The physical and psychological health of migrants in guangzhou, china: How does neighborhood matter? INQUIRY: The Journal of Health Care Organization, Provision, and Financing 53:0046958016668065.

Chersich, M.F., Pham, M.D., Areal, A., Haghighi, M.M., Manyuchi, A., Swift, C.P., et al., 2020. Associations between high temperatures in pregnancy and risk of preterm birth, low birth weight, and stillbirths: Systematic review and meta-analysis. BMJ 371.

Collins, J., 2007. Global epidemiology of multiple birth. Reprod. Biomed. Online 15, 45–52.

Dreiling, C.E., Carman, F.S., Brown, D.E., 1991. Maternal endocrine and fetal metabolic responses to heat stress. J. Dairy Sci. 74 (1), 312–327.

Estrada, F., Perron, P., 2021. Disentangling the trend in the warming of urban areas into global and local factors. Ann. N. Y. Acad. Sci. 1504 (1), 230–246.

Gasparrini, A., Guo, Y., Hashizume, M., Lavigne, E., Zanobetti, A., Schwartz, J., Tobias, A., Tong, S., Rocklöv, J., Forsberg, B., Leone, M., De Sario, M., Bell, M.L., Guo, Y.-L., Wu, C.-f., Kan, H., Yi, S.-M., de Sousa Zanotti Stagliorio Coelho, M., Saldiva, P.H.N., Honda, Y., Kim, H.o., Armstrong, B., 2015. Mortality risk attributable to high and low ambient temperature: A multicountry observational study. Lancet 386 (9991), 369–375.

Gronlund, C.J., Zanobetti, A., Schwartz, J.D., Wellenius, G.A., O'Neill, M.S., 2014. Heat, heat waves, and hospital admissions among the elderly in the united states, 1992–2006. Environ. Health Perspect. 122 (11), 1187–1192.

He, J.-R., Liu, Y.u., Xia, X.-Y., Ma, W.-J., Lin, H.-L., Kan, H.-D., Lu, J.-H., Feng, Q., Mo, W.-J., Wang, P., Xia, H.-M., Qiu, X., Muglia, L.J., 2016. Ambient temperature and the risk of preterm birth in guangzhou, china (2001–2011). Environ. Health Perspect. 124 (7), 1100–1106.

Ho, J.Y., Shi, Y., Lau, K.K.L., Ng, E.Y.Y., Ren, C., Goggins, W.B., 2023. Urban heat island effect-related mortality under extreme heat and non-extreme heat scenarios: A 2010–2019 case study in hong kong. Sci. Total Environ. 858.

Iungman, T., Cirach, M., Marando, F., Pereira Barboza, E., Khomenko, S., Masselot, P., Quijal-Zamorano, M., Mueller, N., Gasparrini, A., Urquiza, J., Heris, M., Thondoo, M., Nieuwenhuijsen, M., 2023. Cooling cities through urban green infrastructure: A health impact assessment of european cities. Lancet 401 (10376), 577–589.

Kloog, I., 2019. Air pollution, ambient temperature, green space and preterm birth. Curr. Opin. Pediatr. 31, 237–243.

Lao, T.T., Ho, L.-F., Chan, B.C., Leung, W.-C., 2006. Maternal age and prevalence of gestational diabetes mellitus. Diabetes Care 29, 948–949.

Lean, S.C., Derricott, H., Jones, R.L., Heazell, A.E.P., Bhutta, Z.A., 2017. Advanced maternal age and adverse pregnancy outcomes: A systematic review and meta-analysis. PLoS One 12 (10).

Lee, C.S., Zhu, S., Wu, Q.i., Hu, Y., Chen, Y., Chen, D., Liang, Z., 2023. Independent and joint associations of age, pre-pregnancy bmi, and gestational weight gain with adverse pregnancy outcomes in gestational diabetes mellitus. Diabetes Therapy 14 (2), 363–375.

Li, S., Chen, G., Jaakkola, J.J., Williams, G., Guo, Y., 2018. Temporal change in the impacts of ambient temperature on preterm birth and stillbirth: Brisbane, 1994–2013. Sci. Total Environ. 634, 579–585.

Li, Y., Ren, X., He, L., Li, J., Zhang, S., Chen, W., 2020. Maternal age and the risk of gestational diabetes mellitus: A systematic review and meta-analysis of over 120 million participants. Diabetes Res. Clin. Pract. 162.

Luo, Y.-N., Yang, B.-Y., Zou, Z., Markevych, I., Browning, M.H.E.M., Heinrich, J., et al., 2022. Associations of greenness surrounding schools with blood pressure and hypertension: A nationwide cross-sectional study of 61,229 children and adolescents in china. Environ. Res. 204, 112004.

Ma, W., Wang, L., Lin, H., Liu, T., Zhang, Y., Rutherford, S., Luo, Y., Zeng, W., Zhang, Y., Wang, X., Gu, X., Chu, C., Xiao, J., Zhou, M., 2015. The temperature–mortality relationship in china: An analysis from 66 chinese communities. Environ. Res. 137, 72–77.

Masson-Delmotte V, Zhai P, Pörtner H-O, Roberts D, Skea J, Shukla PR, et al. 2018. Global warming of 1.5 c. An IPCC Special Report on the impacts of global warming of 1:43-50.

McElroy, S., Ilango, S., Dimitrova, A., Gershunov, A., Benmarhnia, T., 2022. Extreme heat, preterm birth, and stillbirth: A global analysis across 14 lower-middle income countries. Environ. Int. 158, 106902.

Noelke, C., Chen, Y.-H., Osypuk, T.L., Acevedo-Garcia, D., 2019. Economic downturns and inequities in birth outcomes: Evidence from 149 million us births. Am. J. Epidemiol. 188, 1092–1100.

Raptis, V.S., Vaughan, R.A., Wright, G.G., 2003. The effect of scaling on land cover classification from satellite data. Comput. Geosci. 29 (6), 705–714.

Ren, M., Wang, Q., Zhao, W., Ren, Z., Zhang, H., Jalaludin, B., Benmarhnia, T., Di, J., Hu, H., Wang, Y., Ji, J.S., Liang, W., Huang, C., 2022. Effects of extreme temperature on the risk of preterm birth in china: A population-based multi-center cohort study. Lancet Regional Health-Western Pac. 24.

Rudolph KE, Shev A, Paksarian D, Merikangas KR, Mennitt DJ, James P, et al. 2019. Environmental noise and sleep and mental health outcomes in a nationally representative sample of urban us adolescents. Environmental Epidemiology 3.

Saigal, S., Doyle, L.W., 2008. An overview of mortality and sequelae of preterm birth from infancy to adulthood. Lancet 371 (9608), 261–269.

Seto, K.C., Güneralp, B., Hutyra, L.R., 2012. Global forecasts of urban expansion to 2030 and direct impacts on biodiversity and carbon pools. Proc. Natl. Acad. Sci. 109 (40), 16083–16088.

Shi, Y., Katzschner, L., Ng, E., 2018. Modelling the fine-scale spatiotemporal pattern of urban heat island effect using land use regression approach in a megacity. Sci. Total Environ. 618, 891–904.

Son, J.-Y., Lane, K.J., Lee, J.-T., Bell, M.L., 2016. Urban vegetation and heat-related mortality in seoul, korea. Environ. Res. 151, 728–733.

Son, J.-Y., Lee, J.-T., Lane, K.J., Bell, M.L., 2019. Impacts of high temperature on adverse birth outcomes in seoul, korea: Disparities by individual-and community-level characteristics. Environ. Res. 168, 460–466.

Son, J.-Y., Choi, H.M., Miranda, M.L., Bell, M.L., 2022. Exposure to heat during pregnancy and preterm birth in north carolina: Main effect and disparities by residential greenness, urbanicity, and socioeconomic status. Environ. Res. 204, 112315.

Stan, C.M., Boulvain, M., Pfister, R., Hirsbrunner-Almagbaly, P., 2013. Hydration for treatment of preterm labour. Cochrane Database Syst. Rev.

Stewart, I.D., Oke, T.R., 2012. Local climate zones for urban temperature studies. Bull. Am. Meteorol. Soc. 93, 1879–1900.

Sulla-Menashe D, Friedl MA. 2018. User guide to collection 6 modis land cover (mcd12q1 and mcd12c1) product. USGS: Reston, VA, USA 1:18.

Sulla-Menashe, D., Gray, J.M., Abercrombie, S.P., Friedl, M.A., 2019. Hierarchical mapping of annual global land cover 2001 to present: The modis collection 6 land cover product. Remote Sens. Environ. 222, 183–194.

Sun, Y., Ilango, S.D., Schwarz, L., Wang, Q., Chen, J.-C., Lawrence, J.M., et al., 2020. Examining the joint effects of heatwaves, air pollution, and green space on the risk of preterm birth in california. Environ. Res. Lett. 15, 104099.

Ulpiani, G., 2021. On the linkage between urban heat island and urban pollution island: Three-decade literature review towards a conceptual framework. Sci. Total Environ. 751.

United Nations. 2018. World urbanization prospects: The 2018 revision, key facts. Economics & Social Affairs:2.

Wang, Q., Li, J., Zheng, S., Li, J.-Y., Pang, Y.i., Huang, R., Zhang, B.-N., Zhang, B., Yang, H.-J., Xie, X.-M., Tang, Z.-H., Li, H., He, J.-J., Fan, J.-H., Qiao, Y.-L., 2012. Breast cancer stage at diagnosis and area-based socioeconomic status: A multicenter 10-year retrospective clinical epidemiological study in china. BMC Cancer 12 (1).

Wang, Q., Li, B., Benmarhnia, T., Hajat, S., Ren, M., Liu, T., et al., 2020. Independent and combined effects of heatwaves and pm2.5 on preterm birth in guangzhou, china: A survival analysis. Environ. Health Perspect. 128, 017006.

Ward, K., Lauf, S., Kleinschmit, B., Endlicher, W., 2016. Heat waves and urban heat islands in europe: A review of relevant drivers. Sci. Total Environ. 569–570, 527–539.

WHO. 2012. Born too soon: The global action report on preterm birth.

Willis, M.D., Hill, E.L., Boslett, A., Kile, M.L., Carozza, S.E., Hystad, P., 2021. Associations between residential proximity to oil and gas drilling and term birth weight and small-for-gestational-age infants in texas: A difference-in-differences analysis. Environ. Health Perspect. 129, 077002.

Xiao X, Gao M, Zhou Y, Xu S-L, Knibbs LD, Heinrich J, et al. 2022. Is greener better? Associations between greenness and birth outcomes in both urban and non-urban settings. International journal of epidemiology 51:88-98.

Xiao, X., Liu, R., Yu, Y., Zhang, Z., Knibbs, L.D., Jalaludin, B., Morawska, L., Dharmage, S.C., Heinrich, J., Papatheodorou, S., Guo, Y., Xu, Y., Jin, L., Guo, Y., Yue, W., Yao, J., Zhang, Y., Wang, C., Gao, S., Zhang, E., Su, S., Zhu, T., Dong, G.-H., Gao, M., Yin, C., 2023. Evidence of interactive effects of late-pregnancy exposure to air pollution and extreme temperature on preterm birth in china: A nationwide study. Environ. Res. Lett. 18 (9).

Yao, Y., Jin, X., Cao, K., Zhao, M., Zhu, T., Zhang, J., et al., 2021. Residential proximity to major roadways and cognitive function among chinese adults 65 years and older. Sci. Total Environ. 766, 142607.

Ye, X., Wolff, R., Yu, W., Vaneckova, P., Pan, X., Tong, S., 2012. Ambient temperature and morbidity: A review of epidemiological evidence. Environ. Health Perspect. 120 (1), 19–28.

Yu, Z., Wei, F., Zhang, X., Wu, M., Lin, H., Shui, L., et al., 2021. Air pollution, surrounding green, road proximity and parkinson's disease: A prospective cohort study. Environ. Res. 197, 111170.

Yue, W., Zhang, E., Liu, R., Zhang, Y., Wang, C., Gao, S., Su, S., Gao, X., Wu, Q., Yang, X., Papageorghiou, A.T., Yin, C., 2022. The china birth cohort study (cbcs). Eur. J. Epidemiol. 37 (3), 295–304.

Zhang, T., Zhou, Y., Zhu, Z., Li, X., Asrar, G.R., 2022. A global seamless 1 km resolution daily land surface temperature dataset (2003–2020). Earth Syst. Sci. Data 14, 651–664.

Zheng, X., Zhang, W., Lu, C., Norbäck, D., Deng, Q., 2018. An epidemiological assessment of the effect of ambient temperature on the incidence of preterm births: Identifying windows of susceptibility during pregnancy. J. Therm. Biol. 74, 201–207.

Zhong, Q., Lu, C., Zhang, W., Zheng, X., Deng, Q., 2018. Preterm birth and ambient temperature: Strong association during night-time and warm seasons. J. Therm. Biol. 78, 381–390.