Associations of $PM_{2.5}$ and its components with term preterm rupture of membranes: a retrospective study

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ABSTRACT

Background. There is evidence that fine particulate matter ($PM_{2.5}$) exposure is associated with premature rupture of membranes (PROM); however, studies of its effect on term PROM (TPROM) are limited, and the results are inconsistent.
Objective. This study aimed to investigate the association between exposure to $PM_{2.5}$ and its components and the risk of TPROM.
Methods. From 2018 to 2022, we collected delivery data from pregnant women in Guangzhou. Using 1:1 case matching, we included 1,216 TPROM cases and 1,216 controls. $PM_{2.5}$ and its component concentrations were obtained from Tracking Air Pollution in China. The time-varying mean concentration method was used to estimate exposure to $PM_{2.5}$ and its components during different trimesters. Cox proportional hazards models were used to calculate hazard ratios (HRs) and 95% confidence intervals (CIs) to evaluate the associations of exposure to $PM_{2.5}$ and its components with the risk of TPROM.
Results. The incidence of TPROM in this study was 19.66%. After adjusting for potential confounders, statistically significant associations were found between TPROM and exposure to $PM_{2.5}$, nitrate (NO_3^-), ammonium (NH_4^+), and black carbon (BC) during the second trimester and between TPROM and exposure to $PM_{2.5}$, sulphate (SO_4^{2-}), and BC during the third trimester. Specifically, the interquartile range (IQR) 3 (IQR3) and IQR4 of SO_4^{2-} exposure during the third trimester increased the risk of TPROM by 18% (95% CIs [1.01–1.39]) and 18% (95% CIs [1.01–1.39]), respectively. A nonlinear relationship was observed between exposure to $PM_{2.5}$, SO_4^{2-}, NH_4^+, and OM during the second trimester and the risk of TPROM. No significant interactions were found between $PM_{2.5}$ and its components with TPROM across various subgroups.
Conclusion. Our findings indicate significant associations between the risk of TPROM and exposure to $PM_{2.5}$ and several of its components during pregnancy. Contribute to the literature on the associations of $PM_{2.5}$ and its components with TPROM.

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INTRODUCTION

Premature rupture of membranes (PROM) refers to the breaking of foetal membranes before labour begins, with no sign of labour present after one hour (*Committee on Practice Bulletins-Obstetrics, 2018*). PROM can be divided into preterm and term PROM (TPROMs). Preterm PROM typically occurs before 37 weeks of gestation, and TPROM are defined as the rupture of membranes that occurs from 37 weeks of gestation to the start of labour (*Endale et al., 2016*). Approximately 8% of pregnant women at term experience PROM (*American College of Obstetricians and Gynecologists' Committee on Practice Bulletins—Obstetrics, 2016*). The incidence of PROM in the United States is 5% (*Getahun et al., 2007*); in Nepal, it is 8% (*Prasad Dwa, Bhandari & Bajracharya, 2023*); and in China, the incidence of PROM is 18.72% (*Zhuang et al., 2020*). Despite the widespread concern about preterm PROMs, TPROMs are also a pregnancy complication that should not be ignored, and their occurrence can lead to adverse outcomes such as perinatal death, increased rates of caesarean section, early-onset neonatal pneumonia, and neonatal sepsis (*Herbst & Kallen, 2007*; *Middleton et al., 2017*; *Namli Kalem et al., 2017*; *Zhuang et al., 2022*).

Although the causes of PROM remain unclear, several factors have been implicated, including age, previous preterm birth, smoking, polyhydramnios, urinary and sexually transmitted infections, previous PROM, caesarean section and cervical incompetence (*ACOG Committee on Practice Bulletins-Obstetrics, 2007*; *Kaye, 2001*; *Kilpatrick et al., 2006*; *Puji Astuti, Ariyani & Mahayati, 2022*). Exposure to fine particulate matter ($PM_{2.5}$) increases the risk of PROM, according to the findings of recent investigations into the relationship between air pollutants and PROM (*Dadvand et al., 2014*; *Han et al., 2020*; *Ren et al., 2024*; *Zhang et al., 2021*). A retrospective study conducted in Anhui, China, involving 4,276 participants reported that for each 10 $\mu g/m^3$ increase in $PM_{2.5}$ exposure, the risk of PROM increased by 48% (95% confidence interval (CI) [1.16–1.89]) (*Yang et al., 2024*). A retrospective cohort study conducted in southern California revealed that mothers exposed to higher levels of $PM_{2.5}$ during pregnancy had an increased risk of PROM associated with heatwaves (*Jiao et al., 2023b*). A meta-analysis by *Liang et al. (2024)* indicated that $PM_{2.5}$ exposure during mid-pregnancy and short-term maternal exposure to $PM_{2.5}$ are associated with an increased risk of PROM. Therefore, $PM_{2.5}$ exposure during pregnancy is closely associated with PROM.

The aim of this study was to analyse data from pregnant women delivering at the Maternal and Children Health Care Hospital of Huadu in Guangzhou from 2018–2022, with a focus on the associations between exposure to $PM_{2.5}$ and its components and TPROM during pregnancy.

METHODS

Subjects

This retrospective study involved pregnant women who delivered at the Maternal and Children Health Care Hospital of Huadu in Guangzhou from November 2018 to December 2022. Data were collected using the hospital's electronic medical record management system. Relevant information, including age, occupation, ethnicity, blood type, delivery date, and clinical diagnosis, was obtained by reviewing the electronic medical records. Diagnoses were classified according to the ICD-10 codes. The exclusion criteria for the study participants were as follows: (1) residing outside Guangzhou; (2) *in vitro* fertilisation; (3) pregnancy of twins; (4) diabetes before pregnancy; (5) hypertension before pregnancy; and (6) insufficient data (Fig. 1). The study focused on subjects diagnosed with PROM (ICD-10 codes O42.000, O42.000 × 001, O42.100, O42.100 × 011, O42.200, O42.900), designated the disease group, with the other subjects forming the control group. This study received approval from the Ethics Committee of the Maternal and Children's Health Care Hospital of Huadu (approval no. 2024-001). The committee waived the requirement for informed consent because anonymised data were used. This study complied with the ethical principles outlined in the 1975 Declaration of Helsinki.

Assessment of air pollution concentrations

We obtained the spatially continuous, grid-based daily average concentrations of $PM_{2.5}$ and its constituents from 2018–2022 from tracking air pollution (TAP) in China (http://tapdata.org.cn/). The TAP is a near-real-time air pollutant database that integrates information from ground observations, satellite aerosol optical depth, operational chemical transport model simulations and meteorological fields. It is based on a two-stage machine learning model that uses synthetic minority oversampling techniques and tree-based gap-filling estimation methods and has provided $PM_{2.5}$ data at a 10 × 10 km resolution since 2000 (*Geng et al., 2021*). On the basis of the 10 × 10 km resolution dataset, improving the dust emission module in the Community Multiscale Air Quality Modeling System and using the XGBoost algorithm to adjust the relative contributions of the $PM_{2.5}$ component concentrations ultimately provides more accurate 10 × 10 km resolution data for sulphate (SO_4^{2-}), nitrate (NO_3^-), ammonium (NH_4^+), organic matter (OM), and black carbon (BC) (*Liu et al., 2022*).

We used the time-varying average concentration approach to assess the relationships between exposure to $PM_{2.5}$ and its components and different stages of pregnancy, which were based on the date of birth and the last menstrual period. Following previous research (*Gong et al., 2022*), we determined the mean exposure concentrations for three specific intervals: the first trimester (weeks 1–12 of pregnancy; T1), the second trimester (weeks 13–27; T2) and the third trimester (T3), which was defined as the period from the 28th week until the birth of the baby.

Covariates

For this study, covariates were selected on the basis of prior research (*Jena et al., 2022*; *Muniz Rodriguez, Pastor & Fox, 2021*; *Wallace et al., 2016*) and data available from the

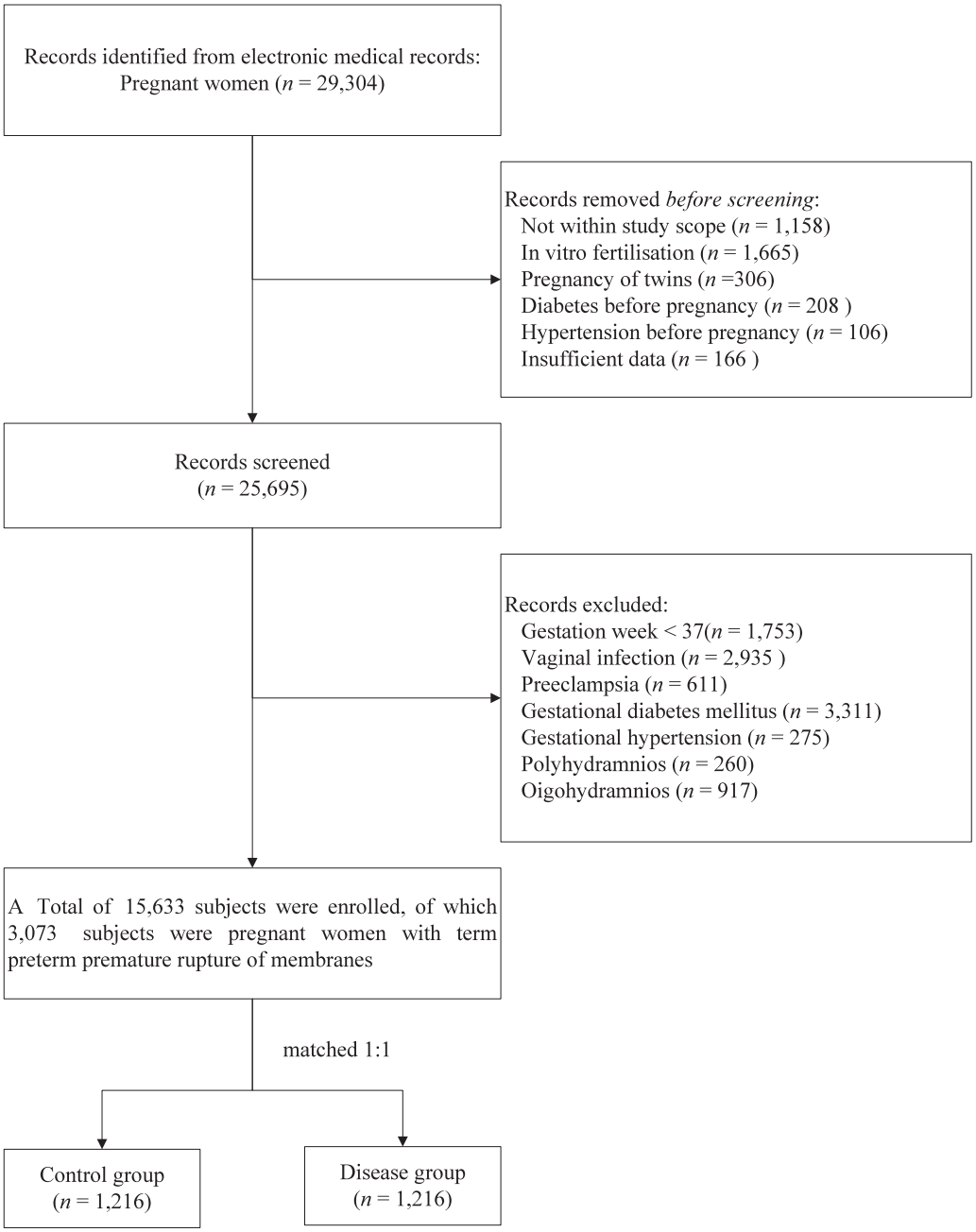

Figure 1 **Flowchart of participant screening.**

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hospital's electronic medical record system. The covariates were age, ethnicity, occupation, blood type, primary, anaemia, adverse reproductive history, uterine scar, hepatitis B virus (HBV) status, and obesity during pregnancy.

The participants provided self-reported information regarding their ethnicity (such as Han, Hui, Miao, and Tujia), occupation category (such as employee, civil servant, professional, self-employed, farmer, and unemployed), marital status (married or

divorced), and blood type (A, B, O, and AB), and the study focused on women who were pregnant and gave birth for the first time. For further analysis, ethnicity was reclassified into Han or other, occupation type was regrouped as employed, self-employed, or other, and infant weight was stratified on the basis of recorded birth weight into low birth weight (<2,500 g), normal birth weight (2,500–4,000 g), or macrosomia (>4,000 g). Hepatitis B virus status indicates that a subject is a carrier of HBV. Obesity during pregnancy was defined as a body mass index greater than or equal to 28.0 kg/m^2 during pregnancy. An adverse reproductive history refers to a history of previous poor pregnancy outcomes or obstetric complications.

Diagnosis of PROM

TPROM was determined based on the clinical diagnoses in the electronic medical records system. The diagnosis of PROM is based on three specific indicators observed by the clinician during a sterile speculum examination: (1) accumulation of clear fluid in the posterior vaginal fornix or exudation of fluid from the cervical orifice; (2) alkaline pH of the cervicovaginal secretions, usually detected by a change in colour from yellow to blue on nitrozine paper; and/or (3) the appearance of fernlike patterns in the dry cervicovaginal secretions under the microscope (*Caughey, Robinson & Norwitz, 2008*; *Wang et al., 2019*).

Statistical analyses

The descriptive characteristics of the participants were analysed *via* nonparametric tests for continuous variables and the chi-square test (χ^2) for categorical variables. This retrospective study used a case-control design, with cases being TPROM patients and controls being non-TPROM patients. Patients and controls were matched 1:1 for age and last menstrual period (LMP). This matching strategy aimed to ensure that all participants had the same starting point in early pregnancy, thereby placing each in a similar environment for most of their pregnancies. Once matching was complete, a Cox proportional hazards model was used to estimate hazard ratios (HRs) and 95% confidence intervals (CIs) to assess the associations of exposure to $PM_{2.5}$ and its components with the risk of TPROM, controlling for potential confounders, including age, occupation, blood group, ethnicity, parity, HBV status, obesity during pregnancy, adverse reproductive history, and uterine scar. Based on previous studies (*Desquilbet & Mariotti, 2010*; *Fan, Zhang & Zhong, 2017*; *Wan et al., 2024*), we used Cox proportional hazards model alongside restricted cubic splines curves to assess the relationship between exposure to $PM_{2.5}$ and its constituents and the risk of TPROM. The reference value, established at the 10th percentile with an HR of 1, was compared using knots positioned at the 5th, 35th, 65th, and 95th percentiles of the concentration levels of $PM_{2.5}$ and its components. In addition, interaction analyses were performed to explore possible interactions between exposure to air pollutants during pregnancy and these confounders. Matching was performed *via* R version 4.2.2, and regression analyses were performed using STATA 16.0. A p value of less than 0.05 was considered indicative of statistical significance.

RESULTS

Baseline characteristics

In a sample of 15,633 cases, 19.66% of full-term pregnant women experienced TPROM, using 1:1 case matching, we included 1,216 TPROM cases and 1,216 controls. After matching, the Z-values or χ^2-values for age, ethnicity, occupation, primary, anaemia, adverse reproductive history, uterine scar, Hepatitis B (HBV) status, infant weight, and pollution concentration all decreased to varying degrees. Specifically, age, race, occupation and adverse obstetric history changed significantly before and after matching, with p-values of 0.025, 0.016, <0.001 and 0.017 before matching and 1,000, 0.169, 0.777 and 0.205 after matching, respectively (Table 1), indicating that the differences between the case and control groups were significantly reduced. This suggests that case matching helps balance baseline characteristics, enhancing the accuracy of the assessment of factors associated with TPROM.

Correlations among $PM_{2.5}$, SO_4^{2-}, NO_3^-, NH_4^+, OM, and BC

Table S1 displays the spearman correlation coefficients for mean daily concentrations of $PM_{2.5}$ and its components. $PM_{2.5}$ showed strong positive correlations with all of its components, ranging from 0.933 (with NO_3^-) to 0.990 (with OM). SO_4^{2-}, NO_3^-, NH_4^+, OM, and BC also exhibited high correlations, indicating strong associations among these pollutants.

Association of air pollution with PROM

After adjusting for potential confounders, we observed no statistically significant HR for the association of TPROM with exposure to $PM_{2.5}$ or its components during the first trimester (Table 2). During the second trimester, we observed a statistically significant association between TPROM and exposure to $PM_{2.5}$, NO_3^-, NH_4^+, and BC. Specifically, increases in the interquartile range (IQR) 2 of $PM_{2.5}$, NO_3^-, and NH_4^+ were associated with hazard ratios of 1.19 (95% CI [1.01–1.40]), 1.19 (95% CI [1.02–1.40]), and 1.21 (95% CI [1.03–1.42]), respectively. Additionally, a significant association was observed with an increase in IQR3 for BC, with an HR of 1.18 (95% CI [1.01–1.39]) (Table 3). In the third trimester, TPROM was significantly associated with exposure to $PM_{2.5}$, SO_4^{2-}, and BC. Specifically, the IQR3 and IQR4 of SO_4^{2-} exposure during the third trimester increased the risk of TPROM by 18% (95% CIs [1.01–1.39]) and 18% (95% CIs [1.01–1.39]), respectively (Table 4).

After adjusting for covariates, a nonlinear relationship was observed between exposure to $PM_{2.5}$, SO_4^{2-}, NH_4^+, and OM during the second trimester and the risk of TPROM (p values for nonlinearity of 0.019, 0.044, 0.035, and 0.034, respectively) (Fig. 2).

Subgroup analysis

In subgroup analyses after adjustment for confounders, we observed no significant interactions between exposure to $PM_{2.5}$, SO_4^{2-}, NO_3^-, NH_4^+, OM, or BC and TPROM during pregnancy in terms of age, occupation, ethnicity, parity, HBV status, adverse reproductive history, or uterine scar subgroup (Table 5 and Fig. 3).

Table 1 Descriptive characteristics of this study, 2018–2022.

Variable	Before matching				After matching			
	Control group ($n = 12,560$)	Disease group ($n = 3,073$)	Z/χ^2	*p*-value	Control group ($n = 1,216$)	Disease group ($n = 1,216$)	Z/χ^2	*p*-value
Age, mean (SD)	29.30 (4.59)	29.2 (4.47)	2.238	0.025	28.8 (3.26)	28.8 (3.26)	0.000	1.000
Ethnicity[a], *n* (%)	☐	☐	5.755	0.016	☐	☐	1.894	0.169
Han	12,305 (98.0%)	2,989 (97.3%)			1,194 (98.2%)	1,184 (97.4%)		
Other	255 (2.03%)	84 (2.73%)			22 (1.81%)	32 (2.63%)		
Occupation[b], *n* (%)	☐	☐	19.100	<0.001	☐	☐	0.505	0.777
Employed	7,300 (58.1%)	1,888 (61.4%)			729 (60.0%)	739 (60.8%)		
Self-employed	788 (6.27%)	139 (4.52%)			61 (5.02%)	54 (4.44%)		
Other	4,472 (35.6%)	1,046 (34.0%)			426 (35.0%)	423 (34.8%)		
Blood Type, *n* (%)	☐	☐	1.345	0.719	☐	☐	2.347	0.504
Type A	3,500 (27.9%)	856 (27.9%)			326 (26.8%)	338 (27.8%)		
Type B	3,134 (25.0%)	763 (24.8%)			302 (24.8%)	271 (22.3%)		
Type O	5,053 (40.2%)	1,257 (40.9%)			503 (41.4%)	524 (43.1%)		
Type AB	873 (6.95%)	197 (6.41%)			85 (6.99%)	83 (6.83%)		
Primary, *n* (%)	☐	☐	71.117	<0.001	☐	☐	24.440	<0.001
NO	4,692 (37.4%)	898 (29.2%)			401 (33.0%)	291 (23.9%)		
Yes	7,868 (62.6%)	2,175 (70.8%)			815 (67.0%)	925 (76.1%)		
Anemia, *n* (%)	☐	☐	0.450	0.502	☐	☐	0.279	0.597
No	5,958 (47.4%)	1,437 (46.8%)			562 (46.2%)	575 (47.3%)		
Yes	6,602 (52.6%)	1,636 (53.2%)			654 (53.8%)	641 (52.7%)		
Adverse reproductive history, *n* (%)	☐	☐	5.699	0.017	☐	☐	1.798	0.205
No	11,394 (90.7%)	2,830 (92.1%)			1,109 (91.2%)	1,127 (92.7%)		
Yes	1,166 (9.28%)	243 (7.91%)			107 (8.80%)	89 (7.32%)		

(*continued on next page*)

Table 1 (*continued*)

Variable	Before matching				After matching			
	Control group ($n = 12,560$)	Disease group ($n = 3,073$)	Z/χ^2	*p*-value	Control group ($n = 1,216$)	Disease group ($n = 1,216$)	Z/χ^2	*p*-value
Uterine scar, *n* (%)	☐	☐	254.427	<0.001	☐	☐	148.632	<0.001
No	10,003 (79.6%)	2,825 (92.0%)			915 (75.2%)	1,134 (93.3%)		
Yes	2,557 (20.4%)	247 (8.04%)			301 (24.8%)	82 (6.74%)		
HBV status, *n* (%)	☐	☐	7.354	0.007	☐	☐	4.433	0.042
No	11,511 (91.6%)	2,862 (93.1%)			1,106 (91.0%)	1,134 (93.3%)		
Yes	1,049 (8.35%)	211 (6.87%)			110 (9.05%)	82 (6.74%)		
Obesity in pregnancy, *n* (%)	☐	☐	0.157	0.692	☐	☐	2.586	0.108
No	12,486 (99.4%)	3,053 (99.3%)			1,206 (99.2%)	1,212 (99.7%)		
Yes	74 (0.59%)	20 (0.65%)			10 (0.82%)	4 (0.33%)		
Infant gender, *n* (%)	☐	☐	0.162	0.688	☐	☐	0.200	0.655
Male	6,685 (53.2%)	1,648 (53.6%)			649 (53.4%)	660 (54.3%)		
Female	5,875 (46.8%)	1,425 (46.4%)			567 (46.6%)	556 (45.7%)		
Infant Weight, *n* (%)	☐	☐	84.714	<0.001	☐	☐	13.557	0.001
<2,500 g	351 (2.79%)	176 (5.73%)			38 (3.12%)	57 (4.69%)		
2,500–4,000 g	11,945 (95.1%)	2,871 (93.4%)			1,150 (94.6%)	1,150 (94.6%)		
>4,000 g	264 (2.10%)	26 (0.85%)			28 (2.30%)	9 (0.74%)		
Pollution, median (IQR)[c]	☐	☐			☐	☐		
$PM_{2.5}$ ($\mu g/m^3$)	27.8 (21.9, 29.8)	27.7 (21.7, 29.7)	1.173	0.241	28.10 (22.10, 29.80)	28.10 (22.10, 29.80)	−0.060	0.950
SO_4^{2-} ($\mu g/m^3$)	5.4 (4.28, 5.88)	5.39 (4.27, 5.87)	1.103	0.270	5.46 (4.33, 5.88)	5.46 (4.32, 5.88)	−0.060	0.952
NO_3^- ($\mu g/m^3$)	3.81 (3.20, 4.38)	3.77 (3.12, 4.36)	1.662	0.097	3.82 (3.22, 4.41)	3.82 (3.20, 4.41)	−0.001	0.999

(*continued on next page*)

Table 1 (*continued*)

Variable	Before matching				After matching			
	Control group ($n = 12,560$)	Disease group ($n = 3,073$)	Z/χ^2	*p*-value	Control group ($n = 1,216$)	Disease group ($n = 1,216$)	Z/χ^2	*p*-value
NH_4^+ (μg/m^3)	2.91 (2.39, 3.28)	2.9 (2.35, 3.26)	1.619	0.106	2.92 (2.42, 3.28)	2.93 (2.40, 3.29)	−0.048	0.962
OM (μg/m^3)	7.38 (5.72, 7.97)	7.36 (5.71, 7.94)	1.015	0.310	7.47 (5.75, 7.97)	7.48 (5.74, 7.97)	−0.063	0.950
BC (μg/m^3)	1.52 (1.19, 1.64)	1.52 (1.19, 1.64)	0.896	0.370	1.54 (1.20, 1.64)	1.54 (1.20, 1.65)	−0.075	0.940

Notes.

[a]Han, Hui, Miao, Tujia, *etc.*

[b]Employee, civil servant, professional, self-employed, farmer, unemployed, *etc.*

[c]Median (IQR) for exposure during first to third trimester.

HBV status, hepatitis B virus status; IQR, interquartile range.

$PM_{2.5}$, particulate matter with aerodynamic diameter of ≤2.5 μm; SO_4^{2-}, sulfate; NO_3^-, nitrate.

NH^+, ammonium; OM, organic matter; BC, black carbon.

DISCUSSION

In a retrospective study, we investigated the associations of exposure to $PM_{2.5}$ and its components during pregnancy with TPROM. We found that exposure to $PM_{2.5}$, SO_4^{2-}, NO_3^-, NH_4^+, and BC was significantly associated with an increased risk of TPROM. However, when we conducted subgroup analyses by age, ethnicity, occupation, blood type, parity, adverse reproductive history, and uterine scarring, we did not observe any significant interactions between exposure to $PM_{2.5}$ and its components and TPROM. The findings suggest that exposure to air pollution during pregnancy increases the risk of TPROM irrespective of individual characteristics.

An increasing number of studies indicate that exposure to respirable particulate matter, especially $PM_{2.5}$, is closely related to oxidative stress responses (*Ambroz et al., 2016*; *Moller & Loft, 2010*; *Orellano et al., 2020*; *Saffari et al., 2014*). Long-term exposure to $PM_{2.5}$ can inhibit nitric oxide (NO)-dependent microvascular dilation and impair mitochondrial oxidative capacity (*Della Guardia & Wang, 2023*). Because mitochondria are prone to accumulate oxidative DNA modifications in oxidative environments (*Muftuoglu, Mori & De Souza-Pinto, 2014*), this may affect the function and integrity of foetal membranes, potentially leading to PROM. A study conducted in Taiyuan, China, revealed a significant association between oxidative stress and exposure to $PM_{2.5}$ and its components (*Li et al., 2023*). *Kumari et al. (2023)* reported in a case-control study that the mtDNA copy number was significantly greater in patients with early membrane rupture than in controls. In addition, *Menon et al. (2012)* conducted a study in the United States on telomere length in foetal leukocytes associated with preterm-PROM compared with intact membranes in preterm and term births. They reported that telomere length was significantly shorter in preterm-PROM cases than in age-matched preterm controls. Therefore, exposure to $PM_{2.5}$ during pregnancy may contribute to PROM.

The incidence of TPROM in this study was 19.66%, which is consistent with the 19.55% incidence rate reported in Shanghai (*Li et al., 2021*). This similarity may be attributed

Table 2 HRs and 95% CIs associated with TPROM in the first trimester per IQR increase in $PM_{2.5}$ and its components.

Variable		Crude		Adjusted[a]	
		HRs (95% CIs)	*p*-value	HRs (95% CIs)	*p*-value
$PM_{2.5}$	IQR1	Ref (–)		Ref (–)	
	IQR2	0.89 (0.76–1.04)	0.138	0.88 (0.74–1.03)	0.105
	IQR3	1.02 (0.87–1.20)	0.785	1.03 (0.88–1.21)	0.713
	IQR4	1.12 (0.96–1.31)	0.162	1.10 (0.94–1.29)	0.249
SO_4^{2-}	IQR1	Ref (–)		Ref (–)	
	IQR2	0.93 (0.80–1.09)	0.391	0.91 (0.78–1.07)	0.265
	IQR3	1.05 (0.90–1.24)	0.524	1.04 (0.88–1.22)	0.636
	IQR4	1.10 (0.94–1.29)	0.228	1.11 (0.94–1.30)	0.221
NO_3^-	IQR1	Ref (–)		Ref (–)	
	IQR2	0.97 (0.83–1.13)	0.682	0.95 (0.81–1.11)	0.494
	IQR3	1.01 (0.87–1.19)	0.868	1.01 (0.86–1.18)	0.910
	IQR4	1.11 (0.95–1.31)	0.188	1.08 (0.92–1.27)	0.365
NH_4^+	IQR1	Ref (–)		Ref (–)	
	IQR2	0.95 (0.81–1.12)	0.537	0.94 (0.80–1.10)	0.429
	IQR3	1.02 (0.87–1.20)	0.805	1.02 (0.87–1.20)	0.809
	IQR4	1.16 (0.99–1.36)	0.067	1.11 (0.95–1.31)	0.190
OM	IQR1	Ref (–)		Ref (–)	
	IQR2	0.91 (0.77–1.06)	0.222	0.89 (0.76–1.05)	0.170
	IQR3	1.01 (0.87–1.19)	0.867	1.01 (0.86–1.19)	0.876
	IQR4	1.11 (0.94–1.30)	0.219	1.10 (0.94–1.29)	0.249
BC	IQR1	Ref (–)		Ref (–)	
	IQR2	0.94 (0.80–1.10)	0.431	0.94 (0.80–1.10)	0.414
	IQR3	1.06 (0.90–1.24)	0.475	1.07 (0.91–1.26)	0.419
	IQR4	1.15 (0.98–1.35)	0.083	1.16 (0.98–1.36)	0.083

Notes.

[a]Adjusted for age, occupation, blood group, ethnicity, parity, HBV status, obesity in pregnancy, adverse reproductive history, and uterine scar.

HRs, hazard ratio; 95% CIs, 95% confidence intervals; TPROM, term premature rupture of membranes; IQR, Interquartile Range; Ref, Reference.

$PM_{2.5}$, particulate matter with aerodynamic diameter of ≤2.5 μm; SO_4^{2-}, sulfate; NO_3^-, nitrate; NH^+, ammonium; OM, organic matter; BC, black carbon.

to both cities being economically developed metropolitan areas with similar healthcare conditions, socioeconomic levels, and environmental factors. Additionally, although the study periods differed, their time spans were relatively close, and similarities in public health policies and living environments may also have contributed to the similarity of the results. Previous studies of the relationship between $PM_{2.5}$ and the risk of PROM have yielded inconsistent results. A retrospective study conducted in the United States revealed that the risk of PROM increased in the days or hours before delivery (*Wallace et al., 2016*). In a cohort study in Wuhan, China, involving 4,364 pregnant women, there was a positive association between $PM_{2.5}$ exposure and PROM. For each 10 $\mu g/m^3$ increase in $PM_{2.5}$ exposure, the risk of PROM increased by 14% (95% CI [1.02–1.26]), 9% (95% CI [1.00–1.18]), and 13% (95% CI [1.03–1.24]) in the first, second, and third

Table 3 HRs and 95% CIs associated with TPROM in the second trimester per IQR increase in $PM_{2.5}$ and its components.

Variable		Crude		Adjusted[a]	
		HRs (95% CIs)	*p*-value	HRs (95% CIs)	*p*-value
$PM_{2.5}$	IQR1	Ref (–)	□	Ref (–)	□
	IQR2	1.20 (1.03–1.41)	0.023	1.19 (1.01–1.40)	0.035
	IQR3	1.13 (0.97–1.33)	0.121	1.14 (0.97–1.34)	0.107
	IQR4	1.02 (0.87–1.20)	0.779	1.06 (0.91–1.25)	0.459
SO_4^{2-}	IQR1	Ref (–)	□	Ref (–)	□
	IQR2	1.17 (1.00–1.37)	0.057	1.16 (0.99–1.36)	0.069
	IQR3	1.17 (1.00–1.37)	0.054	1.17 (1.00–1.37)	0.054
	IQR4	1.01 (0.86–1.19)	0.88	1.06 (0.90–1.24)	0.495
NO_3^-	IQR1	Ref (–)	□	Ref (–)	□
	IQR2	1.22 (1.04–1.43)	0.014	1.19 (1.02–1.40)	0.032
	IQR3	1.13 (0.97–1.33)	0.121	1.16 (0.99–1.36)	0.065
	IQR4	1.00 (0.85–1.17)	0.967	1.03 (0.88–1.21)	0.705
NH_4^+	IQR1	Ref (–)	□	Ref (–)	□
	IQR2	1.23 (1.05–1.44)	0.011	1.21 (1.03–1.45)	0.023
	IQR3	1.12 (0.96–1.31)	0.160	1.15 (0.98–1.35)	0.081
	IQR4	1.01 (0.86–1.18)	0.907	1.05 (0.89–1.23)	0.577
OM	IQR1	Ref (–)	□	Ref (–)	□
	IQR2	1.16 (0.99–1.37)	0.062	1.16 (0.99–1.36)	0.071
	IQR3	1.14 (0.97–1.33)	0.115	1.15 (0.97–1.34)	0.101
	IQR4	1.06 (0.90–1.24)	0.497	1.10 (0.94–1.29)	0.248
BC	IQR1	Ref (–)	□	Ref (–)	□
	IQR2	1.13 (0.97–1.33)	0.125	1.14 (0.97–1.33)	0.123
	IQR3	1.18 (1.01–1.38)	0.044	1.18 (1.01–1.39)	0.043
	IQR4	1.05 (0.90–1.23)	0.557	1.10 (0.94–1.29)	0.247

Notes.

[a]Adjusted for age, occupation, blood group, ethnicity, parity, HBV status, obesity in pregnancy, adverse reproductive history, and uterine scar.

HRs, hazard ratio; 95% CIs, 95% confidence intervals; TPROM, term premature rupture of membranes; IQR, Interquartile Range; Ref, Reference.

$PM_{2.5}$, particulate matter with aerodynamic diameter of ≤2.5 μm; SO_4^{2-}, sulfate; NO_3^-, nitrate; NH^+, ammonium; OM, organic matter; BC, black carbon.

trimesters, respectively (*Wang et al., 2019*). However, a time series study by *Li et al. (2021)* in Shanghai, China, involving 100,200 pregnant women revealed that $PM_{2.5}$ exposure did not increase the risk of PROM. Similarly, a longitudinal study conducted in New York, USA, with 130,070 participants reported no association between $PM_{2.5}$ levels and preterm PROM (*Pereira et al., 2016*). Additionally, a study in Spain on the relationship between air pollution and preterm PROM indicated that increasing $PM_{2.5}$ exposure by one quartile did not increase the risk of preterm PROM (OR: 1.04, 95% CI [0.76–1.43]) (*Dadvand et al., 2014*). The results of this study differ from those of previous investigations. In this study, exposure to $PM_{2.5}$ during the second and third trimesters of pregnancy increased the risk of TPROM. The differences in the results may be due to several factors. First, differences in geographical regions and environmental conditions between studies could

Table 4 HRs and 95% CIs associated with TPROM in the third trimester per IQR increase in $PM_{2.5}$ and its components.

Variable		Crude		Adjusted[a]	
		HRs (95% CIs)	*p*-value	HRs (95% CIs)	*p*-value
$PM_{2.5}$	IQR1	Ref (–)	□	Ref (–)	□
	IQR2	1.08 (0.93–1.27)	0.318	1.08 (0.92–1.27)	0.333
	IQR3	1.17 (0.99–1.37)	0.060	1.21 (1.03–1.42)	0.024
	IQR4	1.13 (0.96–1.32)	0.145	1.14 (0.97–1.34)	0.119
SO_4^{2-}	IQR1	Ref (–)	□	Ref (–)	□
	IQR2	1.14 (0.97–1.33)	0.114	1.13 (0.96–1.32)	0.149
	IQR3	1.14 (0.97–1.34)	0.106	1.18 (1.01–1.39)	0.040
	IQR4	1.18 (1.00–1.38)	0.045	1.18 (1.01–1.39)	0.042
NO_3^-	IQR1	Ref (–)	□	Ref (–)	□
	IQR2	1.07 (0.91–1.25)	0.417	1.06 (0.91–1.25)	0.452
	IQR3	1.06 (0.91–1.24)	0.461	1.07 (0.91–1.26)	0.397
	IQR4	1.08 (0.92–1.26)	0.357	1.10 (0.94–1.29)	0.250
NH_4^+	IQR1	Ref (–)	□	Ref (–)	□
	IQR2	1.04 (0.89–1.22)	0.652	1.03 (0.88–1.21)	0.686
	IQR3	1.04 (0.89–1.22)	0.609	1.05 (0.90–1.24)	0.519
	IQR4	1.09 (0.93–1.28)	0.285	1.11 (0.95–1.30)	0.206
OM	IQR1	Ref (–)	□	Ref (–)	□
	IQR2	1.12 (0.96–1.31)	0.164	1.12 (0.96–1.31)	0.165
	IQR3	1.08 (0.92–1.26)	0.372	1.11 (0.94–1.30)	0.216
	IQR4	1.14 (0.97–1.34)	0.105	1.15 (0.98–1.35)	0.088
BC	IQR1	Ref (–)	□	Ref (–)	□
	IQR2	1.05 (0.90–1.23)	0.532	1.04 (0.89–1.22)	0.611
	IQR3	1.17 (1.00–1.37)	0.057	1.20 (1.03–1.41)	0.024
	IQR4	1.10 (0.94–1.29)	0.224	1.12 (0.95–1.31)	0.170

Notes.

[a]Adjusted for age, occupation, blood group, ethnicity, parity, HBV status, obesity in pregnancy, adverse reproductive history, and uterine scar.

HRs, hazard ratio; 95% CIs, 95% confidence intervals; TPROM, term premature rupture of membranes; IQR, Interquartile Range; Ref, Reference.

$PM_{2.5}$, particulate matter with aerodynamic diameter of ≤2.5 μm; SO_4^{2-}, sulfate; NO_3^-, nitrate; NH^+, ammonium; OM, organic matter; BC, black carbon.

lead to differences in the composition and concentration of $PM_{2.5}$, which could affect the risk of PROM. Second, differences in study methods and designs, such as sample size, exposure assessment methods and analytical techniques, could affect the accuracy of the results. For example, time series analysis was used in a study conducted in Shanghai, logistic regression models were used in Wuhan, and Cox proportional hazards models were used in this study. Finally, differences in the lifestyle, health status and genetic background of pregnant women may lead to different responses to $PM_{2.5}$ exposure.

Few studies have investigated the relationships between $PM_{2.5}$ components and PROM, particularly TPROM. *Han et al. (2020)* conducted a study in Nanjing on 1,715 pregnant women and reported that exposure to black carbon and organic matter increased the risk of PROM and shortened the gestational age. A previous study conducted in Spain on

Table 5 Subgroup analysis of the associations of exposure to $PM_{2.5}$, SO_4^{2-}, NO_3^- and TPROM during pregnancy.

Variable	$PM_{2.5}$			SO_4^{2-}			NO_3^-		
	Adjusted HR (95% CI)[a]	*P* value	*P* for interaction	Adjusted HR (95% CI)[a]	*P* value	*P* for interaction	Adjusted HR (95% CI)[a]	*P* value	*P* for interaction
Age			0.459			0.420			0.448
>35 years	1.01 (1.00–1.03)	0.142		1.06 (0.98–1.15)	0.137		1.04 (0.95–1.12)	0.412	
≥35 years	1.04 (0.98–1.11)	0.221		1.26 (0.89–1.77)	0.187		1.23 (0.84–1.80)	0.280	
Ethnicity			0.821			0.713			0.626
Han	1.01 (1.00–1.03)	0.086		1.07 (0.99–1.16)	0.084		1.05 (0.97–1.14)	0.236	
Other	1.01 (0.92–1.12)	0.788		1.13 (0.67–1.91)	0.654		0.88 (0.53–1.44)	0.606	
Occupation			0.546			0.536			0.632
Employed	1.02 (1.00–1.03)	0.107		1.09 (0.99–1.20)	0.089		1.05 (0.95–1.17)	0.317	
Self-employed	1.06 (0.98–1.15)	0.168		1.35 (0.88–2.07)	0.166		1.31 (0.82–2.10)	0.255	
Other	1.00 (0.98–1.03)	0.743		1.02 (0.89–1.16)	0.77		1.01 (0.88–1.15)	0.906	
Blood type			0.727			0.707			0.630
Type A	1.02 (0.99–1.04)	0.260		1.08 (0.94–1.24)	0.304		1.08 (0.93–1.25)	0.322	
Type B	1.02 (0.99–1.05)	0.210		1.12 (0.95–1.32)	0.161		1.09 (0.92–1.29)	0.340	
Type O	1.01 (0.99–1.03)	0.375		1.05 (0.94–1.18)	0.381		1.02 (0.90–1.14)	0.779	
Primary			0.242			0.368			0.149
No	1.02 (1.00–1.04)	0.030		1.10 (1.01–1.2)	0.037		1.08 (0.99–1.19)	0.096	
Yes	1.00 (0.97–1.03)	0.873		1.00 (0.85–1.18)	0.967		0.94 (0.79–1.11)	0.447	
Adverse reproductive history			0.645			0.944			0.258
No	1.01 (1.00–1.03)	0.057		1.08 (1.00–1.17)	0.065		1.06 (0.98–1.15)	0.157	
Yes	0.99 (0.94–1.05)	0.738		1.01 (0.75–1.35)	0.964		0.83 (0.61–1.14)	0.254	
Uterine scar			0.883			0.964			0.842
No	1.01 (1.00–1.03)	0.079		1.08 (1.00–1.17)	0.065		1.05 (0.97–1.14)	0.235	
Yes	1.02 (0.95–1.09)	0.652		1.05 (0.74–1.49)	0.775		0.97 (0.69–1.37)	0.883	
HBV status			0.760			0.917			0.276
No	1.01 (1.00–1.03)	0.094		1.07 (0.99–1.16)	0.079		1.04 (0.95–1.12)	0.401	
Yes	1.02 (0.96–1.10)	0.468		1.09 (0.78–1.54)	0.608		1.26 (0.87–1.84)	0.217	

Notes.

[a]Adjusted for age, occupation, blood group, ethnicity, parity, HBV status, obesity in pregnancy, adverse reproductive history, and uterine scar.

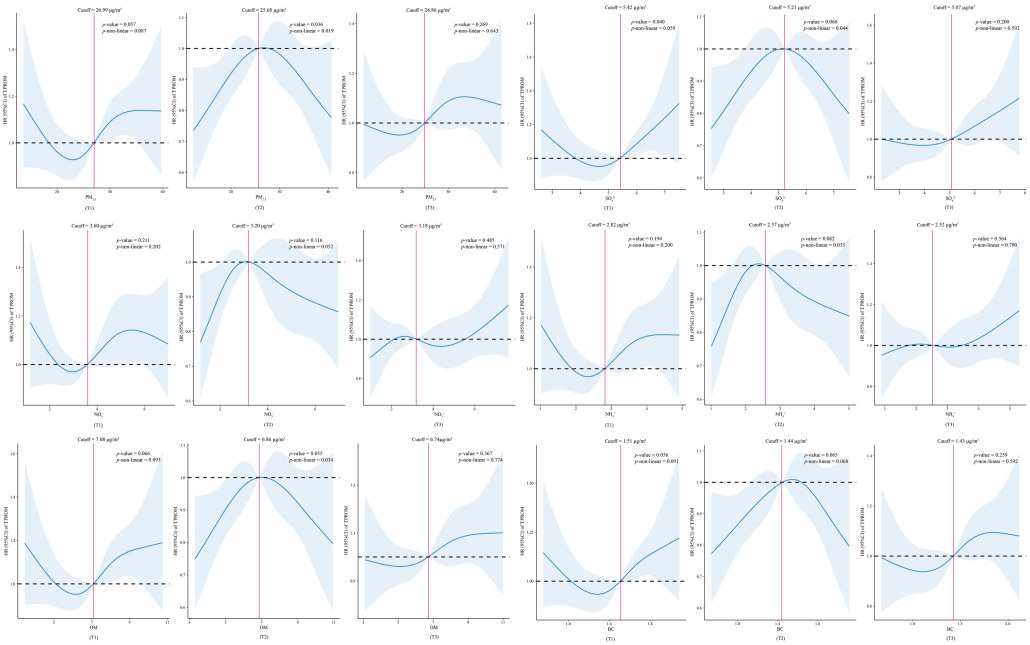

Figure 2 Association between predicted exposure to $PM_{2.5}$ and its constituents and TPROM risk. T1, the first trimester. T2, the second trimester. T3, the third trimester. HR, hazard ratio. 95% CIs, 95% confidence intervals. TPROM, term premature rupture of membranes. $PM_{2.5}$, fine particulate matter. SO_4^{2-}, sulfate. NO_3^-, nitrate. NH^+, ammonium. OM, organic matter. BC, black carbon.

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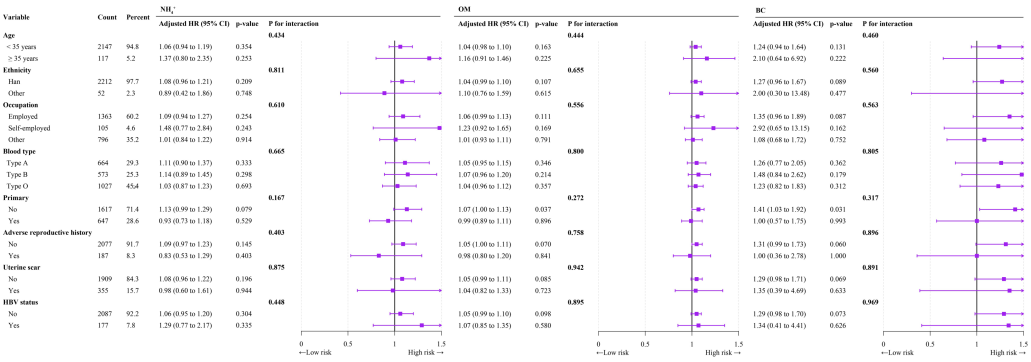

Variable	Count	Percent	NH_4^+ Adjusted HR (95% CI)	p-value	P for interaction	OM Adjusted HR (95% CI)	p-value	P for interaction	BC Adjusted HR (95% CI)	p-value	P for interaction
Age					0.434			0.444			0.460
< 35 years	2147	94.8	1.06 (0.94 to 1.19)	0.354		1.04 (0.98 to 1.10)	0.163		1.24 (0.94 to 1.64)	0.131	
≥ 35 years	117	5.2	1.37 (0.80 to 2.35)	0.253		1.16 (0.91 to 1.46)	0.225		2.10 (0.64 to 6.92)	0.222	
Ethnicity					0.811			0.655			0.560
Han	2212	97.7	1.08 (0.96 to 1.21)	0.209		1.04 (0.99 to 1.10)	0.107		1.27 (0.96 to 1.67)	0.089	
Other	52	2.3	0.89 (0.42 to 1.86)	0.748		1.10 (0.76 to 1.59)	0.615		2.00 (0.30 to 13.48)	0.477	
Occupation					0.610			0.556			0.563
Employed	1363	60.2	1.09 (0.94 to 1.27)	0.254		1.06 (0.99 to 1.13)	0.111		1.35 (0.96 to 1.89)	0.087	
Self-employed	105	4.6	1.48 (0.77 to 2.84)	0.243		1.23 (0.92 to 1.65)	0.169		2.92 (0.65 to 13.15)	0.162	
Other	796	35.2	1.01 (0.84 to 1.22)	0.914		1.01 (0.93 to 1.11)	0.791		1.08 (0.68 to 1.72)	0.752	
Blood type					0.665			0.800			0.805
Type A	664	29.3	1.11 (0.90 to 1.37)	0.333		1.05 (0.95 to 1.15)	0.346		1.26 (0.77 to 2.05)	0.362	
Type B	573	25.3	1.14 (0.89 to 1.45)	0.298		1.07 (0.96 to 1.20)	0.214		1.48 (0.84 to 2.62)	0.179	
Type O	1027	45.4	1.03 (0.87 to 1.23)	0.693		1.04 (0.96 to 1.12)	0.357		1.23 (0.82 to 1.83)	0.312	
Primary					0.167			0.272			0.317
No	1617	71.4	1.13 (0.99 to 1.29)	0.079		1.07 (1.00 to 1.13)	0.037		1.41 (1.03 to 1.92)	0.031	
Yes	647	28.6	0.93 (0.73 to 1.18)	0.529		0.99 (0.89 to 1.11)	0.896		1.00 (0.57 to 1.75)	0.993	
Adverse reproductive history					0.403			0.758			0.896
No	2077	91.7	1.09 (0.97 to 1.23)	0.145		1.05 (1.00 to 1.11)	0.070		1.31 (0.99 to 1.73)	0.060	
Yes	187	8.3	0.83 (0.53 to 1.29)	0.403		0.98 (0.80 to 1.20)	0.841		1.00 (0.36 to 2.78)	1.000	
Uterine scar					0.875			0.942			0.891
No	1909	84.3	1.08 (0.96 to 1.22)	0.196		1.05 (0.99 to 1.11)	0.085		1.29 (0.98 to 1.71)	0.069	
Yes	355	15.7	0.98 (0.60 to 1.61)	0.944		1.04 (0.82 to 1.33)	0.723		1.35 (0.39 to 4.69)	0.633	
HBV status					0.448			0.895			0.969
No	2087	92.2	1.06 (0.95 to 1.20)	0.304		1.05 (0.99 to 1.10)	0.098		1.29 (0.98 to 1.70)	0.073	
Yes	177	7.8	1.29 (0.77 to 2.17)	0.335		1.07 (0.85 to 1.35)	0.580		1.34 (0.41 to 4.41)	0.626	

Figure 3 Forest plot of subgroup analyses of the relationships of NH_4^+, OM, and BC exposure with TPROM during pregnancy.

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the relationship between air pollution and PROM indicated that for each interquartile range (IQR) increase in $PM_{2.5}$ absorbance, the risk of PROM increased by 47% (95% CI [1.08–2.00]) (*Dadvand et al., 2014*). $PM_{2.5}$ absorbance is considered a measure of black carbon (*Durant et al., 2014*). A large retrospective study conducted in the United States on prenatal exposure to air pollutants and PROM revealed that exposure to sulphates, nitrates, ammonium, and organic matter increased the risk of spontaneous PROM (*Jiao et al., 2023a*). A case-crossover study conducted in Shijiazhuang, China, on mixtures of

$PM_{2.5}$ components and TPROM revealed that exposure to SO_4^{2-}, NO_3^-, NH_4^+, and OM was significantly associated with an increased risk of TPROM (*Ren et al., 2024*). The results of these works differ slightly from those of this study, in which prenatal exposure to SO_4^{2-}, NO_3^-, NH_4^+, and BC was significantly associated with an increased risk of TPROM. Inconsistencies in results may stem from multiple factors. First, the precision of exposure assessment may be affected by the use of different assessment methods, such as monitoring station data and satellite remote-sensing data, thereby influencing the estimation of the relationship between exposure and health. Second, the biological activities of the components of $PM_{2.5}$ differ, and their direct effects on membranes and indirect effects on maternal physiology can vary depending on region and environmental conditions. Third, discrepancies in the level of control over confounding factors in studies also contribute to the variations in results. Therefore, pregnant women should therefore minimise outdoor activities during peak pollution periods and may use air purifiers to reduce indoor $PM_{2.5}$ levels. If outdoor activities in highly polluted areas are necessary, masks and other personal protective equipment should be worn to reduce the risk of inhaling harmful particulate matter. In addition, government policies can achieve long-term improvements in air quality through a range of measures, including increasing urban green spaces; strictly enforcing vehicle emission standards; restricting highly polluting industrial activities; and promoting the use of clean energy. These integrated strategies not only help improve environmental quality in general but also effectively reduce the risk of PROM in pregnant women.

This study has several strengths. First, there was a significant association between prenatal $PM_{2.5}$ exposure and preterm labour, particularly in the second and third trimesters, which improves our understanding of the effects of environmental pollution on maternal health. Second, this study considered the effects of $PM_{2.5}$ components on preterm rupture of membranes, providing insight into the roles of SO_4^{2-}, NO_3^-, NH_4^+ and black carbon in the risk of preterm rupture of membranes. Finally, the data support further investigations into the effects of $PM_{2.5}$ on the PROM and are consistent with findings from other cities, providing robust evidence for use by air pollution control policy-makers. However, the study has several limitations. First, the exposure assessment was based on the average exposure level at the home address, without accounting for individual exposure variations at different locations, such as daily activity spaces and workplaces. Therefore, the values may not accurately reflect the true exposure levels of individuals and could lead to biased results. Second, the analysis did not include certain health behaviours and lifestyle factors, such as smoking or cocaine use during pregnancy, as covariates, which increase the risk of PROM (*Myles et al., 1998*). Other factors, such as diet, exercise, and weight management, could also influence the results (*Faucett et al., 2016*; *Lin et al., 2024*; *Woods Jr, Plessinger & Miller, 2001*). Although age and last menstrual period were used as matching criteria to reduce confounding effects from age and gestational age, differences in gestational age might have biased the results. Finally, there are limitations regarding sample representativeness; the participants were primarily from Guangzhou, which may restrict the generalisability and applicability of the findings. The regional and socioeconomic backgrounds of the participants may not be broadly representative, affecting the applicability of the results.

Further research should incorporate participants from other regions and with other backgrounds to validate and generalise the findings.

CONCLUSIONS

This retrospective study, which was conducted in Guangzhou, China, investigated the associations between maternal exposure to $PM_{2.5}$ and its components and TPROM. The results revealed that exposure to $PM_{2.5}$ and its components (SO_4^{2-}, NO_3^-, NH_4^+, and BC) significantly increased the risk of TPROM, adding new evidence to the literature and deepening our understanding of the underlying mechanisms of this adverse pregnancy outcome. Given the regional differences in air pollution levels and composition, further studies in other areas are needed to validate these findings and to explore potential regional differences.

ADDITIONAL INFORMATION AND DECLARATIONS

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Competing Interests

The authors declare there are no competing interests.

Author Contributions

- Jiangxia Qin performed the experiments, authored or reviewed drafts of the article, and approved the final draft.
- Weiling Liu performed the experiments, analyzed the data, authored or reviewed drafts of the article, and approved the final draft.
- Haidong Zou performed the experiments, prepared figures and/or tables, and approved the final draft.
- Chong Zeng performed the experiments, prepared figures and/or tables, and approved the final draft.
- Cifeng Gao conceived and designed the experiments, performed the experiments, authored or reviewed drafts of the article, and approved the final draft.
- Weiqi Liu conceived and designed the experiments, performed the experiments, analyzed the data, prepared figures and/or tables, and approved the final draft.

Human Ethics

The following information was supplied relating to ethical approvals (*i.e.*, approving body and any reference numbers):

The studies involving human participants were reviewed and approved by the Ethics Committee of the Maternal and Children Health Care Hospital of Huadu (approval no. 2024-001).

Data Availability

The following information was supplied regarding data availability:

The raw data is available in the Supplemental Files.

Supplemental Information

Supplemental information for this article can be found online at http://dx.doi.org/10.7717/peerj.18886#supplemental-information.

REFERENCES

ACOG Committee on Practice Bulletins-Obstetrics. 2007. ACOG practice bulletin no. 80: premature rupture of membranes. Clinical management guidelines for obstetrician-gynecologists. *Obstetrics & Gynecology* **109**:1007–1019 DOI 10.1097/01.AOG.0000263888.69178.1f.

Ambroz A, Vlkova V, Rossner Jr P, Rossnerova A, Svecova V, Milcova A, Pulkrabova J, Hajslova J, Veleminsky Jr M, Solansky I, Sram RJ. 2016. Impact of air pollution on oxidative DNA damage and lipid peroxidation in mothers and their newborns. *International Journal of Hygiene and Environmental Health* **219**:545–556 DOI 10.1016/j.ijheh.2016.05.010.

American College of Obstetricians and Gynecologists' Committee on Practice Bulletins—Obstetrics. 2016. Practice bulletin no. 172: premature rupture of membranes. *Obstetrics & Gynecology* **128**:e165–e177 DOI 10.1097/AOG.0000000000001712.

Caughey AB, Robinson JN, Norwitz ER. 2008. Contemporary diagnosis and management of preterm premature rupture of membranes. *Reviews in Obstetrics and Gynecology* **1**:11–22.

Committee on Practice Bulletins-Obstetrics. 2018. ACOG practice bulletin no. 188: prelabor rupture of membranes. *Obstetrics & Gynecology* **131**:e1–e14 DOI 10.1097/AOG.0000000000002455.

Dadvand P, Basagana X, Figueras F, Martinez D, Beelen R, Cirach M, De Nazelle A, Hoek G, Ostro B, Nieuwenhuijsen MJ. 2014. Air pollution and preterm premature rupture of membranes: a spatiotemporal analysis. *American Journal of Epidemiology* **179**:200–207 DOI 10.1093/aje/kwt240.

Della Guardia L, Wang L. 2023. Fine particulate matter induces adipose tissue expansion and weight gain: pathophysiology. *Obesity Reviews* **24**:e13552 DOI 10.1111/obr.13552.

Desquilbet L, Mariotti F. 2010. Dose-response analyses using restricted cubic spline functions in public health research. *Statistics in Medicine* **29**:1037–1057 DOI 10.1002/sim.3841.

Durant JL, Beelen R, Eeftens M, Meliefste K, Cyrys J, Heinrich J, Bellander T, Lewne M, Brunekreef B, Hoek G. 2014. Comparison of ambient airborne $PM_{2.5}$, $PM_{2.5}$ absorbance and nitrogen dioxide ratios measured in 1999 and 2009 in three areas in Europe. *Science of the Total Environment* **487**:290–298 DOI 10.1016/j.scitotenv.2014.04.019.

Endale T, Fentahun N, Gemada D, Hussen MA. 2016. Maternal and fetal outcomes in term premature rupture of membrane. *World Journal of Emergency Medicine* **7**:147–152 DOI 10.5847/wjem.j.1920-8642.2016.02.011.

Fan R, Zhang A, Zhong F. 2017. Association between homocysteine levels and all-cause mortality: a dose-response meta-analysis of prospective studies. *Scientific Reports* **7**:4769 DOI 10.1038/s41598-017-05205-3.

Faucett AM, Metz TD, DeWitt PE, Gibbs RS. 2016. Effect of obesity on neonatal outcomes in pregnancies with preterm premature rupture of membranes. *American Journal of Obstetrics and Gynecology* **214**:287 e281–e287 e285 DOI 10.1016/j.ajog.2015.09.093.

Geng G, Xiao Q, Liu S, Liu X, Cheng J, Zheng Y, Xue T, Tong D, Zheng B, Peng Y, Huang X, He K, Zhang Q. 2021. Tracking air pollution in China: near real-time $PM_{2.5}$ retrievals from multisource data fusion. *Environmental Science & Technology* **55**:12106–12115 DOI 10.1021/acs.est.1c01863.

Getahun D, Ananth CV, Oyelese Y, Peltier MR, Smulian JC, Vintzileos AM. 2007. Acute and chronic respiratory diseases in pregnancy: associations with spontaneous premature rupture of membranes. *Journal of Maternal-Fetal and Neonatal Medicine* **20**:669–675 DOI 10.1080/14767050701516063.

Gong Y, Sun P, Fu X, Jiang L, Yang M, Zhang J, Li Q, Chai J, He Y, Shi C, Wu J, Li Z, Yu F, Ba Y, Zhou G. 2022. The type of previous abortion modifies the association between air pollution and the risk of preterm birth. *Environmental Research* **212**:113166 DOI 10.1016/j.envres.2022.113166.

Han Y, Wang W, Wang X, Dong T, Van Donkelaar A, Martin RV, Chen Y, Kan H, Xia Y. 2020. Prenatal exposure to fine particles, premature rupture of membranes and gestational age: a prospective cohort study. *Environment International* **145**:106146 DOI 10.1016/j.envint.2020.106146.

Herbst A, Kallen K. 2007. Time between membrane rupture and delivery and septicemia in term neonates. *Obstetrics & Gynecology* **110**:612–618 DOI 10.1097/01.AOG.0000277632.36186.84.

Jena BH, Biks GA, Gete YK, Gelaye KA. 2022. Incidence of preterm premature rupture of membranes and its association with inter-pregnancy interval: a prospective cohort study. *Scientific Reports* **12**:5714 DOI 10.1038/s41598-022-09743-3.

Jiao A, Sun Y, Avila C, Chiu V, Molitor J, Slezak J, Sacks DA, Chen JC, Benmarhnia T, Getahun D, Wu J. 2023a. Maternal exposure to ambient air pollution mixture and premature rupture of membranes: evidence from a large cohort in Southern California (2008–2018). *Environment International* **177**:108030 DOI 10.1016/j.envint.2023.108030.

Jiao A, Sun Y, Sacks DA, Avila C, Chiu V, Molitor J, Chen JC, Sanders KT, Abatzoglou JT, Slezak J, Benmarhnia T, Getahun D, Wu J. 2023b. The role of extreme heat exposure on premature rupture of membranes in Southern California: a study from a large pregnancy cohort. *Environment International* **173**:107824 DOI 10.1016/j.envint.2023.107824.

Kaye D. 2001. Risk factors for preterm premature rupture of membranes at Mulago Hospital, Kampala. *East African Medical Journal* **78**:65–69.

Kilpatrick SJ, Patil R, Connell J, Nichols J, Studee L. 2006. Risk factors for previable premature rupture of membranes or advanced cervical dilation: a case

control study. *American Journal of Obstetrics and Gynecology* **194**:1168–1174 DOI 10.1016/j.ajog.2005.12.017.

Kumari R, Suneja A, Mehndiratta M, Guleria K, Malik R. 2023. Maternal serum vitamin E levels and its association with cord blood telomere length and mitochondrial DNA copy number in preterm premature rupture of membranes. *The Journal of Obstetrics and Gynecology of India* **73**:9–14 DOI 10.1007/s13224-022-01684-1.

Li X, Wu H, Xing W, Xia W, Jia P, Yuan K, Guo F, Ran J, Wang X, Ren Y, Dong L, Sun S, Xu D, Li J. 2023. Short-term association of fine particulate matter and its constituents with oxidative stress, symptoms and quality of life in patients with allergic rhinitis: a panel study. *Environment International* **182**:108319 DOI 10.1016/j.envint.2023.108319.

Li C, Xu JJ, He YC, Chen L, Dennis CL, Huang HF, Wu YT. 2021. Effects of acute ambient pollution exposure on preterm prelabor rupture of membranes: a time-series analysis in Shanghai, China. *Environmental Pollution* **276**:116756 DOI 10.1016/j.envpol.2021.116756.

Liang Y, Li M, Lyu Q, Li P, Lyu Y, Yu Y, Peng W. 2024. The relationship between maternal exposure to ambient air pollutants and premature rupture of membranes: a systematic review and meta-analysis. *Environmental Pollution* **347**:123611 DOI 10.1016/j.envpol.2024.123611.

Lin D, Hu B, Xiu Y, Ji R, Zeng H, Chen H, Wu Y. 2024. Risk factors for premature rupture of membranes in pregnant women: a systematic review and meta-analysis. *BMJ Open* **14**:e077727 DOI 10.1136/bmjopen-2023-077727.

Liu S, Geng G, Xiao Q, Zheng Y, Liu X, Cheng J, Zhang Q. 2022. Tracking daily concentrations of $PM_{2.5}$ chemical composition in China since 2000. *Environmental Science & Technology* **56**:16517–16527 DOI 10.1021/acs.est.2c06510.

Menon R, Yu J, Basanta-Henry P, Brou L, Berga SL, Fortunato SJ, Taylor RN. 2012. Short fetal leukocyte telomere length and preterm prelabor rupture of the membranes. *PLOS ONE* **7**:e31136 DOI 10.1371/journal.pone.0031136.

Middleton P, Shepherd E, Flenady V, McBain RD, Crowther CA. 2017. Planned early birth *versus* expectant management (waiting) for prelabour rupture of membranes at term (37 weeks or more). *Cochrane Database of Systematic Reviews* **1**:CD005302 DOI 10.1002/14651858.CD005302.pub3.

Moller P, Loft S. 2010. Oxidative damage to DNA and lipids as biomarkers of exposure to air pollution. *Environmental Health Perspectives* **118**:1126–1136 DOI 10.1289/ehp.0901725.

Muftuoglu M, Mori MP, De Souza-Pinto NC. 2014. Formation and repair of oxidative damage in the mitochondrial DNA. *Mitochondrion* **17**:164–181 DOI 10.1016/j.mito.2014.03.007.

Muniz Rodriguez A, Pastor A, Fox NS. 2021. The association between Shirodkar cerclage and preterm premature rupture of membranes in singleton pregnancies. *American Journal of Perinatology* **38**:e347–e350 DOI 10.1055/s-0040-1710009.

Myles TD, Espinoza R, Meyer W, Bieniarz A, Nguyen T. 1998. Effects of smoking, alcohol, and drugs of abuse on the outcome of expectantly managed cases of

preterm premature rupture of membranes. *The Journal of Maternal-Fetal Medicine* **7**:157–161.

Namli Kalem M, Kosus A, Kamalak Z, Kosus N, Kalem Z. 2017. Factors affecting the rates of caesarean sections in cases with premature rupture of membranes (PROM) at term. *Journal of Obstetrics and Gynaecology* **37**:585–590 DOI 10.1080/01443615.2016.1274291.

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. *Environment International* **142**:105876 DOI 10.1016/j.envint.2020.105876.

Pereira G, Evans KA, Rich DQ, Bracken MB, Bell ML. 2016. Fine particulates, preterm birth, and membrane rupture in Rochester, NY. *Epidemiology* **27**:66–73 DOI 10.1097/EDE.0000000000000366.

Prasad Dwa Y, Bhandari S, Bajracharya M. 2023. Prelabour rupture of membranes among pregnant women visiting a tertiary care centre: a descriptive cross-sectional study. *Journal of Nepal Medical Association* **61**:506–509 DOI 10.31729/jnma.8186.

Puji Astuti DL, Ariyani NW, Mahayati SSTNMD. 2022. Prevalence and factors associated with premature rupture of membranes in Denpasar Bali. *International Journal of Science and Healthcare Research* **7**:7–12 DOI 10.52403/ijshr.20221002.

Ren W, Yang H, Liu W, Zhang S, Yang Y, Yang L, Liu W, Zhang H, He K, Li X, Ge J. 2024. Exposure to mixtures of $PM_{2.5}$ components and term premature rupture of membranes: a case-crossover study in Shijiazhuang, China. *International Journal of Environmental Health Research* **34**:1–13 DOI 10.1080/09603123.2024.2308017.

Saffari A, Daher N, Shafer MM, Schauer JJ, Sioutas C. 2014. Global perspective on the oxidative potential of airborne particulate matter: a synthesis of research findings. *Environmental Science & Technology* **48**:7576–7583 DOI 10.1021/es500937x.

Wallace ME, Grantz KL, Liu D, Zhu Y, Kim SS, Mendola P. 2016. Exposure to ambient air pollution and premature rupture of membranes. *American Journal of Epidemiology* **183**:1114–1121 DOI 10.1093/aje/kwv284.

Wan Z, Zhang S, Zhuang G, Liu W, Qiu C, Lai H, Liu W. 2024. Effect of fine particulate matter exposure on gestational diabetes mellitus risk: a retrospective cohort study. *European Journal of Public Health* **34**:787–793 DOI 10.1093/eurpub/ckae094.

Wang K, Tian Y, Zheng H, Shan S, Zhao X, Liu C. 2019. Maternal exposure to ambient fine particulate matter and risk of premature rupture of membranes in Wuhan, Central China: a cohort study. *Environmental Health* **18**:96 DOI 10.1186/s12940-019-0534-y.

Woods Jr JR, Plessinger MA, Miller RK. 2001. Vitamins C and E: missing links in preventing preterm premature rupture of membranes? *American Journal of Obstetrics and Gynecology* **185**:5–10 DOI 10.1067/mob.2001.115868.

Yang X, Xu F, Ma G, Pu F. 2024. Maternal exposure to environmental air pollution and premature rupture of membranes: evidence from Southern China. *Medical Science Monitor* **30**:e943601 DOI 10.12659/MSM.943601.

Zhang C, Li S, Guo GL, Hao JW, Cheng P, Xiong LL, Chen ST, Cao JY, Guo YW, Hao JH. 2021. Acute associations between air pollution on premature rupture of membranes in Hefei, China. *Environmental Geochemistry and Health* **43**:3393–3406 DOI 10.1007/s10653-021-00833-1.

Zhuang L, Li ZK, Zhu YF, Ju R, Hua SD, Yu CZ, Li X, Zhang YP, Li L, Yu Y, Zeng W, Cui J, Chen XY, Peng JY, Li T, Feng ZC. 2020. The correlation between prelabour rupture of the membranes and neonatal infectious diseases, and the evaluation of guideline implementation in China: a multi-centre prospective cohort study. *The Lancet Regional Health—Western Pacific* **3**:100029 DOI 10.1016/j.lanwpc.2020.100029.

Zhuang L, Li ZK, Zhu YF, Ju R, Hua SD, Yu CZ, Li X, Zhang YP, Li L, Yu Y, Zeng W, Cui J, Chen XY, Peng JY, Li T, Feng ZC. 2022. Latency period of PROM at term and the risk of neonatal infectious diseases. *Scientific Reports* **12**:12275 DOI 10.1038/s41598-022-16593-6.