Poor Air Quality and Pregnancy Outcome in Dhaka, Bangladesh

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Key Words

Air pollution, air quality index, premature birth, low birth weight, particulate matter $PM_{2.5}$

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ACRONYMS

AQI	Air Quality Index
BNAAQS	Bangladesh National Ambient Air Quality Standards
CAMS	Continuous Air Monitoring Stations
CASE	Clean Air and Sustainable Environment
DALYs	Disability Adjusted Life Years
DHS	Demographic and Health Survey
LBW	Low Birth Weight
MCHTI	Maternal and Child Health Training Institute
PTB	Preterm Birth
PM	Particulate Matter
US EPA	United States Environmental Protection Authority

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EXECUTIVE SUMMARY

Around the world in 2015, about one in seven babies was born with low birth weight (LBW, less than 2.5 kg.). This rate declined far too slow to attain the World Health Assembly nutrition target to reduce LBW by 30% between 2012 and 2015. Almost half of the 20.5 million LBW babies were born in South Asia, where many of the causative factors in more developed countries do not apply: older maternal age and related fertility treatments, maternal smoking during pregnancy, for example. One cause which might be common is the environmental factors which interfere with maternal blood supply to the foetus, and one factor which can theoretically cause this is the poor quality air in the mother's environment.

Air pollution is now recognized as a major cause of some seven million deaths globally, and a cause of much morbidity through breathing difficulties, and long-term damage to the cardio- and cerebro-vascular systems. Dhaka is one of the highest ranking cities in the world for air pollution levels, with almost half the days of the year experiencing "Unhealthy", "Very Unhealthy" or "Extremely Unhealthy" Air Quality Index (AQI) levels by United States Environmental Protection Agency's (US EPA) air quality standard. Thus it may be expected that this environmental threat would have negative consequences for vulnerable populations like pregnant women.

In this study, some 5,532 births from 2014 to 2017 taking place in Maternal and Child Health Training Institute (MCHTI), Dhaka, where air pollution levels are high and have been monitored by the Clean Air for Sustainable Environment (CASE) Project, were listed. A number of characteristics of the mother were collected and included in the analyses including maternal age, parity, blood pressure, and others. Not all variables could be obtained for all mothers and these cases were dropped. At analysis we used 3,206 cases where all required information of mother and children were available.

Most of the mothers were found living in the immediate area, and thus were exposed to the levels of ambient air pollution measured by CASE. This study analyzed levels of overall AQI as a risk factor, and birth weight and pregnancy duration, as outcome measures. Bangladesh has very recently developed its own AQI adopting the US EPA's air quality standard, setting own pollutant specific National Ambient Air Quality Standards (NAAQS) for Bangladesh. The AQI number represent the status of the air of any specific area on a daily basis- based on 5 criteria pollutants and 6 level categories considering different health implications and vulnerable groups. Among the AQI pollutants, $PM_{2.5}$ is of great concern due to its critical health impact. In this study, we assessed the pregnancy outcome in terms of LBW and prematurity against AQI. AQI provides an opportunity for generalization and comparison among different countries and thus planned intervention for improved air quality management.

The levels of air pollution in Dhaka are quite seasonal, with a brief low period during the monsoon from June to September. The rest of the year AQI levels are high. It was expected that pregnancies which occur outside the monsoon season would suffer higher cumulative exposure than those which include the monsoon, but this did not appear to be the case. Indeed, overall cumulative AQI exposure during pregnancy did not seem to be significantly linked to LBW or premature outcomes. Exposure levels in the second trimester, especially months 4 and 5, appear to negatively affect outcomes- both LBW and premature babies, so it is hypothesized that certain aspects of foetal development might be slowed or harmed by air pollution at that stage of pregnancy. The present study findings thus uphold the importance of more investigation to fully understand the overall mechanism- from source to exposure and outcome.

1. INTRODUCTION

Air pollution- the biggest environmental risk to health, is responsible for about one in every nine deaths annually (WHO, 2016). There are two most distinct types of air pollution- indoor air pollution and ambient or outdoor air pollution - the latter being one of the most critical risk factors contributing to death and disability (HEI, 2018). More than 92% of the world's population is exposed to unsafe levels of air pollution as per World Health Organization (WHO) guideline standards (Shaddick et al., 2016).

Preterm birth (at <37 completed weeks of gestation) is a 'major cause of (postnatal) death and a significant cause of long-term loss of human potential' (WHO, 2012). Exposure to air pollution can result in premature birth, low birth weight, poor lung development, mortality due to respiratory infections, and may also hamper cognitive development (Clifford, Lang, Chen, Anstey, & Seaton, 2016; Cohen et al., 2017; CPCB, 2012; Siddiqui et al., 2008).

In Bangladesh, 1 in 40 children dies as a neonate (NIPORT, Mitra and Associates, & ICF International, 2016), the leading cause of which is premature birth (Uthman, 2016). While very little is known about the adverse effect of air pollution on growing fetuses in Bangladesh, evidence of increasing air pollution reported in terms of Air Quality Index (AQI) by the Clean Air and Sustainable Environment (CASE) project (http://case.doe.gov.bd/) of Department of Environment, under the Ministry of Environment, Forest and Climate Change (MoEFCC) of Government of Bangladesh (GoB) has raised some critical concerns (DoE, 2016). AQI, first developed by the United States Environmental Protection Agency (US EPA), is generally used to report the status of air on a daily basis taking account of several types of pollutants by a single number ranging from 0 – 500. Bangladesh has developed its own Ambient Air Quality Standard (AAQS) reporting mechanism based on the US EPA AQI with slight modification in pollutant specific National Ambient Air Quality Standards (NAAQS) for policy integration, programme intervention, and overall air quality monitoring and management (DoE, 2016).

The impact of air pollution on health is receiving critical concern in the developing world and suggests the dire necessity of carrying out research on this field. The need for research is critical to estimate the number of adverse pregnancy outcomes attributable to high AQI exposure, especially for Dhaka city, where air pollution has become quite severe. Such research would draw the attention of policy makers and is expected to lead to better interventions to reduce air pollution and improve overall AQI in Bangladesh.

1.1. Goal and Objective

The goal of the study is to gain more knowledge about the negative health impact of air pollution (in terms of AQI) on growing fetuses and newborn babies.

1.1.1 Primary Objective

To quantify the association between low birth weight (LBW), preterm birth (PTB), and AQI in Dhaka city in Bangladesh.

2. BACKGROUND AND RATIONALE OF THE STUDY

Air pollution is defined by the state of indoor and outdoor air that has been contaminated by some gaseous and solid particles in its' natural characteristics and become harmful to health; major air pollutants include particulate matter ($PM_{2.5}$ and PM_{10}), carbon monoxide (CO), ozone (O_3), black carbon (BC), sulfur dioxide (SO_2) and nitrogen oxides (NOx) (WHO, 2018d).

2.1 Ambient air pollution and public health impact

Air pollution is the biggest environmental threat to health- causing one in every nine deaths in the world (WHO, 2016). In 2016, around seven million deaths were attributed to air pollution of which about 94% took place in low and middle-income (LMI) countries (WHO, 2018a). Ambient air pollution is an important contributor to global disease burden. It accounts for 7·6% of total deaths and 4·2% of Disability Adjusted Life Years (DALYs) globally; and around 59% of these occurred in east and south Asia (Cohen et al., 2017).

Air pollution also negatively impacted embryo development at genetic and epigenetic level and thus influenced the reproductive capacity of exposed populations (Carré, Gatimel, Moreau, Parinaud, & Léandri, 2017). Maternal exposure to ambient fine particulate material has been identified as a risk factor for adverse pregnancy outcome (Malley et al., 2017), and was found to be associated with preterm birth, low birth weight, and small-for-gestational age (SGA) births (Shah et al., 2015). The most vulnerable regions for preterm birth were found to be South and East Asia, North Africa/Middle East and West sub-Saharan Africa (Malley et al., 2017).

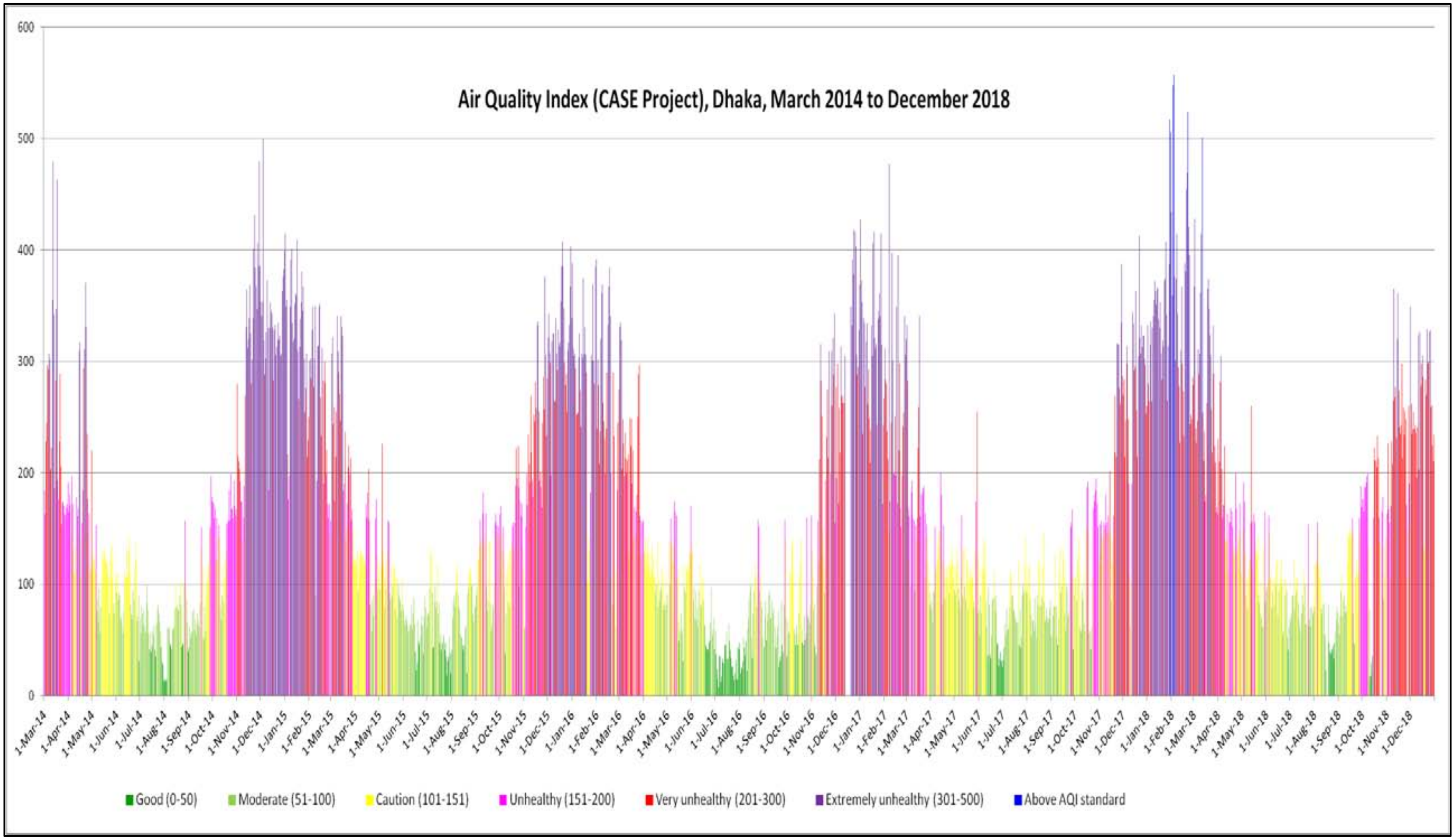
2.2 Air pollution and Bangladesh

Major sources of air pollution are vehicular and brick kiln emissions, construction sites, and refuse burning, with clear seasonal variation and elevated concentrations during the winter, and meteorological effects (B. A. Begum & Hopke, 2018). There are no long-term trend data for Bangladesh, but the Clean Air and Sustainable Environment (CASE) project (http://case.doe.gov.bd/) has four years of Air Quality Index (AQI) for Dhaka and several other cities. This shows that on almost half the days of the year the AQI ranks, according to WHO criteria and Bangladesh National Ambient Air Quality Standards (BNAAQS), as "Unhealthy", "Very Unhealthy" or "Extremely Unhealthy" (DoE, 2016). The patterns are highly seasonal with low AQI during the rainy (monsoon) season and high AQI the other 8-9 dry season months (Figure 2.1).

Air quality studies carried out in Bangladesh were primarily on the physical and chemical aspects of the air and pollutants- the majority of the studies only assessed the air quality of the Dhaka and other industrial cities of Bangladesh (B. Begum, 2016; B. A. Begum, Ahmed, Sarkar, Islam, & Rahman, 2015; B. A. Begum, Biswas, & Hopke, 2006; B. A. Begum, Nasiruddin, Randall, et al., 2014; Rana, Sulaiman, Sivertsen, Khan, & Nasreen, 2016) and evaluated the outcome of different policy interventions (B. A. Begum & Hopke, 2018; Wadud & Khan, 2013). Only a very few of the studies tried to assess the health burden due to air pollution, however, the majority of them were on indoor air pollution (Ahmad et al., 2008; Aktar & Shimada, 2005; Alam et al., 2012; Huq, Dasgupta, Khaliquzzaman, Pandey, & Wheeler, 2004; Junaid et al., 2017; Motalib, Lasco, Pacardo, Rebancos, & Dizon, 2015; Nahar, Khan, & Ahmad, 2016). Only one study tried to assess the association between pregnancy outcome with air pollution, i.e. LBW and indoor air pollution (IAP) by biomass fuel

(Haider et al., 2016). No other studies so far assessed the ambient air pollution, especially AQI exposure and its association with pregnancy outcome (PTB, LBW, SGA, etc.) in Bangladesh. Thus it is of critical importance to assess the impact of air pollution on pregnancy outcome among a vulnerable population.

Figure 2.1: Air quality of Dhaka city from March 2014 to March 2018



3. METHODOLOGY

The study was carried out to assess the air quality in Dhaka city in terms of AQI and its association with pregnancy outcome. The study quantified the prevalence of LBW and PTB among women living in Dhaka city who delivered at a hospital in Dhaka city and explored the association between AQI and adverse pregnancy outcomes.

3.1. Pregnancy Outcome Data

The study collected hospital record on pregnancy outcomes from the Maternal and Child Health Training Institute (MCHTI), Azimpur, Dhaka that operates under Directorate General of Family Planning (DGFP) of Ministry of Health and Family Welfare (MoHFW) of Government of Bangladesh. MCHTI provides antenatal (ANC), delivery and post-natal care (PNC) services to women. ANC is provided to women when they first come at the 4th month of pregnancy. ANC is then provided in 1-month intervals, at 5, 6, and 7 months of pregnancy; 15 days interval visits in 8th month and 7 days interval visit at 9th month. Records are maintained through ANC card. Women presenting with labor pain are admitted to labor ward and a history and examination sheet is opened for each admitted woman. Normal delivery takes place at labor ward, where the Confinement Sheet is partially filled up. When the baby is born, the rest of the sheet is filled up in post-operative care and entered into a register book as well.

MCHTI provided birth data and pregnancy information such as gestation duration, birth weight, and pregnancy history of the mothers from 2014-2017. The study population was restricted to the population living in Dhaka city. We used further exclusion based on the completeness of the data we received from MCHTI. We included women who had singleton delivery and had complete hospital record and delivered by vaginal delivery. We excluded women who had "Abortion (including 'incomplete abortion')", "Referred to other hospital", and who had "still birth".

The study included a total 5,532 birth records from the register book of normal vaginal delivery that covered the period of 2014-2017, four years. Then based on the unique registration number we matched the mother's additional information from the 'Confinement sheet,' 'History and Examination sheet, 'Indoor form.' There was complete matching of 3,206 records which were taken into for final analysis.

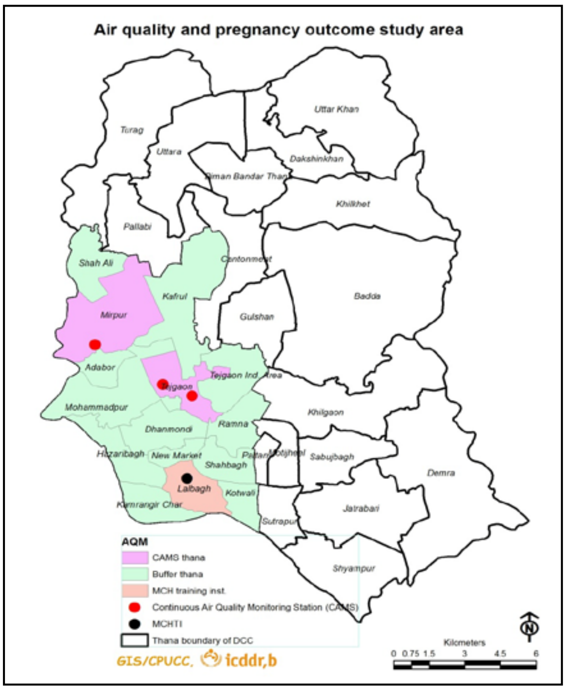
3.2 Air pollution Data

Air pollution data was used from the DoE run CASE) project. . The World Bank funded CASE project has four years of available data on various air quality parameters: Particulate matter ($PM_{2.5}$ and PM_{10}), Sulfur dioxide (SO_2), Nitrogen Dioxide (NO_2), Ozone (O_3), and Carbon monoxide (CO) that has been used to prepare AQI. The project records different air quality parameters in three locations (Mirpur Dar us Salam, Farmgate and National Parliament building) of Dhaka city by Continuous Air Monitoring Stations (CAMS) and reports the air quality status of Dhaka city on its website by AQI on daily basis. This study collected the online reports and extracted the AQI for the period of 2014-2017 for these three CAMS of Dhaka city.

3.3 Study Area

The study was conducted in the selected thanas (second largest administrative unit) in Dhaka city, the capital of Bangladesh. The study only considered the population living in Dhaka city.

Figure 3.1: Location of the CAMS in Dhaka city



3.4 Limitations of the study

This study used retrospective cross-sectional secondary data which allowed us to assess correlation of air quality and pregnancy outcome, not causality, which is a limitation. Air quality data was collected from three stations. There was no provision to have location specific exposure to air pollution of pregnant mothers residing in different parts of Dhaka city. The study used average AQI value from CASE project and assumed that mothers were exposed to the same level of exposure for that particular period of time. The study also did not have any information on indoor air pollution and thus couldn't assess the overall impact of air pollution to pregnancy outcome. A mother living in safe ambient air might be exposed to very unhealthy indoor air pollution and vice versa; however, within the limited scope of the study; there was no provision to measure the whole range of exposure.

The study was conducted in a government hospital using routine service data, and thus availability of certain variables was limited. Quality of some data was also questionable. The MCHTI maintains separate records of C-section deliveries using a different register, which we could not access. The analysis further missed cases of women who were "Discharged on Risk Bond (DORB)" or "Discharged on Request (DOR)", had "Abortion (including 'incomplete abortion')", "Referred to other hospital", and who had "still birth", which further limited our analysis.

4. RESULTS

4.1 Babies:

4.1.1 Years and months of birth

The women selected for this study gave birth in the MCHTI, Azimpur, Dhaka, commonly known as Azimpur Maternity Clinic, in the years 2014 (N=1,381), 2015 (N=1,689), 2016 (N=1,419), 2017 (N=1,039) and 4 in 2018. The monthly births were evenly spread (7 to 9%) over all 12 months, though slightly above average (10.7%) in August. This is a common pattern in Bangladesh, as consistently recorded over 50 years in icddr,b Matlab Health and Demographic Surveillance System, where monthly numbers of births are some 30% higher in September and October compared to earlier in the year around March and April. It affects all parity births, not just first born. The reasons have never been fully explained, though it may be related to fluctuating nutrition levels affecting fecundity (Becker, 1981).

4.1.2 Sex of babies

The sex ratio of the births was exactly equal, at 100 males to 100 females, slightly different from the expected biologically 105:100, and suggesting that no male preference sex selection has taken place.

4.1.3 Parity of viable births

Focusing on previous viable pregnancies, 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%). This resembles the pattern of national births where fertility levels are close to replacement levels (national replacement Total Fertility Rate in 2015 is 2.15), and urban levels are lower than rural levels.

4.1.4 Delivery type

Normal deliveries accounted for 100% of all births (99.4% with head first, plus another 0.4% with back first). As mentioned earlier, this study is done with normal delivery cases only. C-sections were excluded.

4.1.5 Status after delivery

There were very few stillbirths, only 2.1% (N=118) of births were dead on delivery, and 97.9% were alive. There may, of course, have been more stillbirths which occurred before the pregnant women came to the Maternity Clinic, and these would not be recorded in this cohort. The majority of those born alive were in good condition, with 93.2% recorded as being "Well".

4.1.6 Birth weights

The birth weight data indicate considerable heaping, with almost half of all births being ascribed weights of 2.5 kg (17.7%) or 3.0 kg (23.7%) (Table 4.1). This creates a major problem for estimating proportions of low LBW babies. If only weights below 2,500 grams are considered LBW, then only one in ten (10.1%) were LBW. However, if weights up to, and including 2,500 grams are considered, then 27.8% were LBW babies, an almost three times higher proportion. Selected analyses will be performed using both assumptions as a form of sensitivity analysis.

Table 4.1: Distribution of Birth Weight

Birth Weight Group	Percentage of Births
Less than 1,999 grams	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% (N=5,382)

4.1.7 Gestation (pregnancy duration)

Two thirds of births had a gestation length between 265 and 285 days, which centers around nine months plus or minus 10 days (Table 4.2). One in eight babies (12.3%) were premature (less than 37 weeks or 259 days). The distribution was approximately normal, though skewed to shorter durations, as would be expected.

Table 4.2: Distribution of Gestation / Pregnancy Duration (Days)

Gestation (Days)	Percentage of Births
Less than 255	9.7
255-264	9.8
265-269	11.9
270-274	16.4
275-279	20.3
280-284	17.5
285-289	6.9
290 or more	7.6
TOTAL	100% (n=2,695)

4.1.8 APGAR Score

The APGAR (Appearance, Pulse, Grimace, Activity, and Respiration) score is a simple test to report the condition of newborn babies and identify if additional medical intervention is needed to ensure survival. The overall scores, based on 5 items with possible score of 0, 1 or 2, giving range 0-10 = best) for 2685 babies measured, are remarkably similar with 93% scored as 8. Only 3% are in the moderately normal range of 4 to 6. About the same (2.9%) are in the critically below normal range of 3 or less. The latter are mostly scored zero which indicates no pulse and not breathing, indicating likely death, unless immediate resuscitation is successful.

4.2 Mothers:

4.2.1 Age of mothers

Overall, the vast majority (88%) of births occurred to women aged under 30 years. Almost one quarter (23%) were teenage births, and a further two-thirds are to women in their twenties. This is consistent with the national pattern of early marriage and low lifetime fertility. (Table 4.3)

Table 4.3: Age Group of Women Giving Birth

Age Group	Frequency	Percent
<15	3	0.1
15-19	1,235	22.9
20-24	2,103	39.1
25-29	1,403	26.1
30-34	511	9.5
35-39	118	2.2
40+	7	0.1
Total	5,382	100%

4.2.2 Mother's weight

The distribution of mother's weights is approximately normal, with the largest proportion (over one third) in the 50 to 59 kg range, and almost another one third 60 to 69 kg. (see Table A.1 in Appendix A). One in eight (12.6%) were less than 50 kg. But as overweight and obesity become more common in Bangladesh, around one in six women weighed more than 70 kg. It must be noted that weights were taken, in many cases, in the last trimester or stage of pregnancy, so they reflect the combined weight of mother and fetus, along with amniotic fluid, enlarged uterine muscle mass, placenta, etc., and therefore will overestimate maternal non pregnant weight.

4.2.3 Mothers' height

More than 90% of the mothers were between 1.4 and 1.6 metres in height, with 1.5-1.6 metres being the most common range (Appendix A Table A.2). As 145 cms is taken as a cutoff for risk for obstructed labour, this group had 11.1% in the elevated risk group under 145 cms. This compares closely with the 11.8% seen in the urban sample of the Bangladesh Demographic and Health Surveys (BDHS) 2014 (NIPORT et al., 2016).

4.2.4 Mother's blood pressure

Two components make up the diagnosis of hypertension – systolic and diastolic blood pressure measurements (see Table 4.4). The cutoffs used in this study were consistent with those used in BDHSs and other recognized sources, and they derive from the American Heart Association (AHA) 2016 guidelines (AHA, 2016). It should be mentioned that since this study was conducted, the AHA has produced slightly different guidelines (AHA, 2017).

Table 4.4: Classification of Hypertension

Classification	Systolic BP (in mm Hg)		Diastolic BP (in mm Hg)
Not elevated			
Normal	Less than 120	and	Less than 80
Prehypertension	120-139	or	80 – 89
Elevated (Hypertensive)			
Stage 1	140 – 159	or	90 – 99
Stage 2	160 or higher	or	100 or higher

(Source: (AHA, 2016)

More than half the mothers (52.4%) were in the normal range in regard to Systolic BP. Another one third (36.2%) were in the Prehypertensive range. One in ten (10.1%) were in Stage 1, and 1.2% were in the Stage 2 hypertensive ranges. Similarly, for Diastolic BP, half (51.1%) were in the normal range, with one in three (38.8%) in the Prehypertensive range, 8.1% in Stage 1 and 1.9% in Stage 2 ranges of Hypertension, respectively.

When both components of hypertension are looked at together, the picture is somewhat different. Among these delivering women, 43.1% had normal blood pressure (green), while 46.0% had pre-hypertension (yellow), 8.7% had stage 1 elevated hypertension (orange), and 2.2% were stage 2 elevated hypertension (red) (Table 4.5).

Table 4.5: Distribution of Mothers by Hypertensions Status

Systolic BP	Diastolic BP				
	Less than 80	80-89	90-99	100 or more	Total
Less than 120	**1,294 (43.1%)**	**274 (9.1%)**	**6 (0.2%)**	**0 (0.0%)**	1,574 (52.2%)
120-139	**240 (8.0%)**	**865 (28.8%)**	**156 (5.2%)**	**7 (0.2%)**	1,268 (42.3%)
140-159	**1 (0.0%)**	**25 (0.8%)**	**74 (2.5%)**	**36 (1.2%)**	136 (4.5%)
160 or more	**0 (0.0%)**	**2 (0.1%)**	**7 (0.2%)**	**12 (0.4%)**	21 (0.7%)
Total	1,535 (51.2%)	1,166 (38.9%)	243 (8.1%)	55 (1.8%)	2,999 (100%)

Normal BP	**Prehypertension**	**Hypertensive Stage 1**	**Hypertensive Stage 2**

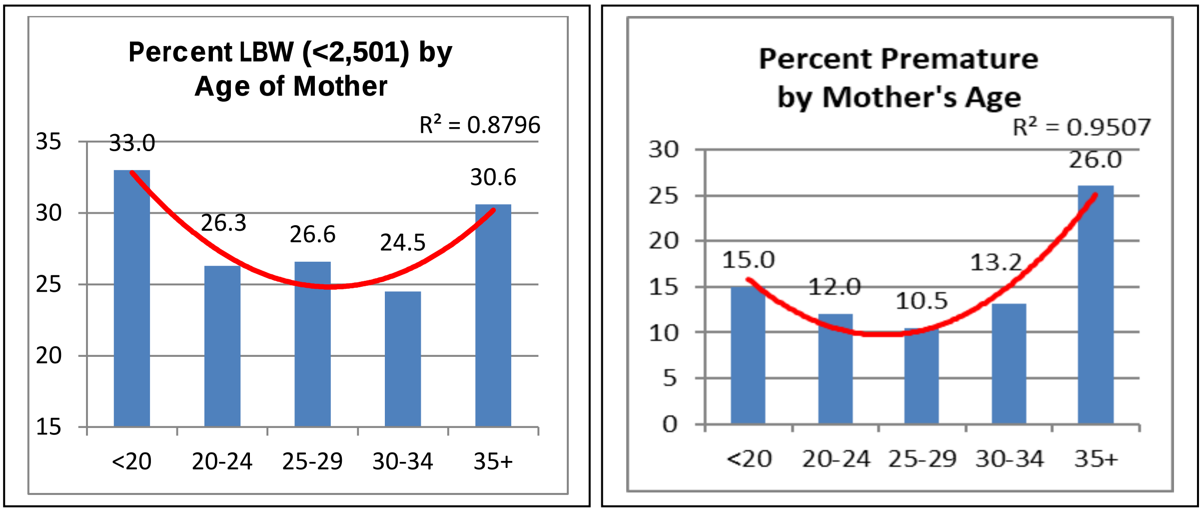
As comparison, the 2011 BDHS had a module on hypertension among women aged 35 and over. Very few of the women in this study were aged over 35 years, so comparison with BDHS 2011 is hazardous. However, even among this younger sample, only 43% were normal in comparison with 55% of the BDHS sample aged 35 or more. This suggests that hypertension is more prevalent here than in the national sample. Even taking into account that the urban level of hypertension tends to be one third higher than rural levels, this is of concern. It may, of course, partly reflect the stresses of living among the less advantaged residents of this megacity. The distribution of mother's systolic blood pressure and diastolic blood pressure is provided in Appendix A (Table A.3 and Table A.4 respectively)

4.3 Patterns of Birth Weight (% LBW) and Prematurity (% Premature) by mother's characteristics:

4.3.1 Mother's age

There is no clear relationship between mother's age and proportions of LBW births, either using the 2,499 or the 2,500 gram cutoff. Though, it could be said that using the higher cutoff shows slightly higher proportions LBW among younger mothers. The difference among the age groups with this higher cutoff are significantly different, but not in a linear fashion – more U-shaped with age. There are very few births among the older women, so these higher values do not influence the overall averages to any great extent. (Figure 4.1a).

Figure 4.1 (a) Percent LBW, and (b) Percent Premature by Mother's Age



Overall, 11.1% of births were premature (before 37 weeks of pregnancy). Mean days of gestation was 273.6. Like LBW, the risk of premature birth is U-shaped by age of mother. Teenage mothers are at somewhat elevated risk, but older mothers, aged 35 or more, are at greatly elevated risk (Fig 4.1b). This may be due to the presence of certain medical conditions, such as hypertension.

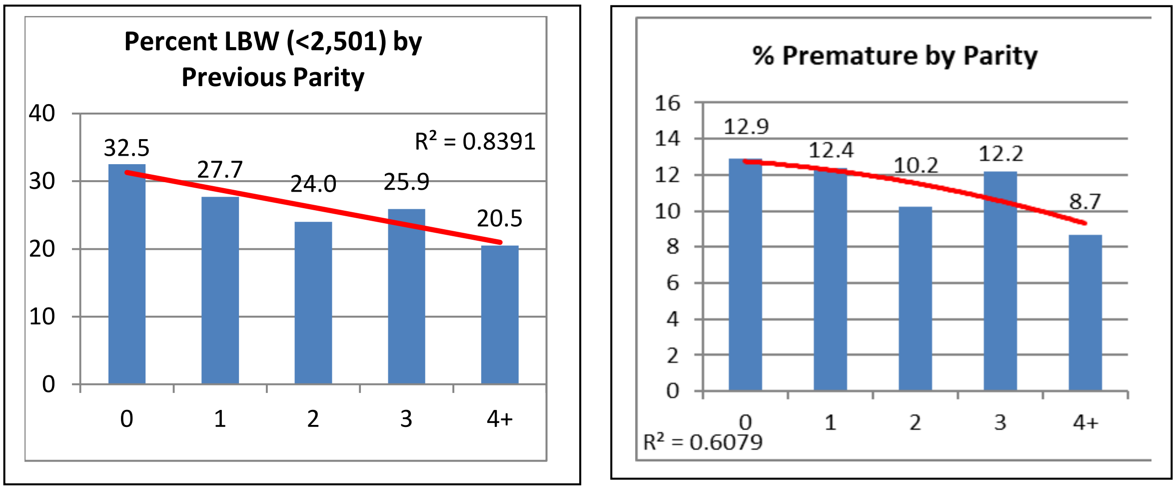
Between the ages of 20 and 35, the risk of premature births is fairly constant. So the fact that there is a highly significant relationship between mother's age and risk of prematurity must be due to the younger and older age mothers.

4.3.2 Previous parity

The proportion of LBW births declines steadily with higher parities up to 4+ for both LBW cutoffs, though only those using the higher cutoff are statistically significant. The difference is mainly between first births (zero has 32.5% LBW) and others (down to 20.5% for 4+) (Fig 4.2a).

A first-born child will be zero previous parity (though not necessarily zero gravidity, if the woman has experienced any previous pregnancies which ended in miscarriage or abortion). In Fig 4.2b, the risk of premature births bears little relationship to previous parity, until parity four or more, when, surprisingly, the risk is reduced. But the numbers of births in the four or higher previous parities are small so the relationship between parity and risk of prematurity is not even close to significant.

Figure 4.2: (a) Percent LBW, and (b) Percent Premature, by Previous Parity

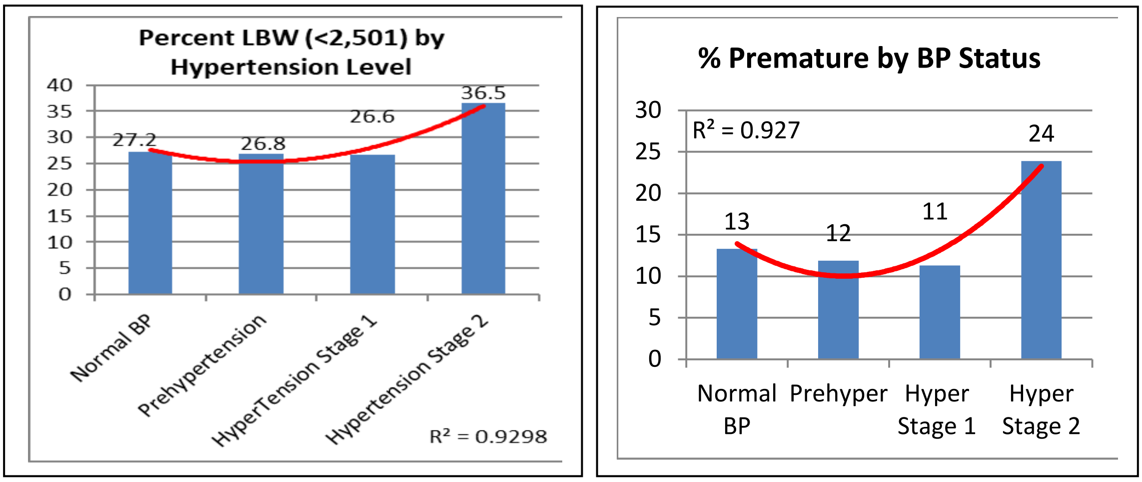


4.3.3 Hypertension status

As discussed earlier, the levels of pre- and full hypertension are higher than what might be expected for predominantly young women, when compared to the national Bangladesh DHS 2011.

What is somewhat surprising, however, is that hypertension does not appear to have a negative impact on either percent low birth weight (Fig 4.3a) or percent premature (Fig 4.3b) until reaching the highest level - elevated hypertension stage 2. As this group accounts for only 2% of the group of mothers represented in this study, it is not yet having a wide impact, though it must be of some concern due to being primarily among women aged under 30 years.

Figure 4.3: (a) Percent LBW (<2,501), and (b) Percent Premature, by Mother's Hypertension Status



4.4. Analysis of poor air quality exposure and birth outcomes- birth weight

4.4.1 Air Quality Index (AQI)

The Air Quality Index (AQI) used is a combination of 5 criteria pollutants; Particulate Matter (PM_{10} and $PM_{2.5}$), NO_2, CO, SO_2 and Ozone (O_3) (DoE, 2016). The AQI set by Department of Environment for Bangladesh is as follows:

Table 4.5: Air Quality Index (AQI) from 'Good' to 'Extremely Unhealthy' for Bangladesh

Air Quality Index	Category	Color
0 – 50	Good	Green
51 – 100	Moderate	Yellow Green
101- 150	Caution	Yellow
151 – 200	Unhealthy	Orange
201 – 300	Very unhealthy	Red
301 – 500	Extremely unhealthy	Purple

(source: (DoE, 2016)

It is recorded daily in three stations in Dhaka City, but for this study based on Azimpur the station closest has been selected. The pattern of residence shown earlier confirms that most women reside in an area very close to Azimpur.

4.4.2 Daily exposures

In the four years from March 1, 2014 covered by this study, the AQI has ranged from a solitary single digit reading (8) on July 5, 2016, to a high of 479 on March 12, 2014 (March 11, 2018 reached 501). In the 1,460 days covered, almost half are in the "Unhealthy", Very Unhealthy" or "Extremely Unhealthy" categories (Table 4.6). The levels are highest in the dry season from November through May, and lowest in the monsoon (wet) season from June to September when the rains bring much of the particulate matter out of the air.

Incidentally, the brick making kilns, which are believed to contribute greatly to Dhaka air pollution, cease operations during the wet season, as most of them are inundated with the water from the rivers to which they are adjacent (Randall et al., 2011).

4.4.3 Monthly exposures

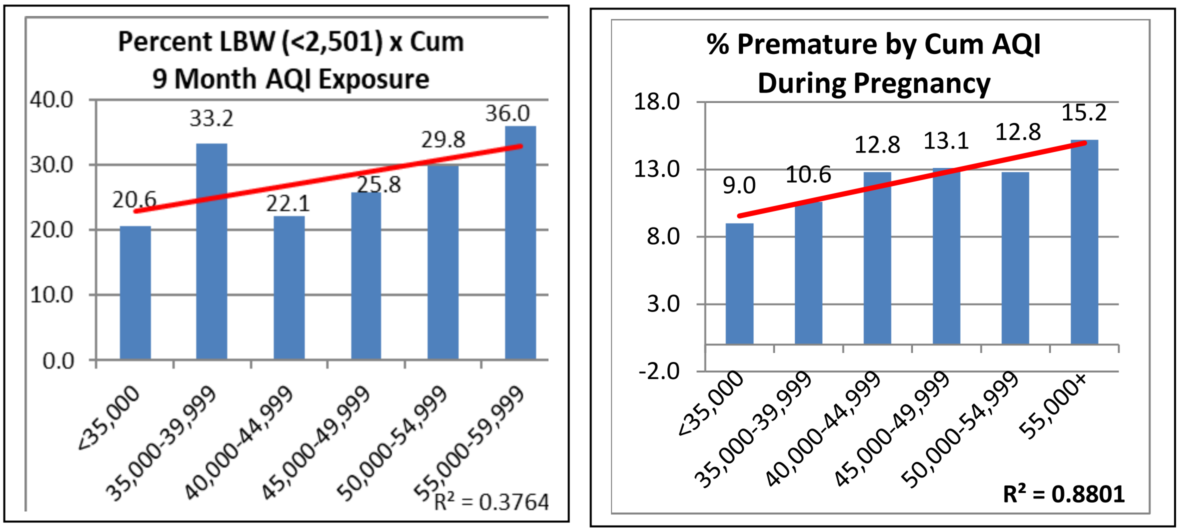
For the purposes of analysis, the daily readings have been cumulated for each of the 48 months. We could then estimate cumulative exposure for each pregnant woman during her pregnancy, assuming, of course, that she was living in her normal residential area. The monthly readings range from a low of 989 in July 2016, to a high of 11,072 in February 2018.

4.4.4 Nine month exposure

For the analysis of risk of a low birth weight outcome, the cumulative monthly exposures were further cumulated to nine months exposures for the full pregnancy. These ranged from a low of 28,652 for births in December 2016, to a high of 58,215 (more than double the low value) for births in June 2015.

The prevalence of LBW increased gradually from one in five births (20.6%) for the lowest category of cumulative 9 month exposure (<35,000), to well over one in three (36.0%) among those with highest exposure (55,000-59,000) (Fig. 4.4a). With one exception, the trend is strongly linear. Similarly, percent premature births showed a linear increase with level of cumulative 9 month AQI exposure (Fig. 4.4b).

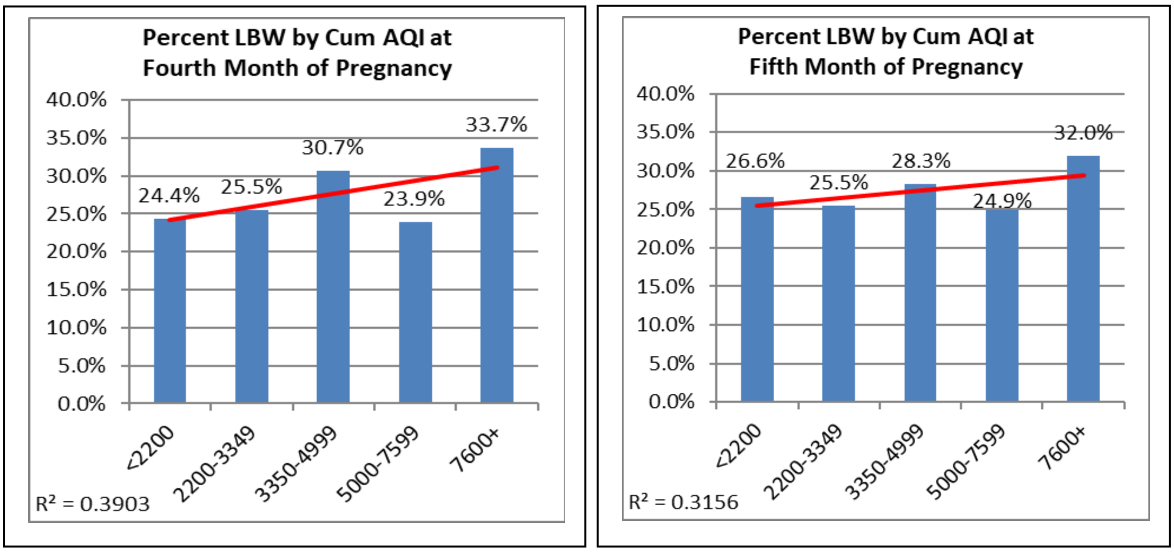
Figure 4.4: (a) Percent LBW and (b) Percent Premature, by Cumulative 9 Month Exposure to AQI



4.4.5 Second or third trimester exposure

AQI exposure can be further subdivided. For example, cumulative exposure in the second trimester, which ranged from 5,142 in January 2017 to 29,252 in May of 2015. Or in the third trimester, which ranged from 5,142 for births in October 2016 to 30,247 in March 2018 (Fig 4.5a and b).

Figure 4.5: Percent LBW by Cumulative AQI at (a) Fourth Month of Pregnancy, and (b) at Fifth Month of Pregnancy



The second trimester exposure showed a relationship with percent LBW; in particular, exposure in the fourth month (Fig 4.5a), and to a lesser degree, in the fifth month (Fig 4.5b). Risk of LBW rose by almost

10 percentage points as exposure increased from less than 2,200 to 7,600+ in the fourth month of pregnancy.

4.5 Multivariate Analysis of Low Birth Weight Risk by AQI Exposure

The multivariate analysis approach was to use Logistic Regression with birth weight as a binary or dichotomous dependent variable (low birth weight = 1, normal birth weight = 0). As described earlier, LBW is normally defined as births weighing up to and including 2,499 grams, and normal birth weight is 2,500 grams or more. However, in this study, there was a huge amount of 'rounding' on 2,500 grams – 17.7% of all births. Thus, the analysis was done (a) excluding 2,500 grams, and (b) including 2,500 grams as LBW. When 2,500 grams is excluded, the proportion LBW is about 10%, but when 2,500 grams is included as LBW, the percentage is 27.8%, closer to the national estimate of 22.6% in the 2015 National Low Birth Weight Survey (SSMF, 2017). However both analyses were conducted.

In determining which independent variables should be included, age of mother was definitely important, as LBW rates are higher among younger mothers (Figure 4.1). Parity (previous parity) is also related to LBW, but as parity is highly correlated with age of mother, it was decided not to include both variables. Stage 2 elevated blood pressures (hypertension) was noted as a risk factor for LBW so 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 season 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 (Table 4.7), taking LBW as including 2,500 grams as the outcome variable, are shown below. 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, as seen in the univariate graph. Surprisingly, hypertension (HighBP) does not show a significant relationship with risk of LBW, although the very highest level of hypertension (HighBP(3)) 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 (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. This is consistent with the univariate pattern where trimester 3 showed an unexpected, non-linear, or inverted-U pattern. The pattern in trimester 2 is as expected, though it is only exposure level 5 (25,000-29,999) which is significantly related to LBW with an Odds Ratio of 1.867, indicating an almost doubling of LBW risk at that level of exposure[1].

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[1] Note, care has to be taken with interpreting Exp (B) results as conventional Odds Ratios, because they are actually expressions or exponentials of the Logit of the B coefficients.

Table 4.6: Variables used in the Logistic Regression to show Low Birth Weight Risk by AQI Exposure

Variables in the Equation

	B	S.E.	Wald	df	Sig.	Exp(B)	95% C.I.for EXP(B)	
							Lower	Upper
AGE	-.021	.010	4.781	1	.029	.979	.960	.998
HIGHBP			3.451	3	.327			
HIGHBP(1)	.019	.090	.043	1	.835	1.019	.854	1.216
HIGHBP(2)	.074	.159	.218	1	.641	1.077	.789	1.470
HIGHBP(3)	.501	.274	3.338	1	.068	1.650	.964	2.823
AQI_CUM_TRIM3_R1			13.667	5	.018			
AQI_CUM_TRIM3_R1(1)	.092	.162	.326	1	.568	1.097	.799	1.505
AQI_CUM_TRIM3_R1(2)	-.316	.212	2.222	1	.136	.729	.482	1.104
AQI_CUM_TRIM3_R1(3)	-.586	.221	7.035	1	.008	.557	.361	.858
AQI_CUM_TRIM3_R1(4)	-.252	.169	2.216	1	.137	.777	.558	1.083
AQI_CUM_TRIM3_R1(5)	-.156	.154	1.020	1	.312	.856	.632	1.158
AQI_CUM_TRIM2_R1			19.005	5	.002			
AQI_CUM_TRIM2_R1(1)	.139	.187	.551	1	.458	1.149	.796	1.658
AQI_CUM_TRIM2_R1(2)	.044	.203	.048	1	.827	1.045	.702	1.557
AQI_CUM_TRIM2_R1(3)	-.135	.187	.520	1	.471	.874	.606	1.261
AQI_CUM_TRIM2_R1(4)	.238	.175	1.842	1	.175	1.268	.900	1.788
AQI_CUM_TRIM2_R1(5)	.624	.163	14.760	1	.000	1.867	1.358	2.568
Constant	-.503	.287	3.074	1	.080	.605		

a. Variable(s) entered on step 1: AGE, HIGHBP, AQI_CUM_TRIM3_R1, AQI_CUM_TRIM2_R1.

As blood pressure surprisingly did not prove to be significantly associated with risk of LBW, the analysis was repeated after dropping HighBP. The results were very similar, except that trimester AQI exposure category 3 was no longer significant, though it was close (0.074). Level 5 of trimester 2 remained significant.

It is worth mentioning that when the analyses were repeated using the alternate definition of LBW, that is, not including 2,500 grams, the results were somewhat different. Age of mother was no longer significant, but high blood pressure was significant (0.001) only at the highest level of stage 2 elevated blood pressure (0.004). More important is that neither AQI exposure in trimester 2 (0.362) or trimester 3 (0.298) was significantly related to LBW risk. However, if blood pressure was dropped from the analysis (which it should not be here, as it was significant), then AQI exposure became significant in trimester 3 (0.012), though not in trimester 2 (0.105), even though several higher levels of exposure (3 and 4) were significant.

Clearly more analyses are possible with these data, but it can be concluded from the multivariate analyses that young age of mother is a risk factor, hypertension may well play a role at higher levels, though attaining those levels takes time, and is likely to occur among older women.

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

It will be useful to pursue the importance of this timing, to understand what development phases the foetus is in around that time, and what organs may be developing, where such exposure may be detrimental.

A follow-on question would be, if the second trimester is a particular risk period, then what can mothers be advised to do during that period to protect their unborn baby.

5. DISCUSSION AND CONCLUSION

This study examines two measures of birth outcome, birth weight (mean and percent low birth weight), and prematurity (mean days of gestation and percent born 'premature' before 37 weeks of pregnancy). These two measures are clearly correlated, but not completely, as babies can be born full-term, but have low birth weight due to intra-uterine growth retardation. They can also be born prematurely but not have low birth weight if their foetal development has been rapid.

The main objective of the study is to determine if exposure to poor air quality during pregnancy negatively affects foetal development, and thus birth outcome, in a city with notoriously bad air quality. The women coming to the Azimpur Maternity Centre to deliver between 2014 and 2017, were predominantly residing in the area with a few kilometers of that Centre.

The findings cover the patterns of birth outcome (BW and prematurity) according to most common differentials (mother's age, parity, BP, etc.) but also exposure to poor air quality as measured by AQI.

Childbearing patterns in Bangladesh stubbornly remain that of early marriage for women, immediate initiation of childbearing within marriage, and low fertility. This means that almost all women complete childbearing in their twenties. Fortunately, this age range shows the highest mean birth weights, and lowest proportion of premature births. While a disturbing, and growing number of women are developing high blood pressure relatively early in adult life, this does not result in reduced BW or increased premature births, until the very highest level of hypertension (Stage 2) is reached (2% of total patients).

It was hypothesized from international experience that exposure to poor air quality during pregnancy would have a negative impact on birth outcomes such as BW and prematurity. As data were available on a daily basis for women's exposure to air quality in Dhaka city, it was possible to estimate their total exposure during pregnancy, cumulated over the nine months of pregnancy, and to break that down by exposure in trimesters and into specific months. This was done for overall AQI.

There is linear increase in prevalence of LBW- gradually rising from one in five births for the lowest category of cumulative 9 month exposure (<35,000), to well over one in three among those with highest exposure (55,000-59,000) (Fig. 4.4a). Similarly, percent premature births showed a linear increase with level of cumulative 9 month AQI exposure (Fig. 4.4b). When individual monthly exposure with trimester 3 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 both mean BW and proportion LBW {Figs 4.5 (a) & (b)}.

One explanation for the apparent lack of a strong negative impact of exposure to poor air quality during pregnancy is that most of these pregnant women live their lives in this polluted environment, and thus, exposure during pregnancy is simply 'more of the same'.

Whether there is any adaptive mechanism to exposure to poor air quality, as there is, for example, for those who live long term at high altitudes (increased red blood cell counts to carry more oxygen), is not known. The fact that average birth weights of over 2.8 kgs appear quite good, suggests that somehow these women have adapted to their environmental conditions.

The indications of negative impact of exposure in the second trimester suggest that the development of certain foetal organs or physiological processes may be harmed. By the fourth month the average fetus is about 20 cms in length and weighs around 100 grams, but many organs are already developing. The lungs will not start developing until later, and the surfactant they need to function is not produced until the third trimester. It may be possible that nutrient transfer from the mother's blood across the placental barrier may be harmed by exposure to airborne contaminants. Or simply transfer of oxygen may be negatively affected, with the effect of holding back foetal growth.

It is to be noted that, researches done in other parts of the world also came with varied findings; and not exclusively between pregnancy outcome and AQI level. Pregnancy outcome has been explored with other types of air contaminants as well, some study found association between first and third trimester (Hackmann and Sjöberg, 2017, Wang et al., 1997), while, other study explored association with level of exposure increase (Ritz et al., 2000) and days before delivery (Guo et al., 2017). In this particular study, we only tried to see the association between ambient air pollution, in terms of AQI and birth outcomes of normal delivery cases, whereas, the mothers who went through C- section and other complexities were excluded; the mothers who participated could live in very high concentration indoor air pollution, but could not be differentiated within the limited scope of the study. Also, different socio-economic, physical and environmental parameters could play critical role in the overall birth outcome that could not be adjusted within the scope of the study.

More examination is needed on the embryonic development aspects of these exposures.

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Appendix A

Table A.1: Distribution of Mother's Weight (Kg) Close to Delivery (including foetal weight)[1]

Mother's Weight (Kilograms)	Percentage
Less than 40	0.4%
40 to 49	12.2%
50 to 59	37.7%
60 to 69	32.5%
70 to 79	12.2%
80 to 89	4.2%
90 to 99	0.8%
Total	100% (N=2,778)

Table A.2: Distribution of Mother's Height (CMs)[2]

Mother's Height (Centimeters)	Percentage
Less than 130	0.3%
130 to 139	1.2%
140 to 149	37.1%
150 to 159	54.9%
160 to 169	6.3%
170 to 199	0.1%
Total	100% (N=2,778)

Table A.3: Distribution of Mother's Systolic Blood Pressure

Mother's Systolic BP	Percentage	Mother's Systolic BP	Percentage
70-79	0.0%	140-149	6.1%
80-89	0.8%	150-159	4.0%
90-99	3.5%	160-169	0.5%
100-109	25.0%	170-179	0.6%
110-119	23.1%	180-189	0.1%
120-129	36.1%	190-199	0.0%
130-139	0.1%	200 or more	0.0%
		TOTAL	100.% (n=2,999)

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[1] Information on women's height, weight and BP were collected from the forms, not the register.

[2] It was considered highly unlikely that any patient could be of height less than 1.3 meters, so these 8 cases (0.3%) were excluded from the calculation of body mass index (BMI).

Table A.4: Distribution of Mother's Diastolic Blood Pressure

Mother's Diastolic BP	Percentage
50-59	0.5%
60-69	19.1%
70-79	31.5%
80-89	38.8%
90-99	8.1%
100-109	1.4%
110-119	0.5%
TOTAL	100% (N=2,999)

Table A.5: (a) % Premature and (b) Mean Gestation (Days), by Previous Parity

Parity of Previous Births	Percent premature	Mean Days of Gestation	Number
0	12.9%	273.5	1021
1	12.4%	273.4	772
2	10.2%	273.7	361
3	12.2%	273.7	74
4+	8.7%	274.0	23
TOTAL	12.3	273.5	2,251

(Pearson Chi Square Significance = 0.828) (ANOVA Significance = 0.963)

Table A.6: Mean Birth Weight, by Mother's Hypertension Status

Blood Pressure Status	Mean Birth Weight (grams)	N
Normal BP	2,827	1,268 (43.1%)
Prehypertension	2,875	1,353 (46.0%)
Elevated Hypertension Stage 1	2,888	256 (8.7%)
Elevated Hypertension Stage 2	2,716	63 (2.1%)
Total	2,852	2,940 (100%)

(ANOVA Significance = 0.014) (Pearson Chi-Square Significance = 0.407)

Table A.7: Percent LBW (2 Categories), Mean BW, Percent Premature, Mean Gestation (Days), by Month of Delivery

Month of Delivery	**Percent Low Birth Weight (0-2,499)**	**Percent Low Birth Weight (0-2,500)**	**Mean Birth Weight (Grams)**	**Percent Premature**	**Mean Days of Gestation**
JANUARY	1.5%	26.1%	2849	8.9%	275.0
FEBRUARY	7.4%	22.8%	2898	12.9%	273.7
MARCH	13.7%	28.5%	2826	11.3%	272.1
APRIL	11.1%	24.4%	2816	13.4%	271.8
MAY	11.8%	27.7%	2831	12.2%	272.8
JUNE	12.6%	35.4%	2770	10.1%	273.0
JULY	11.2%	33.5%	2775	11.8%	272.3
AUGUST	8.3%	22.3%	2898	13.8%	273.1
SEPTEMBER	7.8%	26.8%	2877	10.4%	275.1
OCTOBER	8.1%	31.2%	2848	10.7%	273.6
NOVEMBER	9.1%	26.9%	2807	12.5%	271.5
DECEMBER	9.8%	26.5%	2829	7.0%	275.9
TOTAL	10.1 (541/5,381)	27.8 (1,494/5,381)	2836.7	11.3	273.2
Significance	0.028	0.000	0.028	0.641	0.177

Appendix B

Figure B.1: Mean BW by Mother's Age

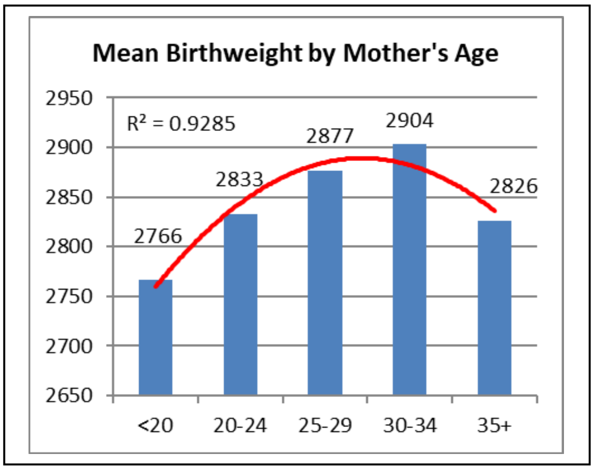


Figure B.2: Average Gestation (Days) by Mother's Age

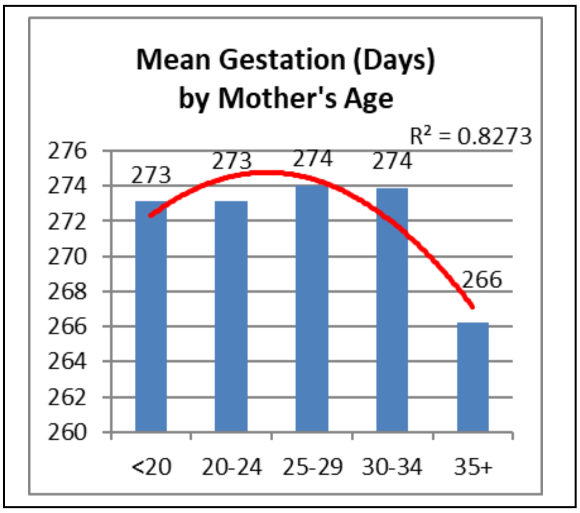


Figure B.3: Average Birth Weight by Previous Parity

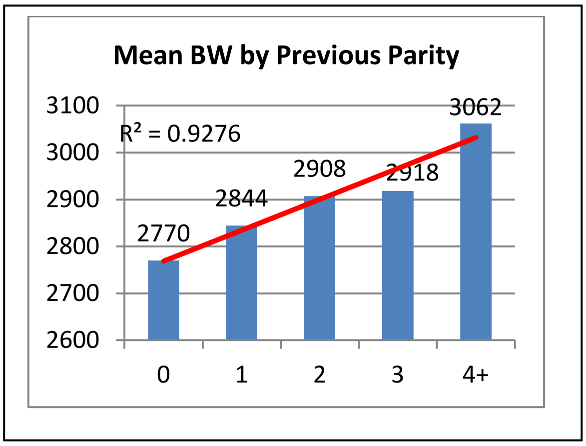


Figure B.4: Average Gestation (Days), and % Premature, by Previous Parity

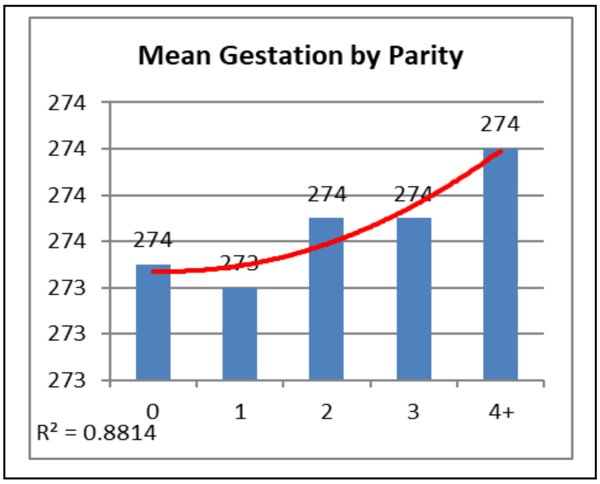


Figure B.5: Mean Birth Weight, and (b) % LBW, by Mother's Hypertension Status

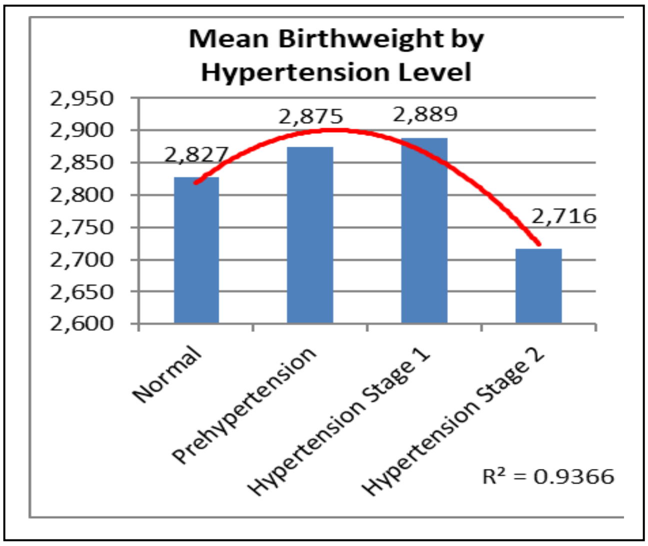


Figure B.6: Mean Gestation (Days), and (b) Percent Premature, by Hypertension Status

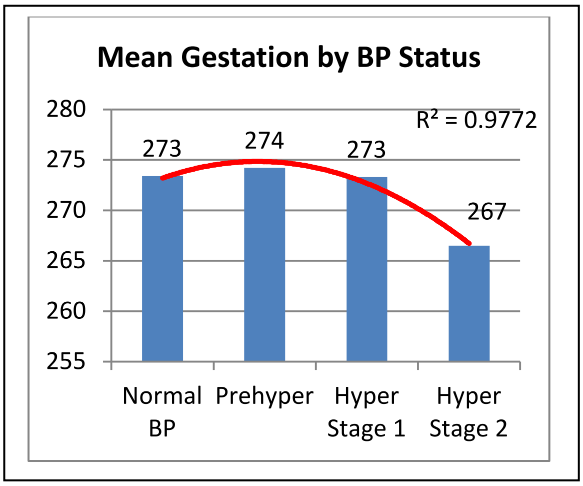


Figure B.7: (a) Percent LBW, and (b) Percent Premature, by Month of Delivery

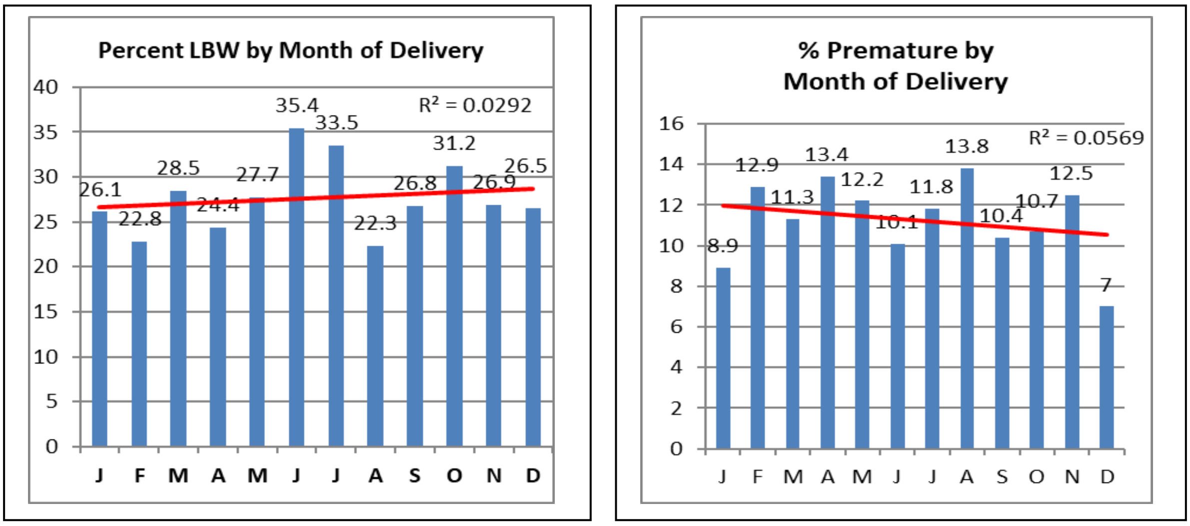


Figure B.8: Mean BW by Cumulative 9 Month Exposure to AQI

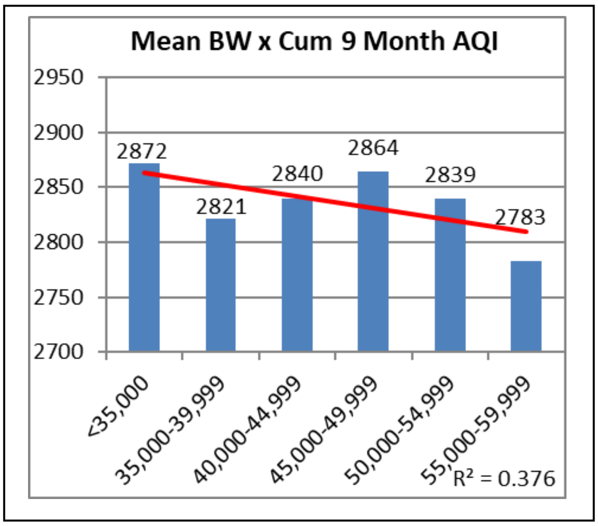
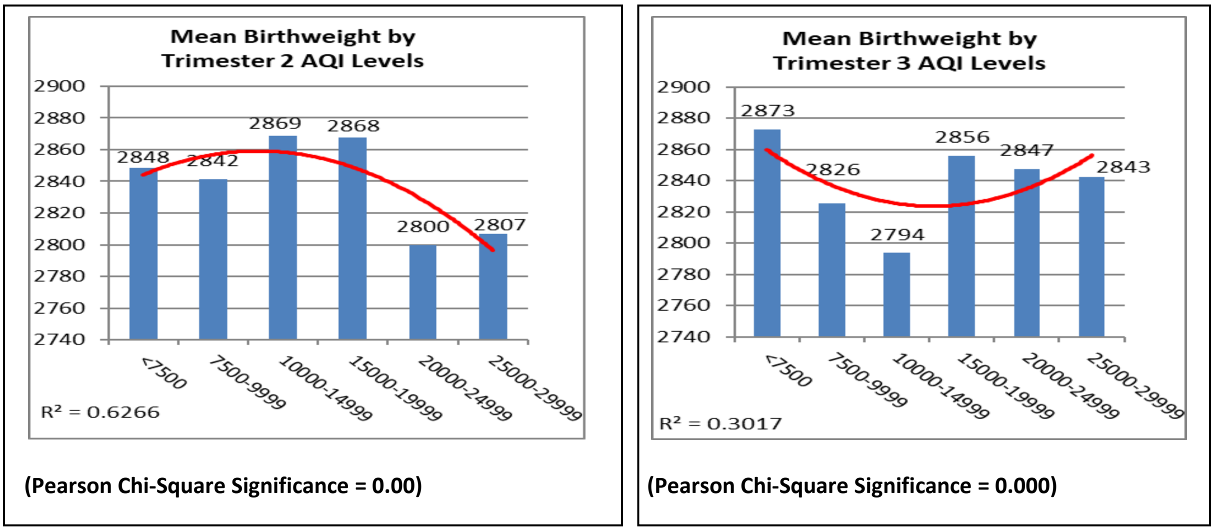


Figure B.9: (a) Mean Birth W by Trimester 2 AQI Levels, and (b) by Trimester 3 AQI Levels



(Pearson Chi-Square Significance = 0.00)

(Pearson Chi-Square Significance = 0.000)

Figure B.10: Mean Birth weight, and (b) Percent Low Birth weight by 9 Month $PM_{2.5}$ Cumulative Total

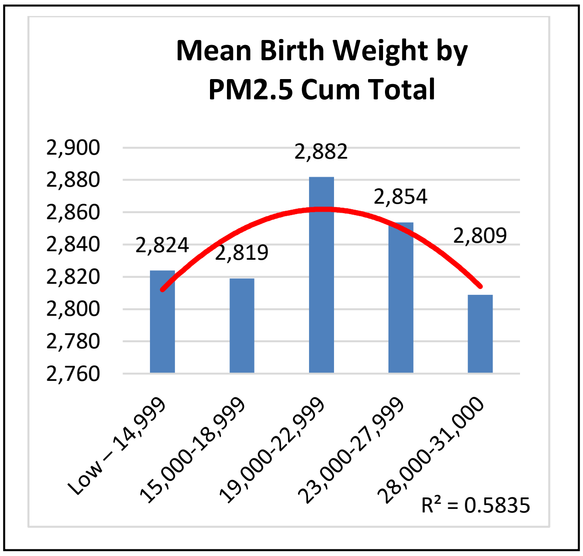


Figure B.11: Mean Birth Weight by Cumulative Monthly $PM_{2.5}$ Exposure

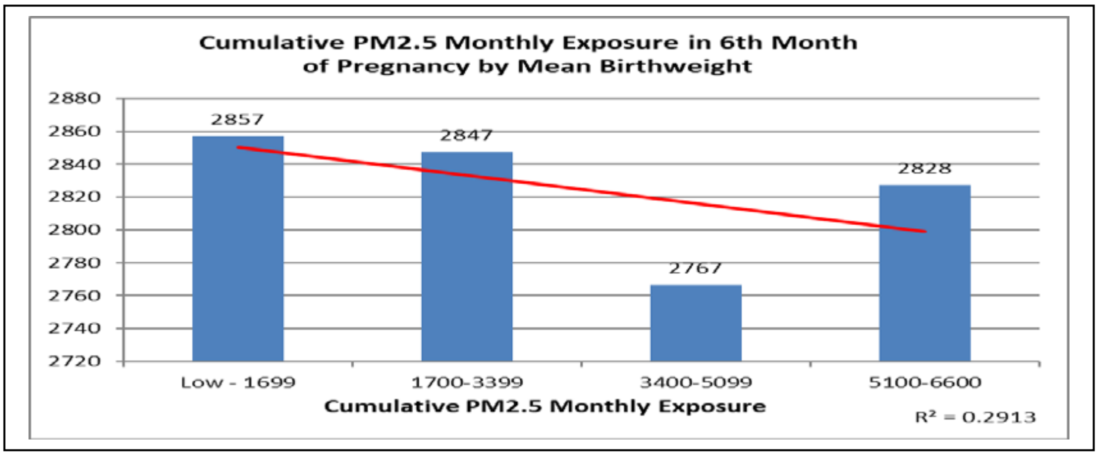


Figure B.12: Mean Gestation (Days) by 9 Month Cumulative AQI