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Research article

Air pollution and pregnancy outcomes in Dhaka, Bangladesh

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A R T I C L E I N F O

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A B S T R A C T

Introduction: Air pollution, one of the biggest environmental risks to health, is a severe problem in Bangladesh. The Lancet "Commission on Pollution and Health" emphasized the importance of research on health effects of ambient air pollution. This study explored the negative health impacts of air pollution on pregnancy outcomes - preterm births (PTB) and low birth weight (LBW).
Methods: The study assessed air quality in terms Air Quality Index (AQI) and quantified the association with LBW and PTB. Pregnancy outcome data were collected from the Maternal and Child Health Training Institute in Dhaka, and the AQI data from the Clean Air and Sustainable Environment Project of the Department of Environment. A total 3,206 birth outcome records were assessed within the period from 2014 to 2017.
Results: Air pollution levels are alarmingly high in Dhaka, with 'Unhealthy' to 'Extremely Unhealthy' levels for almost half of the year. An increase in the prevalence of LBW and PTB was found with increasing cumulative air pollution exposure. LBW increased from 20.6% to 36.0% and PTB increased from 9.0% to 15.2% respectively between the lowest and highest category AQI value exposure. For every 10,000 AQI value increase in cumulative exposure, LBW and PTB increased by 4% and 2%, respectively. There is significant gender differentiated impact on LBW and PTB due to air pollution where female fetuses are at higher risk of LBW and males are more prone to PTB. Air pollution exposure during the second trimester increased LBW and PTB more compared to first and third trimesters, suggesting it is potentially the most vulnerable period of pregnancy.
Conclusion: Air pollution contributes to adverse pregnancy outcomes. To reduce this effect, proper interventions to reduce air pollution levels need to be urgently implemented.

1. Introduction

Air pollution is one of the greatest environmental risks to health, and is responsible for about one in nine deaths globally [1]. Air pollution refers to the state of air that has been contaminated by gaseous and solid particles [2] and has two distinct types - indoor air pollution (IAP), and ambient or outdoor air pollution (AAP). Worldwide, outdoor air pollution, often termed the "modern form of pollution", has become the most severe, with an increased number of attributable deaths and disabilities that now have overtaken the impact of indoor air pollution [3,4]. As per the World Health Organization (WHO) standard, more than 92% of the world's population is exposed to unsafe air [5]. Ambient air pollution killed approximately 4.5 million people in 2019, almost twice as many as indoor air pollution, and this is particularly evident in South Asia, East Asia, and Southeast Asia [4]. The overall situation becomes even more critical as climate change is likely to worsen air quality in densely populated regions through changes in atmospheric ventilation, dilution, removal processes, and precipitation [6].

Air pollution negatively impacts embryonic development at genetic and epigenetic levels and thus influences the reproductive outcome of exposed populations [7,8]. Maternal exposure to ambient fine particulate matter has been identified as a risk factor for adverse pregnancy outcomes [9]. It has been found to be associated with premature births, low birth weight, poor lung development, mortality due to respiratory infections, and also may hamper cognitive development [5,10–14]. Preterm birth (<37 completed weeks of gestation) is a "major cause of (postnatal) death and a significant cause of long-term loss of human potential" [15]. Moreover, exposure to fine particulate matter ($PM_{2.5}$) was responsible for 2.8 million low birth weight and over 5.9 million preterm birth infants in 2019 [16].

Abbreviations: AAP, Ambient (outdoor) Air Pollution; AQI, Air Quality Index; AAQS, Ambient Air Quality Standards; CAMS, Continuous Air Monitoring Stations; CASE, Clean Air and Sustainable Environment; IAP, Indoor air Pollution; LBW, Low Birth Weight; MCHTI, Maternal and Child Health Training Institute; PTB, Preterm Birth; PM, Particulate Matter

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In Bangladesh, 1 in 40 children die in the neonatal period [17] due to premature birth [18]. While very little is known about the adverse effects of air pollution on growing fetuses in Bangladesh, evidence from other countries has raised critical concerns [8,14,19,20]. Only a limited number of studies in Bangladesh have tried to assess the health burdens of air pollution, focusing primarily on IAP and postnatal and other health complications [21–25]. Yet, the Lancet Commission on Pollution and Health has stated that the health burden of AAP exceeds the impacts of IAP [4], and in the city of Dhaka, the massive shift from biofuels to liquified petroleum gas (LPG) for cooking has vastly reduced IAP [26]. Another factor influencing the extent of AAP is that outdoor air quality varies greatly in Dhaka during the dry versus the wet monsoon season. To explore the relationship of air pollution and pregnancy outcomes we opted to use the Air Quality index (AQI) to measure air pollution and to link it to pregnancy outcomes in Bangladesh. Specifically, we explore the relationship of AQI to low birth weight (LBW) deliveries and preterm births (PTB). We hypothesized that poor AQI would be associated with both LBW and PTB.

2. Methods

The study used the Air Quality Index (AQI) as the main independent variable and the percentages of low birth weight (LBW) and preterm birth (PTB) as the main outcome / dependent variables. Air Quality Index is measured on a daily basis at three locations within the city of Dhaka. The components measured are particulate matter ($PM_{2.5}$ and PM_{10}), sulfur dioxide (SO_2), nitrogen dioxide (NO_2), ozone (O_3), and carbon monoxide (CO), and the composite AQI level can range from zero to 500. The Department of Environment regards a daily level below 100 as reflecting acceptable air quality. The association between prematurity and birth weight and air quality were explored, further subcategorizing the cumulative air pollution exposure by days, months, 9 months, and by trimesters. The initial analyses were mainly bivariate, with logistic regression used to determine the significance of the various independent variables studied.

2.1. Pregnancy outcome data

Pregnancy outcome data were obtained retrospectively from the Maternal and Child Health Training Institute (MCHTI) of the Directorate General of Family Planning (DGFP) under the Ministry of Health and Family Welfare (MoHFW). Birth data and pregnancy information such as gestation duration, birth weight, and pregnancy history of the mothers were collected (Table 1).

The study participants were restricted to the population living in the city of Dhaka in order to standardize air quality exposure as much as possible. Participants were included based on the completeness of the data from MCHTI; only women who had a normal singleton vaginal delivery and had a complete hospital record were included. Women who had a “Cesarean delivery” (C-section), an “Abortion (including incomplete abortion)”, were “Referred to other hospital”, and those who had a “Stillbirth” were excluded from the analysis.

The study initially had 5,528 birth records of normal vaginal deliveries for the period of 2014-2017. Complete matched data were available for 3,206 records. The study was approved by the Director General of Directorate General of Family Planning (DGFP) and due to the retrospective nature of the data used for analysis, no further patient / respondent consent or institutional approval was required.

2.2. Air pollution data

Air quality data were collected from the Clean Air and Sustainable Environment (CASE) project (http://case.doe.gov.bd/) of the Department of Environment (DoE), under the Ministry of Environment, Forest, and Climate Change (MoEFCC). The CASE project collects data from three locations within Dhaka by Continuous Air Monitoring Stations (CAMS) and reports air quality on its website on daily basis [19]. As noted above, AQI is calculated for five specific pollutants. Air quality based on pollutant concentrations, is reported on a normalized scale of 0-50 (good air quality) to 300-500 (extremely unhealthy air quality) to convey the levels of air pollution and respective health threats [28,29].

Table 1
Major child and maternal demographic measures from MCHTI

Information on child	Information on mother	Other birth information
Status of child born	Mother’s Age	Registration number
Sex of child	Parity	Address
Weight of child in grams	Number of total pregnancies	Date of delivery
APGAR Score	Mother’s weight	Delivery type
Status after delivery	Mother’s height	Complication during delivery
	Systolic blood pressure	Number of abortions
	Diastolic blood pressure	Number of miscarriages
		Last menstrual period
		Estimated date of delivery

AQI was first developed by the United States Environmental Protection Agency (US EPA) and is used to report the daily status of air, taking account of several types of pollutants combined into a single numerical value between 0 and 500. Bangladesh has developed its own Ambient Air Quality Standard (AAQS), modifying the category name and color designations; however the range is same as the US AQI [19]. This study used the Bangladesh AAQS.

2.3. Data analysis

We analyzed cumulative exposures of the pregnant women to various levels of air pollution during the period of pregnancy. These pregnant women had differing unknowable levels of lifetime exposure; however, subject to certain assumptions, the critical period was the exposure during the pregnancy [8]. As daily measures of air quality data were available for the duration of pregnancies, it was assumed that each woman was residing in the area as per the address they provided and hence the summation of those air quality levels over the duration of the pregnancy should provide an approximate level of exposure. Anecdotal evidence suggests that this is a reasonable assumption, except for a few days’ absence for annual religious festivals when some women return to their natal villages. Furthermore, with the shift from wood to natural liquid gas as major source of cooking fuel in Bangladesh, the impact of indoor air pollution was assumed to be quite minimal on birth outcomes in comparison to ambient or outdoor air pollution.

The cumulative exposure would vary depending on what proportion of the pregnancy was spent in the monsoon quarter when AQI levels were low. Some pregnant women would spend the entire 9-month duration in the pre- and post-monsoon high AQI period, and others would not. The data also made it possible to analyze the levels of exposure in the different trimesters or months of the pregnancy. Data entry was completed with ORACLE Forms Developer (11g) and the database was prepared with ORACLE Database (12c) (Oracle Corporation, Santa Clara). Data analysis was performed with SPSS version 20 (IBM, Armonk).

3. Results

There were data available for 5,528 mothers who gave birth in the years 2014 (N=1,381), 2015 (N=1,689), 2016 (N=1,419), and 2017 (N=1,039). Descriptive statistics on births and mothers follows.

Table 2
Distribution of Birth Weight

Birth Weight Group	Percentage (%) of Births
Less than 1,999 gm	3.3
2,000 to 2,499 gm	6.8
2,500 gm exact	**17.7**
2,501 to 2,999 gm	24.2
3,000 gm exact	**23.7**
3,001 to 3,499 gm	11.5
3,500 to 4,999 gm	12.9
Total	100%

3.1. Information on births

The sex ratio of the births is exactly equal, at 100 males to 100 females, slightly different from the expected biological ratio 105:100. Most births were first born (43.4%), then second born (34.0%), third (17.1%), fourth (4.4%), fifth (1.1%) and finally, sixth (0.1%), which resembles the pattern of national births. There were about 98% live births with infants in good condition.

The birth weight data indicate considerable rounding, with two in five of all births being ascribed exact weights of 2,500 grams (17.7%) or 3,000 grams (23.7%) (Table 2). This creates a problem for estimating proportions of LBW babies. We thus considered weights up to and including (≤) 2,500 grams as LBW and found that about 27.8% babies were LBW which is similar to the level among babies born in Dhaka slums [30].

Prematurity was measured either by percent of births defined as "premature", meaning born before the start of the 37th week of pregnancy, or by mean number of days of gestation, as measured from last menstrual period (LMP). Two thirds of births had gestational durations between 265 and 285 days, around nine months ± 10 days. One in eight babies (12.3%) were premature (less than 37 weeks or 259 days).

3.2. Information on mothers

Most of the mothers (88%) were less than 30 years old. Almost one quarter (23%) were in their teenage years, which is consistent with the national pattern of early marriage and low fertility in Bangladesh. The distribution of mothers' weights is approximately normal, with over one third of women in the 50 to 59 kg range and almost another one third in between 60 and 69 kg. Regarding height, more than 90% of mothers were between 1.4 and 1.6 meters in height. Height of less than 1.45m (145 cm) is considered a cutoff for risk for obstructed labor, with about 11.1% of women falling in that group.

Information was also collected on mothers' blood pressure - normal, prehypertension or hypertension status based on systolic and diastolic blood pressure measurements. As per the American Heart Association (AHA) 2016 guidelines [31], among the delivering women, about 43.1% were normal, 46.0% were in pre-hypertension, 8.7% were in stage 1 hypertension, and 2.2% were in stage 2 hypertension.

3.3. Patterns of birth weight (% LBW) and prematurity (% premature) by mother's characteristics

The prevalence of LBW across the mothers' age groups shows a U-shaped pattern, highest for teenage and older mothers (Table 3). As mentioned, about 11.1% of births were premature (before 37 weeks of pregnancy) with mean days of gestation as 273.6 days. The risk of premature birth is also U-shaped by age of mother. Teenage mothers are at somewhat elevated risk, but older mothers (35+), are at greatly elevated risk.

The proportion of LBW births declines steadily with higher parities up to 4+. The difference is mainly between first births (32.5% LBW) and others (down to 20.5% for 4+) (Table 3). The risk of premature births bears little relationship to previous parity, until the very small category of parity of four or more births, when, surprisingly, the risk of prematurity is lowest.

Table 3
Percent LBW and percent premature by Age of Mother, and Previous Parity

Mother's age	% LBW	% Premature
<20	33.0	15.0
20-24	26.3	12.0
25-29	26.6	10.5
30-34	24.5	13.2
35+	30.6	26.0
Previous parity	**% LBW**	**% Premature**
0	32.5	12.9
1	27.7	12.4
2	24.0	10.2
3	25.9	12.2
4+	20.5	8.7

3.4. Status of air pollution in Dhaka

The trend in air quality in Bangladesh is dominated by different meteorological variables like temperature, humidity, and wind speed and direction that impact the emission and transport of different air pollutants [32]. Though about 60% of the pollutants originate from different anthropogenic sources [33], a clear seasonal pattern of air pollution in Dhaka is seen, with low AQI/ good air quality during the rainy (monsoon) season and high AQI/ poor air quality in the other 8-9 dry season months (Figure 1).

The lowest value of AQI was 8 on July 5, 2016, and ranged as high as 479 on March 12, 2014. In the 1,460 days covered, almost half were in the "Unhealthy", "Very Unhealthy" or "Extremely Unhealthy" categories (Figure 2). The levels were highest in the dry season from October through May, and lowest in the monsoon (wet) season from June to September [34].

3.5. Poor air quality exposure and birth outcomes

The daily AQI values in sequence were added together for the 9 months of each pregnancy to estimate the cumulative exposure for each woman. This ranged from a low of 28,652 for births in December 2016, to a high of 58,215 (almost double of the low value) for births in June 2015.

3.5.1. Impact on birth weight

The prevalence of LBW increased gradually from one in five births (20.6%) for the lowest category of cumulative 9-month exposure (<35,000 AQI value), to well over one in three births (36.0%) among those with highest exposure (55,000-59,000 AQI value). With one exception (35,000-39,999 AQI value), the trend is strongly linear (Figure 3). So, for every 10,000 AQI value increase in cumulative exposure, the rate of LBW increased, on average, by 4%. We further assessed the gendered differentiated impact of air pollution on LBW. At 5% level of significance, there is evidence of a significant association between sex of a baby and low birth weight in boys (26.1%) and girls (29.7%) (p-value = 0.037) suggesting that baby girls were more prone to LBW due to air pollution.

The cumulative AQI exposure was further divided into trimesters. The second trimester exposure ranged from 5,142 to 29,252 AQI values, whereas in the third trimester, cumulative exposure ranged from 5,142 to 30,247. The second trimester exposure showed a relationship with percent LBW; in particular, exposure in the fourth month (Figure 4), and to a lesser degree, in the fifth month (Figure 5)

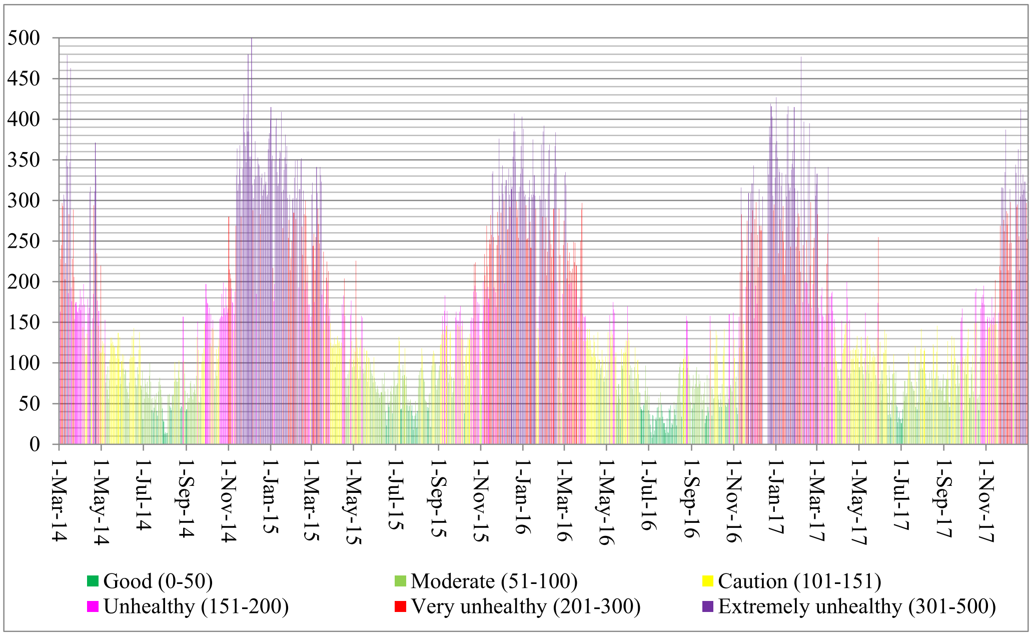

Fig. 1. Air Quality Index (AQI) for Dhaka city, 2014-2017

correlated with increased risk of LBW. Risk of LBW rose by about 7 percentage points as exposure increased from less than 2,200 to 7,600+ in the fourth month of pregnancy.

A multivariate analysis using logistic regression was performed to assess the risk of LBW by AQI exposure. The approach used birth weight as a binary or dichotomous dependent variable (low birth weight = 1, normal birth weight = 0). As described earlier, LBW is defined as births weighing up to and including 2500 grams, and normal birth weight is 2,501 grams or more.

Variables included were age of mother, hypertension, and month of delivery. As elevated blood pressure (hypertension) was noted as a risk factor for LBW, the four categories of hypertension were included as a categorical variable.

Month of delivery was expected to play a role as it is related to cumulative exposure to poor air quality, e.g., if the low AQI monsoon season (June-September) falls in the pregnancy, cumulative exposure will be lower than if the pregnancy occurs in the nine dry months following the monsoon. No other factors from the univariate analyses were expected to be closely related to, or predictive of, low birth weight.

The results of the logistic regression, taking LBW as up to and including 2,500 grams as the outcome variable, are shown in Table 4. Age of mother is significantly associated with LBW, with an Odds Ratio (Exp(B)) of 0.979, so risk of LBW slightly declines with age. Surprisingly, hypertension does not show a significant relationship with risk of LBW, although the very highest level of hypertension of stage 2 elevated blood pressure is close to significant (0.068). Exposure to high AQI in both trimester 2 (0.002) and trimester 3 (0.018) are significantly related to risk of LBW. However, only the third category (AQI value: 15,000-19,999) of Trimester 3 is significant, but the Odds Ratio is 0.557, indicating that risk of LBW is significantly less at that level of exposure, which was also found during the univariate

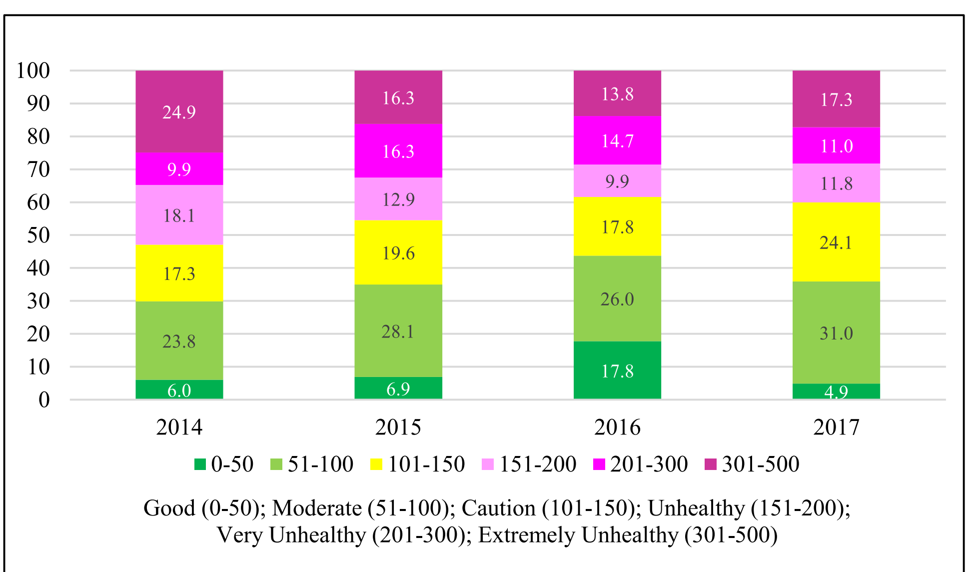

Fig. 2. Air quality trend (distribution of days in %) in Dhaka city 2014-2017

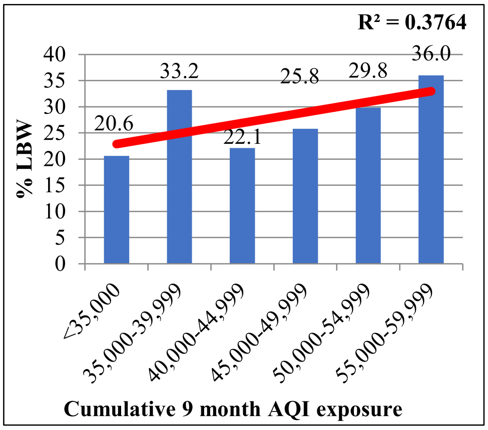

Fig. 3. Percent LBW by cumulative 9 Month Exposure to AQI

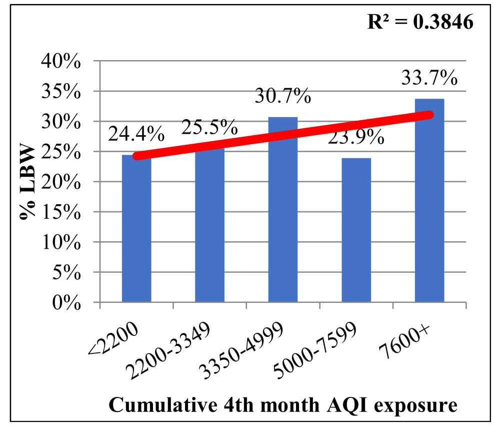

Fig. 4. Percent LBW by cumulative AQI at fourth month of pregnancy

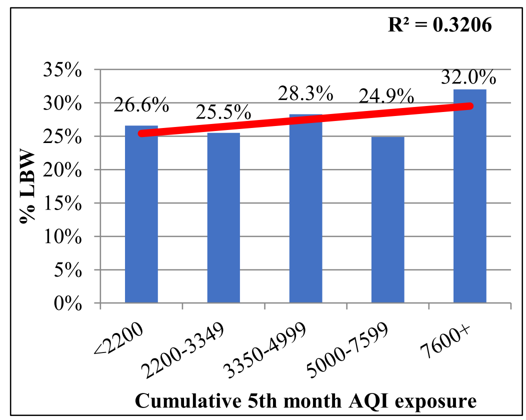

Fig. 5. Percent LBW by cumulative AQI at fifth month of pregnancy

analysis. The pattern in trimester 2 at exposure category five (AQI value: 25,000-29,999) is significantly related to LBW with an Odds Ratio of 1.867, indicating an almost doubling of LBW risk at that level of exposure.

Exposure to higher levels of air pollution does appear to be significantly associated with increased risk of delivering an LBW baby. This is particularly true for exposure in the second trimester of pregnancy, specifically at the fourth and fifth months of pregnancy.

3.5.2. *Impact on prematurity*

The range of cumulative AQI almost doubles between lowest and highest category of nine months exposure. The study found an increasing trend in percent preterm births (PTB) with higher AQI exposure. Percent PTB showed a linear increase with 9-month cumulative AQI from 9.0% to 15.2% between lowest and highest category of exposure (Figure 6). This implies that for every 10,000 points increase in cumulative exposure, the percent premature increased, on average, by about 2%. At 5% level of significance, there is higher association between the gender differentiated impact of air pollution and preterm birth (p-value = 0.001) where premature births among boys were 14.2% and in girls 10.2%.

The following results (Table 5) show that the significant trend is in the expected direction, with proportions of premature births lowest (7%) for lowest AQI exposures (<2,200), and second highest (12%) for highest AQI exposures (7,600+). This trend is highly significant at the 5% level as the numbers in each category are large.

Table 4
Logistic regression for low birthweight (LBW) risk by AQI and BP

Logistic regression co-efficient and adjusted odds ratio (AOR) of air-quality index (AQI) and blood pressure (BP) of mother on low-birthweight (LBW) risk of child.

Background Variables	B	P-value	Exp(B) (Adjusted odds ratio)	95% CI for Lower	Upper
Age of mother	-.021	**.029**	.979*	.960	.998
Blood pressure (BP) (Ref: Normal)					
Prehypertension	.019	.835	1.019	.854	1.216
Stage 1 hypertension	.074	.641	1.077	.789	1.470
Stage 2 hypertension	.501	.068	1.650	.964	2.823
Trimester 3 Cum AQI (Ref: < 7,500)					
7,500 to 9,999	.092	.568	1.097	.799	1.505
10,000 to 14,999	-.316	.136	.729	.482	1.104
15,000 to 19,999	-.586	**.008**	.557**	.361	.858
20,000 to 24,999	-.252	.137	.777	.558	1.083
25,000 to 29,999	-.156	.312	.856	.632	1.158
Trimester 2 Cum AQI (Ref: < 7,500)					
7,500 to 9,999	.139	.458	1.149	.796	1.658
10,000 to 14,999	.044	.827	1.045	.702	1.557
15,000 to 19,999	-.135	.471	.874	.606	1.261
20,000 to 24,999	.238	.175	1.268	.900	1.788
25,000 to 29,999	.624	**.000**	1.867***	1.358	2.568
Constant	-.503	.080	.605		

Exponentiated coefficients; * p < 0.05, ** p < 0.01, *** p < 0.001

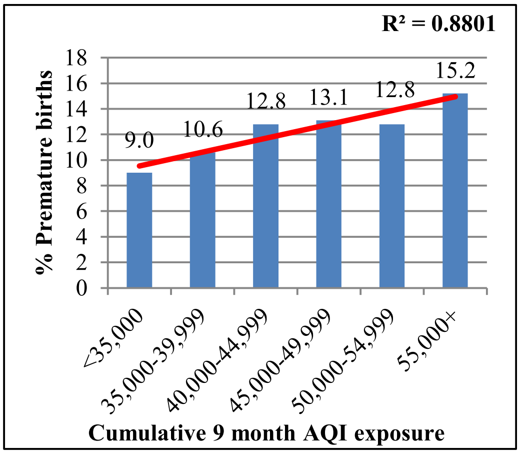

Fig. 6. Percent PTB by cumulative 9 Month Exposure to AQI

4. Discussion

There is growing evidence suggesting that exposure to poor air quality during pregnancy has a negative impact on birth weight and prematurity [14,20]. As AQI data was available on a daily basis for women's exposure to air pollution in the city of Dhaka, it was possible to estimate mothers' total exposure during pregnancy, accumulated over the nine months of pregnancy, and to break that down by exposure in trimesters, and into specific months (assuming same level of indoor air pollution exposure by all subjects). The benefit of using AQI is that it is a standardized indicator of air quality with information on potential health threats [35,36]. AQI is used to indicate the level of severity of air pollution with a set of pre-identified parameters [27,37]

Our data show a linear increase in prevalence of LBW and PTB with higher exposure to air pollution (Figure 3 and 6 respectively). When individual monthly exposures by trimester were examined, it appears that AQI exposure in month 4, and possibly month 5 of pregnancy, have a negative impact on birth outcomes, as measured by LBW (Figures 4 and 5, respectively). This is particularly important, because while causality between air pollution and LBW has already been suggested [14], our data additionally suggest the potentially most vulnerable period of pregnancy. The PTB association roughly follows the same pattern as LBW, with second trimester being the most critical period of exposure; this agrees with recent findings from China [38]. The current study further found gender differentiated risk on birth outcome; female fetuses are at significantly higher risk of LBW and male fetuses are significantly more prone to PTB risk due to prenatal air pollution exposure, which supports the findings of systematic review done by Ghosh, et. al. [39] and is in agreement with molecular epidemiologic studies that suggest the relationship between air pollution and such pregnancy outcomes is genuine [14].

The indications of negative impact due to exposure in the second trimester suggest that the development of certain fetal organs or physiological processes may be harmed. Lung development will tend to continue, while the surfactant they need to function properly is not produced until the third trimester. It may be that nutrient transfer from the mother's blood across the placental barrier may be impeded by exposure to airborne contaminants or simply transfer of oxygen may be negatively affected, with the effect of constraining fetal growth [8]. It is to be noted that research done in other parts of the world also has identified varied findings. Pregnancy outcome has been explored in relation to other types of air contaminants [20], [40], and some studies found an association between exposures in the first and third trimester [41,42], while other studies explored the association with increases in level of exposure in the days before delivery [43,44]. Interestingly, while considering PTB risks, particulate matter seems to have significant effects on the third trimester and entire pregnancy, whereas other types of pollutants have more impact on the first or third trimesters [45]. Our study, identifying the second trimester as the critical period of pregnancy, points to the possibility of an additional excess of other types of pollutants in the air along with particulate matter [46], and this seems feasible as the study area and surroundings are occupied by various small and medium industries.

Table 5
Mean gestation, and percent PTB, by cumulative AQI exposure in fourth month

Categories of Cumulative AQI in Fourth Month	Mean Days of Gestation	Percent Preterm	Number (%)
<2,200	275.3	6.7%	448 (17.0%)
2,200-3,349	272.2	13.3%	428 (16.3%)
3,350-4,999	273.7	10.1%	524 (19.9%)
5,000-7,599	273.2	11.0%	471 (17.9%)
7,600+	272.3	12.0%	758 (28.8%)
Total	273.2	10.8%	2,629 (100%)

(ANOVA Significance = 0.307) (Contingency Coefficient= 0.017**)

Our study is unique in several aspects. Only a few studies on air pollution actually incorporated the air quality index. Our study also was done in a very data scarce setting; however, it presents comparatively clear evidence of the strong association between these negative birth outcomes and air pollution. Our study also investigated the gender differentiated association for low birth weight and premature birth and suggested the potential vulnerable exposure period during the pregnancy.

Our study only examined the association between ambient air pollution with normal delivery cases. We excluded mothers who went through C-section and other scenarios. Although it is possible that some of the mothers experienced very high levels of indoor air pollution during the pregnancy, as national representative data states, the majority of the households now primarily rely on LPG for domestic use [26], thus minimizings this contribution. However, the actual impact of indoor air quality could not be assessed within this study. Also, different socio-economic, physical, and environmental parameters could play critical roles in the overall birth outcomes that could not be adjusted for within the scope of the study.

Our findings point out the implications of ambient air quality on birth outcomes, and this association warrants more in-depth investigation, including a prospective study design. Along with the level of exposure, the timing or exposure window requires critical attention, to understand the specific developmental phases of the fetus and what organs may be developing during which such exposure may be detrimental [14,20,40]. Moreover, climate change and air pollution are "two sides of the same coin" and often are linked to the common sources of greenhouse gas (GHG) emissions [47]. Different air pollutants (CO, NO, NO_2), climate-forcing GHGs (H_2O, CH_4, O_3), and aerosols (H_2SO_4, HNO_3, BC) are accelerating climate change [48], whereas the local, regional and global meteorological variables such as temperature, humidity, precipitation, wind speed and direction influence pollutant emission, transformation, transport, dispersion, and deposition [32]. With climate change and increasing heat waves in urban cities, air pollution could become increasingly dangerous to both the mother and the growing fetus [49].

Conclusion

Air pollution in Dhaka has become a critical public health concern and the overall situation is likely to worsen as the government has initiated several large construction projects within and around the city without any pollution control measures. With increasing climate change, air pollution will become much more severe for the exposed population [4]. As evident from this study, air pollution is associated with increased low birth weight and prematurity with a significant gender differentiated effect among the exposed community. So far, the majority of studies on air pollution and pregnancy outcomes have focused on developed countries whereas underdeveloped and developing countries are experiencing the highest burden. These findings thus call for global attention and combined effort to confront air pollution and climate change. Immediate action and policy support are needed to ensure safer air for all in the city of Dhaka.

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Declaration of Competing Interests

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.

CRediT authorship contribution statement

Mahin Al Nahian: Conceptualization, Data curation, Investigation, Project administration, Resources, Supervision, Writing – original draft. **Tanvir Ahmad:** Project administration, Visualization, Writing – review & editing. **Ishrat Jahan:** Project administration, Resources, Writing – review & editing. **Nitai Chakraborty:** Methodology, Formal analysis, Writing – review & editing. **Quamrun Nahar:** Conceptualization, Funding acquisition, Investigation, Project administration, Resources, Supervision, Writing – review & editing. **Peter Kim Streatfield:** Conceptualization, Data curation, Formal analysis, Funding acquisition, Investigation, Methodology, Supervision, Writing – review & editing.

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References

[1] World Health Organization. Ambient air pollution: a global assessment of exposure and burden of disease. Geneva, Switzerland: World Health Organization; 2016 Report No.: 9241511354.
[2] World Health Organization. Air pollution. [Available from: https://www.who.int/health-topics/air-pollution#tab=tab_1.
[3] Health Effects Institute. State of global air 2018: a special report on global exposure to air pollution and its disease burden. Boston, MA: Health Effects Institute; 2018.
[4] Fuller R, Landrigan PJ, Balakrishnan K, Bathan G, Bose-O'Reilly S, Brauer M, et al. Pollution and health: a progress update. Lancet Planetary Health 2022.
[5] Siddiqui AR, Gold EB, Yang X, Lee K, Brown KH, Bhutta ZA. Prenatal exposure to wood fuel smoke and low birth weight. Environ Health Perspect 2008;116 (4):543.
[6] Fiore AM, Naik V, Leibensperger EM. Air quality and climate connections. J Air Waste Manage Assoc 2015;65(6):645–85.
[7] Carré J, Gatimel N, Moreau J, Parinaud J, Léandri R. Does air pollution play a role in infertility?: a systematic review. Environ Health 2017;16(1):82.
[8] Proietti E, Röösli M, Frey U, Latzin P. Air pollution during pregnancy and neonatal outcome: a review. J Aerosol Med Pulmon Drug Deliv 2013;26 (1):9–23.
[9] Malley CS, Kuylenstierna JC, Vallack HW, Henze DK, Blencowe H, Ashmore MR. Preterm birth associated with maternal fine particulate matter exposure: a global, regional and national assessment. Environ Int 2017;101:173–82.
[10] Cohen AJ, Brauer M, Burnett R, Anderson HR, Frostad J, Estep K, et al. Estimates and 25-year trends of the global burden of disease attributable to ambient air pollution: an analysis of data from the global burden of diseases study 2015. Lancet North Am Ed 2017;389(10082):1907–18.
[11] Clifford A, Lang L, Chen R, Anstey KJ, Seaton A. Exposure to air pollution and cognitive functioning across the life course–a systematic literature review. Environ Res 2016;147:383–98.
[12] Central pollution control board. Study on ambient air quality, respiratory symptoms and lung function of children in Delhi. Delhi, India. Central Pollution Control Board, Ministry of Environment and Forests; 2012.
[13] Shah AS, Lee KK, McAllister DA, Hunter A, Nair H, Whiteley W, et al. Short term exposure to air pollution and stroke: systematic review and meta-analysis. BMJ 2015;350:h1295.
[14] Šrám RJ, Binková B, Dejmek J, Bobak M. Ambient air pollution and pregnancy outcomes: a review of the literature. Environ Health Perspect 2005;113(4):375–82.
[15] World Health Organization. Born too soon: the global action report on preterm birth. Geneva, Switzerland: World Health Organization; 2012 Report No.: 9244503433.
[16] Ghosh R, Causey K, Burkart K, Wozniak S, Cohen A, Brauer M. Ambient and household PM2. 5 pollution and adverse perinatal outcomes: A meta-regression and analysis of attributable global burden for 204 countries and territories. PLoS Med 2021;18(9):e1003718.
[17] National Institute of Population Research and Training, Mitra and Associates, ICF International. Bangladesh demographic and health survey 2014. Dhaka, Bangladesh and Maryland, USA. National Institute of Population Research and Training (NIPORT), Mitra and Associates & ICF International; 2016.
[18] Wang H, Bhutta ZA, Coates MM, Coggeshall M, Dandona L, Diallo K, et al. Global, regional, national, and selected subnational levels of stillbirths, neonatal, infant, and under-5 mortality, 1980–2015: a systematic analysis for the Global Burden of Disease Study 2015. Lancet North Am Ed 2016;388(10053):1725–74.
[19] Department of Environment. Air quality status and trends: 2013-2015. Dhaka, Bangladesh. Department of Environment; 2016.
[20] Klepac P, Locatelli I, Korošec S, Künzli N, Kukec A. Ambient air pollution and pregnancy outcomes: A comprehensive review and identification of environmental public health challenges. Environ Res 2018;167:144–59.
[21] Ahmad S, Sayed M, Khan M, Karim N, Hossain Z, Yasmin N, et al. Assessment of impact of air pollution among school children in selected schools of Dhaka City, Bangladesh. Malé declaration on control and prevention of air pollution and its likely transboundary effect for South Asia. 2008.
[22] Aktar MM, Shimada K. Health and economic assessment of air pollution in Dhaka, Bangladesh. In: Proceedings of the second seminar of Japan Society for Promotion of Science - Vice-Chancellors Council of Malaysia (JSPS-VCC) group. JSPS-VCC; 2005.
[23] Alam DS, Chowdhury MAH, Siddiquee AT, Ahmed S, Hossain MD, Pervin S, et al. Adult cardiopulmonary mortality and indoor air pollution: a 10-year retrospective cohort study in a low-income rural setting. Global Heart 2012;7 (3):215–21.
[24] Huq M, Dasgupta S, Khaliquzzaman v, Pandey K, Wheeler D. Indoor air quality for poor families: new evidence from Bangladesh: The World Bank; 2004.
[25] Nahar M, Khan M, Ahmad S. Indoor air pollutants and respiratory problems among Dhaka city dwellers. Arch Community Med Public Health 2016;2(1):032–6 Archives of Community Medicine and Public Health32. doi: 10.17352/2455-5479.000014.
[26] National Institute of Population Research and Training, International Centre for Diarrhoeal Disease Research, Bangladesh, and, Measure Evaluation. Bangladesh urban health survey 2013 final report Dhaka, Bangladesh. Bangladesh: National Institute of Population Research and Training (NIPORT), Measure Evaluation and International Centre for Diarrhoeal Disease Research; 2015 icddr,b.
[27] Ahmadi A, Abbaspour M, Arjmandi R, Abedi Z. Air quality risk index (AQRI) and its application for a megacity. Int J Environ Sci Technol 2015;12(12):3773–80.
[28] Berry M, Nickerson N, Odum A. Delay discounting as an index of sustainable behavior: devaluation of future air quality and implications for public health. Int J Environ Res Public Health 2017;14(9):997.
[29] Laumbach RJ. Outdoor air pollutants and patient health. Am Fam Phys 2010;81 (2):175.
[30] Partners in Social Sector management Research Training & Development. National Low Birth-weight Survey, Bangladesh, 2015. Dhaka, Bangladesh: Partners in Social Sector management Research Training & Development (PSSMRTD), Directorate General of Health Services, Ministry of Health and Family Welfare (MoHFW), Government of the People's Republic of Bangladesh; 2016.
[31] American Heart Association. The Facts about High Blood Pressure. [Available from: https://www.heart.org/en/health-topics/high-blood-pressure/the-facts-about-high-blood-pressure.
[32] Kinney PL. Climate change, air quality, and human health. Am J Prev Med 2008;35 (5):459–67.
[33] Begum BA, Nasiruddin M, Randall S, Sivertsen B, Hopke PK. Identification and apportionment of sources from air particulate matter at urban environments in Bangladesh. Br J Appl Sci Technol 2014;4(27):3930–55.

[34] Randall S, Sivertsen B, Uddin N, Biswas S, Schneider P, Dam VT, et al. Ambient air pollution screening study in Dhaka. Bangladesh Air Pollut Manag (BAPMAN) Project 2011.
[35] Monteiro A, Vieira M, Gama C, Miranda A. Towards an improved air quality index. Air Qual, Atmos Health 2017;10(4):447–55.
[36] Plaia A, Ruggieri M. Air quality indices: a review. Rev Environ Sci Bio/Technol 2011;10(2):165–79.
[37] Banerjee T, Srivastava RK. Evaluation of environmental impacts of Integrated Industrial Estate—Pantnagar through application of air and water quality indices. Environ Monit Assess 2011;172(1-4):547–60.
[38] Wang Q, Benmarhnia T, Zhang H, Knibbs LD, Sheridan P, Li C, et al. Identifying windows of susceptibility for maternal exposure to ambient air pollution and preterm birth. Environ Int 2018;121:317–24.
[39] Ghosh R, Rankin J, Pless-Mulloli T, Glinianaia S. Does the effect of air pollution on pregnancy outcomes differ by gender? A systematic review. Environ Res 2007;105(3):400–8.
[40] Jacobs M, Zhang G, Chen S, Mullins B, Bell M, Jin L, et al. The association between ambient air pollution and selected adverse pregnancy outcomes in China: a systematic review. Sci Total Environ 2017;579:1179–92.
[41] Hackmann D, Sjöberg E. Ambient air pollution and pregnancy outcomes—a study of functional form and policy implications. Air Qual, Atmos Health 2017;10 (2):129–37.
[42] Wang X, Ding H, Ryan L, Xu X. Association between air pollution and low birth weight: a community-based study. Environ Health Perspect 1997;105(5):514.
[43] Ritz B, Yu F, Chapa G, Fruin S. Effect of air pollution on preterm birth among children born in Southern California between 1989 and 1993. Epidemiology 2000:502–11.
[44] Guo T, Wang Y, Zhang Y, Zhang H, Peng Z, Ma X. Association between PM 2· 5 exposure and the risk of preterm birth in Henan, China: a retrospective cohort study. Lancet North Am Ed 2017;390:S24.
[45] Zhou W, Ming X, Yang Y, Hu Y, He Z, Chen H, et al. Association between maternal exposure to ambient air pollution and the risk of preterm birth: a birth cohort study in Chongqing, China, 2015−2020. Int J Environ Res Public Health 2022;19 (4):2211.
[46] Qian Z, Liang S, Yang S, Trevathan E, Huang Z, Yang R, et al. Ambient air pollution and preterm birth: a prospective birth cohort study in Wuhan, China. Int J Hyg Environ Health. 2016;219(2):195–203.
[47] UNEP. Air pollution and climate change: two sides of the same coin. United Nations Environment Programme; 2019. [Available from: https://www.unep.org/news-and-stories/story/air-pollution-and-climate-change-two-sides-same-coin.
[48] Singh P, Yadav D. Link between air pollution and global climate change. Global Climate Change. Elsevier; 2021. p. 79–108.
[49] Dadvand P, Ostro B, Figueras F, Foraster M, Basagaña X, Valentín A, et al. Residential proximity to major roads and term low birth weight: the roles of air pollution, heat, noise, and road-adjacent trees. Epidemiology 2014:518–25.