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Air Quality and Morbidity in Dhaka City, Bangladesh:

an estimation of the contribution of brick kilns to air quality &

their potential to affect human health

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An abstract of a thesis submitted to the Faculty of the

Rollins School of Public Health of Emory University

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Abstract

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As a densely populated South Asian megacity, Dhaka, Bangladesh, struggles with high levels of ambient air pollution. One of the major sources of emissions in Bangladesh is the brick industry. Kilns emit thousands of tons of particulate matter (PM), which is one of the most hazardous components of air pollution. Exposure to PM has been shown to be associated with several increased morbidities. A quantitative estimation of the contribution of brick kilns to the concentration of PM in Dhaka city's air was calculated based on kiln production and spatial density of kilns in surrounding the city. These estimates were used to generate the approximate number of excess cases of several morbidities and their associated costs. The estimated contribution of brick kilns in the area surrounding Dhaka was 42.77 $\mu g/m^3$ PM_{10} and 25.66 $\mu g/m^3$ $PM_{2.5}$. These increased exposure levels resulted in over 21,000 disability adjusted life years (DALYs) lost due to chronic bronchitis, lower respiratory infection in children, respiratory related hospital admissions and emergency room visits, restricted activity days, and respiratory symptoms. The cost of these morbidities was estimated at 118 million USD. These estimates support the further development and implementation of new, cleaner brick kilns in Dhaka, Bangladesh and in similar areas in South Asia.

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1. Introduction

Ambient air pollution has been implicated as an important risk factor for increased mortality (Samet et al., 2000; Silva et al., 2013; Lelievaeld et al., 2015; Samek, 2016). Approximately 3 million premature deaths occur each year due to outdoor air pollution; an estimated eighty-seven percent of these deaths occur in low or middle income countries (WHO, 2016). In an addition to increased mortality, exposure to ambient air pollution is also significant cause of increased morbidity (Samet et al., 2000; Mehta et al.,2013; Samek, 2016). The World Bank estimates the cost of air pollution related deaths at 225 billion USD in lost labor costs; in South Asia, this cost is nearly one percent of Gross Domestic Product (GDP) (2016).

Bangladesh, like other South Asian countries, is challenged by high levels of ambient air pollution. Dhaka, the largest city and capital of Bangladesh, faces a disproportionate burden due to air pollution. In 2011, WHO named Dhaka within the top twenty most polluted cities in the world (WHO, 2011). Currently, the daily and annual average levels of major pollutants: particulate matter (PM), sulfur dioxide (SO_2), nitrous oxide (NO_x), and carbon monoxide (CO), all exceed both international and Bangladeshi acceptable standards (Table 1).

Dhaka is also repeatedly mentioned as one of the world's fastest growing cities. Currently, the city spreads over 270 kilometers and is home to approximately 17 million people, but is projected to become the third most populated city in the world by 2030 (Khalequzzaman et al., 2017). This high population and structure density results in an environment makes people at high risk for exposure and harm from ambient air pollution (Cooper et al., 2012).

In an attempt to mitigate this harm the Bangladesh government, in coordination with several non-government organizations (NGOs) have worked over the last decade to reduce the amount of air pollution in the country, with a focus on Dhaka's megacity population (Department of Environment, Bangladesh, 2012). As of January 1, 2013, all two-stroke engines, which have a low fuel efficiency, but high emissions of particulate matter when compared to their four-stroke counterparts, were banned from Dhaka city. A follow-up study found that in the two years after the ban, the PM levels in Dhaka city fell considerably after the ban (Begum, 2006).

However, in the years after the ban, the World Bank has estimated that further reduction of ambient air pollution could prevent up to 3,500 deaths and 230 million cases of respiratory disease in Bangladesh (World Bank, 2016). Current efforts to reduce harmful emissions focuses on Bangladesh's brick sector, which is one of the largest sources of air pollution in the country (Department of Environment, Bangladesh, 2012). It is estimated that these kilns emit kilotons of PM and other pollutants each year (Weyant et al., 2014).

Compounding the problems caused by its population boom, Bangladesh is highly dependent on its brick industry. Bangladesh is a rock-poor country, with only minimal resources in country. Brick is often used as a substitute for gravel in road development and is a chief building material for structures (ibid). The World Bank estimates Bangladesh has over 8,000 active traditional brick kilns in the country, with a capacity of nearly 12 billion bricks per year; this industry is expected to grow fifty percent by 2020 (World Bank 2016; UNDP 2011). It has been estimated that Dhaka City, the country's megacity capital, has nearly 1,000 kilns in its vicinity, which makes it an excellent area to investigate the impact of brick kilns on air quality (Sivertsen et. al, 2015). It has been previously estimated that brick kilns contribute thirty-eight percent of fine particulate matter under 2.5 micrometer ($PM_{2.5}$) pollution in Dhaka (Begum, 2008). Emission of PM and other pollutants have harmful effects on health and agricultural yields while also contributing to climate change (EPA, 2016).

Of the many pollutants produced by brick kilns, PM and sulfur dioxide (SO_2) most significantly contribute to declining health in exposed persons. SO_2 has been classified as a carcinogen and induces respiratory and metabolic changes upon acute exposure (Bhat, 2014). Chronic $PM_{2.5}$ exposure has been linked to both cardiopulmonary mortality and lung cancer, while acute exposure has been shown to increase infant and child mortality from respiratory diseases (Pope et al., 2002; Ostro, 2004).

Ninety percent of current brick kilns in Bangladesh are traditional Fixed Chimney Kilns (FCK), each of which uses between 20-22 tons of coal per 100,000 bricks. These kilns emit the highest levels of PM and SO_2 among current technologies. It has been proposed that replacing traditional brick kilns with modern kilns, such as Improved Zigzag (IZK), Vertical Shaft Brick Kiln (VSBK), or Hybrid Hoffmann Kiln (HHK) would require less coal consumption (12-15 tons per 100,000 bricks), thereby mitigating some of the aforementioned impacts (BUET, 2007; World Bank, 2011). However, the private investment costs of these kilns vary from 8 million taka per IZK to 160 million per HHK (Larsen, 2016). These private costs must be weighed in the context of the potential reduction of shared, community costs, such as health outcomes.

The goals of this study were threefold. First, to estimate kiln influence on air quality, we developed a conversion calculation to estimate the impact of brick kiln emissions on $PM_{2.5}$ and PM_{10} concentrations. Next, the study quantitatively estimates the impacts of this increase in PM on the Dhaka's population, with a specific focus on various measures of morbidity and the associated healthcare and other costs. Finally, the study aimed to estimate a brick kiln emissions inventory, which can be used in future air quality studies, specifically spatial atmospheric chemistry modeling, which can provide clearer estimates to the kiln contribution to air quality.

2. Methods

2.1 Identification and Location of Brick Kilns

Google Earth was used to identify the location of FCK brick kilns in the Greater Dhaka region in a previous study (Randall et al., 2012). We chose to focus solely on FCK brick kilns because of their overwhelming majority in the area. This focus allowed the study create an estimate directed at these specific kilns, so a specific and targeted intervention could be based on the calculated emissions and subsequent concentrations.

2.2 Conversion to Concentration Contribution

An estimate of annual brick production was used to estimate the contribution of the brick sector to the national ambient concentrations of PM_{10} and $PM_{2.5}$. We chose to focus our analysis on PM levels due to high levels of reported PM concentrations in Dhaka the availability of observational data on air quality and health outcomes. A previous study found that 180 kilotons of $PM_{2.5}$ emissions translated into a concentration increase of 60 $\mu g/m^3$ (Guttikunda, 2009). A study by Leila et al. (2012) built upon Guttikunda (2009) and estimated the contribution to PM concentrations for multiple types of kilns with a standard production value. From these studies we were able to estimate type specific kiln contribution to PM concentrations.

In order to account for the spatial density of kilns and total study area, we created an area ratio and a kiln density ratio that were applied to the average estimated $\mu g/m^3$ PM concentration for each kiln type (Equation 4.2) To calculate the increase of PM_{10} concentration we divided the $PM_{2.5}$ by a conversion factor of

0.6 (Cohen et al., 2014). Finally, a brick productivity correction was applied to the estimate as our estimated productivity was lower than that in the above studies.

Equation 4.2 Estimation of Contribution to PM_{10} and $PM_{2.5}$ Concentrations by Brick Kilns

Kiln Contribution to Concentration =

(average contribution of kiln type to PM_{10} concentration*kiln density*productivity correction)/area ratio

Area Ratio= Area of Country of Interest/Guttikunda Study Area

Kiln Density=Total number of Kilns in Country of Interest/Number of Kilns in Leila et al.

Productivity Correction = estimated productivity of FCK kiln in Dhaka, Bangladesh / productivity assumed in Leila et al.

2.3 Comparison with Observational Data

Observational data was collected and provided to this study a project of the World Bank's Clean Air and Sustainable Environment Project (Saroah, 2016). Data from three stations were used: Dharusalam, Sangsad, and Bangladesh Agricultural Research Center (BARC). These stations collected $PM_{2.5}$ and PM_{10} during the month of January 2013 and onward. 2013 values were used to estimate the proportion of PM_{10} and $PM_{2.5}$ concentrations attributable to brick kilns surrounding Dhaka City. We first calculated a simple average of the measured concentrations and then the proportion from the estimated brick kiln contributions.

2.4 Health Outcomes and Cost Analysis

To quantify the potential health effects of brick kiln contribution to pollutant concentrations, we created estimates of the number of cases and disability adjusted life years (DALYs) attributable to the increase in PM concentrations cause by brick kilns. Previous studies have estimated the health impacts per each one microgram increase in PM_{10} (Leila, 2012; Guttinkunda et al., 2014). These estimates were scaled by the respective increase in pollutant concentration attributed to the brick kilns as estimated by the simulations.

Finally, a cost benefit analysis was also conducted on these estimates. First, we identified the cost of the following health services: doctor visit, emergency room visit, and hospital stay in Dhaka, Bangladesh. We also identified the average daily wage for a worker in the geographic area. Finally, previously published studies were reviewed for the best way to define the financial impact of the above defined health outcomes. A calculation was created based on these parameters and applied with the above identified price parameters.

2.5 Emission Inventory

A detailed inventory of brick kiln emissions in Greater Dhaka area is necessary for spatial modeling. The creation of this inventory was the first step in this study. Emission factors for $PM_{2.5}$ and PM_{10}, specific to FCK were collected from various sources. These emission factors and their sources are summarized in Table 2. Finally, an estimation of the total mass of FCK produced bricks was calculated by multiplying brick weight by the annual production capacity of a FCK by the number of identified brick kilns. We assumed a constant brick weight of approximately three kilograms (Guttikunda, 2013).

The above collected data was used to calculate an estimated annual emissions inventory from the brick sector using equation 4.1 and species specific emissions factors.

Equation 4.1 Total Annual Emissions Calculation

$TE_i = EF_i * M_i$, where

TE_i=total annual emission of species *i* (tons/year)

EF_i =FCK specific emission factor for species *i* (tons/kilogram)

M_i = mass of annual FCK brick production (kilograms/year)

Emission factors for FCK brick kilns were collected through a literature review and selected values are presented in Table 2.

3. Results

3.1 Identification and Location of Brick Kilns

There were 983 brick kilns identified in the greater Dhaka region (Figure 1). The calculated emission factors for $PM_{2.5}$ and PM_{10} are 0.21 and 0.36 g/kg of fired bricks, respectively. Combined with a calculated annual brick production of 3.6 billion bricks, the estimated emissions from brick kilns were calculated to be 1,761 tons PM2.5 and 2,934 tons PM10 (Table 3).

3.2 Conversion to Concentration Contribution

After applying the developed conversion calculation, it was estimated that the PM2.5 and PM10 emissions contributed 42.8 and 25.7 $\mu g/m^3$ to annual average concentration of these pollutants in the Dhaka Area (Table 4).

3.3 Comparison with Observational Data

The average PM10 and PM2.5 levels in the six months of brick production (October – March) are higher than the summer months (Figures 2 and 3). The PM2.5 concentrations range from 220 $\mu g/m^3$ in January to a mere 20 $\mu g/m^3$ at their lowest in July/August. A similar trend is seen with PM10 with a range from approximately 310 $\mu g/m^3$ to 40 $\mu g/m^3$. Assuming a constant production rate during the sixth months of operation, kilns contribute a 15.4 percent of PM10 and 16.8 percent PM2.5 concentrations (Figure 4).

3.4 Health Outcomes and Cost Analysis

The estimation of excess morbidity was nearly 21,300 DALYs (Table 5). An estimated 3,000 additional cases of chronic bronchitis (CB) in adults and nearly 280,000 excess cases of lower respiratory illness (LRI) in children were attributed to brick kilns. Additionally, over 130,000 excess emergency room visits and 7,000 added hospital admissions were estimated. Kilns caused 22.7 restricted activity days (RADs) and over 72.2 million cases of respiratory symptoms.

The cost of these increased morbidities is estimated at approximately 118 million United States dollars (Table 6). RADs, respiratory symptoms, and CB generated the majority of these costs at approximately 28 million, 75 million, and 13 million dollars respectively. The cost of hospital admissions and emergency room visits were a combined 1.1 million dollars.

4. Discussion

The goal of this study was to provide a quantitative method to estimate the impact of brick kiln emissions on air quality and health outcomes in Greater Dhaka City, Bangladesh. This study estimates a level of kiln generated PM_{10} and $PM_{2.5}$ concentrations which agree with previous studies; however, their relationship to the total amount of PM concentrations is smaller than anticipated. The estimated morbidity impacts show many reduced activity days (RADs) and respiratory symptoms. Finally, chronic bronchitis (CB) had the highest per case annual cost, but respiratory symptoms had the greatest total annual cost.

Our calculated concentration of PM_{10} and $PM_{2.5}$ attributable to kilns is 42.8 and 25.7 $\mu g/m^3$, respectively. These estimates are consistent with previous calculations, which range from 14 to 36 $\mu g/m^3$ (Leila, 2012). This comparison suggests a level of brick production in 2013 that is comparable to the years previous. In subsequent years, however, brick kiln production projected to increase by fifty percent between 2016 and 2020 (Saha, 2016).

The estimated proportion of PM contribution from brick kilns fell at the low end of previously estimated ranges. Previous studies have estimated that fifteen to fifty percent of $PM_{2.5}$ concentrations in Dhaka, Bangladesh was sourced from brick kilns (Begum et al., 2008; Begum et al., 2011; Billah Ibn Azkar et al. 2012; Afrin, 2012; Begum et al., 2013); these estimates however, have been declining steadily, with Begum et al. finding twenty-two percent of $PM_{2.5}$ in their most recent study (2013). One explanation for this dilution of this fraction could be the increase in population growth and transportation within the city. Not only is there an increased number of vehicles on the road at any one point, but this increase also creates a high level of congestion. As cars are stuck in traffic, they contribute high levels of PM (Alam, 2007).

The calculated morbidity estimates over 20,000 DALYs lost each year due to brick kiln emitted PM_{10}. The estimated 75 million cases of respiratory symptoms makes up nearly one-third of the anticipated reduction of respiratory illness with further air quality improvements (World Bank, 2016). Due to the study's narrow focus on only six morbidity endpoints, the estimated health effects are only a proportion of those truly caused by the Furthermore, the impacts of PM exposures are not fully understood—new associations are being uncovered. For example, studies have shown that increased PM concentrations are also associated with decreased mucociliary clearance, which limits immune function in exposed persons; the extent of this physiological change is not fully understood (Ferreira-Ceccato et al., 2011; Wolff, 1986).

The estimated cost of kiln emission related morbidity is approximately 118 million USD. Previous studies have estimated the total social and health cost of brick kilns at over 500 million 2013 USD, (Guttikunda, 2014); our study accounts for only one-fifth of this cost. The additional costs can in part be attributed to mortality or unexamined sources of morbidity. This study only examined the direct health care costs and missed work time. Illnesses, particularly chronic conditions such as chronic bronchitis, can also result in loss in social capital and mental health (Mouvassi et al., 2007; Katon et al., 1990; Ahlström, 2007). A verified cost analysis of these losses could not be located for the Bangladeshi context, but the factors would increase the estimation of associated costs of morbidity.

There are a number of strengths and limitations to this study. One of the strengths of this study was the intentionality of calculations in respect to space. However, this remains a weakness of the study, as it was unable to truly capture the spatial intricacies of emission transport and concentration. A second strength of this study was its specificity in its geographic area of interest. By focusing on a relatively small, but densely populated, area, the study could assume a level of homogeneity of exposure in the population of interest. This assumption allowed the morbidity and associated calculations to create a realistic valuation for this community, yet limits the generalizability of the study's results. primary limitation of this study was the focus on only PM_{10} caused morbidity. $PM_{2.5}$ has been associated with more severe health outcomes than its larger counterpart (EPA, 2003) and other pollutants, such as SO_2 have been associated with increased morbidity as well.

5. Conclusions and Recommendations

5.1 Summary

This study had three primary objectives focused around the development of an approximation of the impact of brick kilns on the regional air quality, morbidity, and health care costs in Dhaka, Bangladesh. The study developed a several quantitative methods based on a review of previously published data on brick kilns in both Bangladesh and South Asia more broadly. The results of this study serve as motivation for further analysis of brick kilns effect on health in Dhaka, Bangladesh.

5.2 Conclusions

Our study further supports the uncertainty in the impacts of brick kilns. The estimates above fall within previous ranges but the PM contributions and proportion of total PM are not consistent to comparisons within studies. For example, while our proportion of $PM_{2.5}$ and PM_{10} are consistent with studies by Begum and Afrin, our $\mu g/m^3$ are not within the same ranges. This comparison displays the need for further, in depth data collection in the area of brick kilns.

Despite this uncertainty, the study demonstrates the critical influence brick kilns have on Dhaka's air quality. While the Bangladeshi government has implemented measures to control air pollution, observational data shows PM levels remain high in Dhaka. Our study estimates that as much as one-quarter of the $PM_{2.5}$ is attributable to brick production in the surrounding area. As brick production is critical for the growth and infrastructure of the city, removing or reducing this production is unlikely. However, this study demonstrates that the improvement of brick firing technologies must be prioritized.

The estimates above show that the cost of increased morbidities is over 100 million dollars. Studies have projected that updating kiln technologies ranges from two to six million dollars (Guttikunda, 2014). This study shows that the cost of updating these kilns is proportionally small when compared to morbidity alone. The burden of the cost of updating, however, is placed on the kiln owner, hindering the progress toward cleaner kilns. The Asian Development Bank and World Bank both actively work to provide funding for kiln modernization, but the demand for funds to update FCKs is extremely high (ABD, 2017; World Bank 2014). Other NGOs and the Bangladesh government should focus on assisting with financing the improvements.

5.3 Recommendations for Further Work

The study's estimates of kiln contribution to concentration are based on calculations with an attempt to reconcile with spatial distribution. However, to refine these estimates, we aim to run spatial atmospheric chemistry models in the Weather Research and Forecasting coupled with Chemistry (WRF-Chem) modeling system. This framework will provide estimates of regional pollutant concentrations with respect to horizontal and vertical space.

Another restricting factor in our analysis is the limited observational data. Estimated emission factors are based off observations of a few kilns, often in similar geographic areas; however, these emission factors are sensitive to production rates and fuel sources. Kilns in the study area of interest typically use coal exported from Northern India, which typically has a higher sulfur and carbon content than coal in other South Asian countries. This analysis uses aggregated observations from FCKs throughout South Asia, which may lead to an under-estimation of key emissions (Guttikunda et al., 2012). Further, site-specific, observations are key to more precise estimations of morbidity effects and associated costs. It is recommended that further experimental and observational data collection is necessary for complete understanding of kiln dynamics.

Finally, an expansion of this method, and the above described modeling studies, to an evaluation of suggested brick kiln improvements will better contextualize the proposed technological improvements for Dhaka area brick kilns. Policymakers and NGOs will benefit from an estimation of the decrease in morbidity and associated costs from these improvements. These improvements are necessary in the path forward to a cleaner, healthier Dhaka city.

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Tables

Table 1 –Bangladesh, United States, and WHO Air Quality Standards for PM

Pollutant	Averaging time	Bangladesh Standard	US Standard	WHO Standard
$PM_{2.5}$ (µg/m³)	Annual	15	15	10
	24 hour	65	35	25
PM_{10} (µg/m³)	Annual	50	n.a.	20
	24 hour	150	150	50

Table 2 – Emission Inventory Parameters with Sources

Pollutant	Emission Factor (g/kg brick)	Estimated Emissions (ton/6 months)	EF Source
SPM	1.180	11,648	Greentech Knowledge Solutions, 2014
PM10	0.297	2,934	calculated from PM2.5 using Cohen, 2006
PM2.5	0.178	1,761	calculated from SPM using Greentech, 2014
SO2	3.623	35,757	UNEP,2016
NOx	0.096	948	UNEP,2016
BC	0.130	1,283	Greentech Knowledge Solutions, 2014
CO2	131.000	1,293,089	Greentech Knowledge Solutions, 2014
CO	2.000	19,742	Greentech Knowledge Solutions, 2014

Table 3 – Emission Inventory Parameters with Sources

Parameter	Value	Source
Type of Kiln	FCK	Randall et al. , 2012
Number of Kilns in Dhaka	938	Randall et al. , 2012
Productivity of Plant (6 months)	3,866,667	Greentech Knowledge Solutions, 2014
Productivity of Plant (1 month)	644,444	calculated
Mass of Bricks (kg/plant/month)	1,933,333	calculated
Fuel & Energy (MJ/kg brick)	1.30	Greentech Knowledge Solutions, 2014
Fuel & Energy (MJ/plant/month)	2,513,333	calculated
Coal Consumption (kg/plant/month)	929,933	calculated
Coal Consumption (kg/plant/month)	872,277,467	calculated
Total Productivity	3,626,933,333	calculated

Table 4 – Estimated Contribution of 938 FCK Kilns Surrounding Dhaka, Bangladesh to Ambient Concentrations of PM_{10} and $PM_{2.5}$

Kiln Type	Approximate Number of Kilns	Adjusted Contribution PM10 (μg/m3)	Adjusted Contribution PM2.5 (μg/m3)	Per Kiln Contribution to PM10 (μg/m3)	Per Kiln Contribution to PM2.5 (μg/m3)
Clamps (firing/down draft kiln)	0	0.000	0.000	0.000	0.000
BTKs (mobile)	0	0.000	0.000	0.000	0.000
FTK	938	42.770	25.662	0.046	0.027
High Draft Kilns (HDK)/Zig-Zag	0	0.000	0.000	0.000	0.000
VSBK	0	0.000	0.000	0.000	0.000
Hoffman	0	0.000	0.000	0.000	0.000
Tunnel Kiln	0	0.000	0.000	0.000	0.000
Total	**938**	**42.77**	**25.66**		

Table 5 – Estimated Excess Morbidity Attributable to Brick Kilns Surrounding Dhaka, Bangladesh

Health end-points	Units	Impacts per 1 μg/m3	Excess Cases	DALYs per 10,000 cases	Total DALYs
Chronic bronchitis (PM 10)	per 100,000 adults	0.87	3,000	22,000	6,600
Hospital admissions (PM 10)	per 100,000 pop.	1.2	7,000	160	100
Emergency room visits (PM10)	per 100,000 pop.	23.54	132,000	45	600
Restricted activity days (PM 10)	per 100,000 adults	5750	22,706,000	3	6,800
Lower respiratory illness in children (PM10)	per 100,000 children	169	279,000	65	1,800
Respiratory symptoms (PM 10)	per 100,000 adults	18300	72,263,000	0.75	5,400
Total					**21,300**

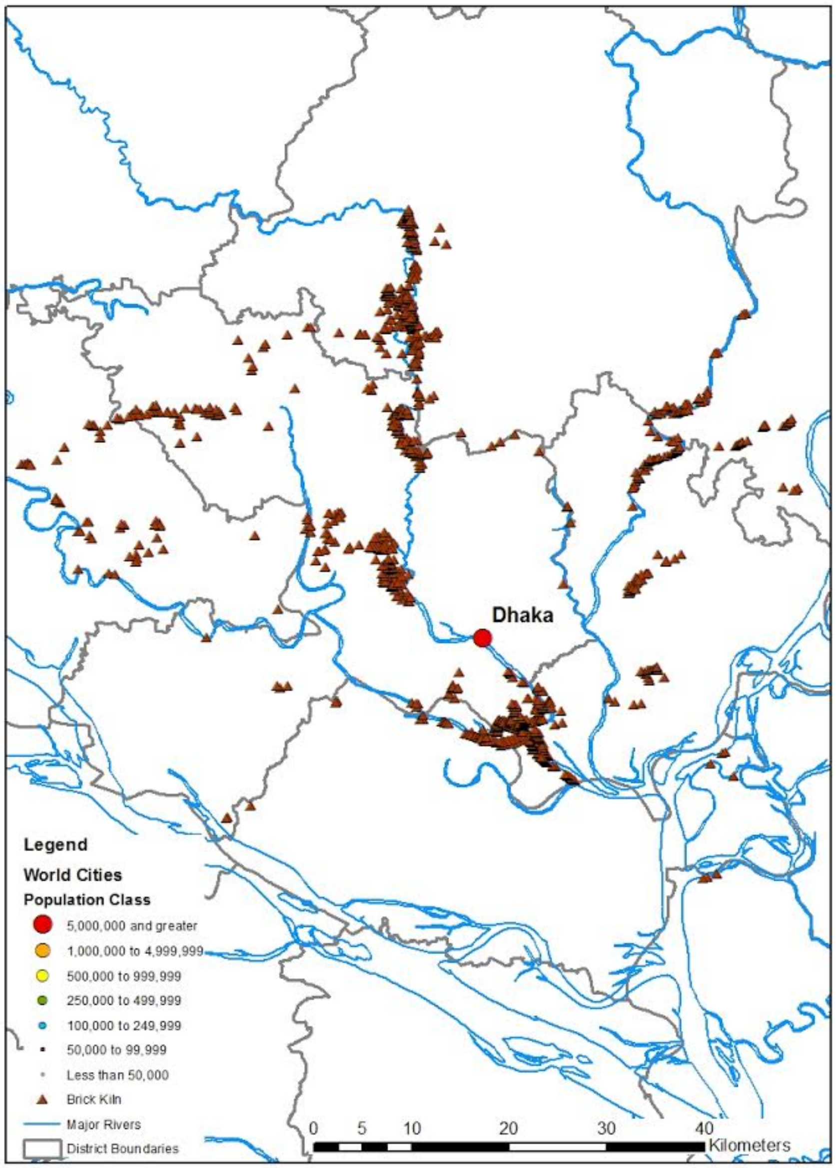
Table 6 – Estimated Cost of Excess Morbidity Attributable to Brick Kilns Surrounding Dhaka, Bangladesh

Health end-points	Cost Per Case (2002 Taka)	Cost Per Case (2017* Dollars)	Cost All Excess Cases (2002 Taka)	Cost All Excess Cases (2017 Dollars)
Respiratory health admission (PM 10)	4,273	99.47	29,911,000	696,276
Emergency room visits (PM10)	127	2.97	16,764,000	392,040
Restricted activity days (PM 10)	54	1.24	1,226,124,000	28,200,852
Respiratory symptoms (PM 10)	45	1.04	823,500	75,117,389
Chronic bronchitis (PM 10)	197,237	4,591.35	591,711,000	13,774,050
		Total	1,865,333,500	118,180,607
	Total (in 2002 Taka)			**1865333500**
	Total (in 2017 Dollars*)			**$ 118,180,607**

*Conversion from 2002 to 2017 dollars via US Bureau of Labor Statistics

Figures

Figure 1:Location of Brick Kilns Surrounding Dhaka City, Bangladesh



Data Sources: Randall, Scott et. al (2014); Esri, DeLorme Publishing Company, Inc. (2011) ; World Food Programme GeoNode (2016)

Figure 2: 2013 Observational $PM_{2.5}$ Concentrations from Three Stations in Dhaka City, Bangladesh

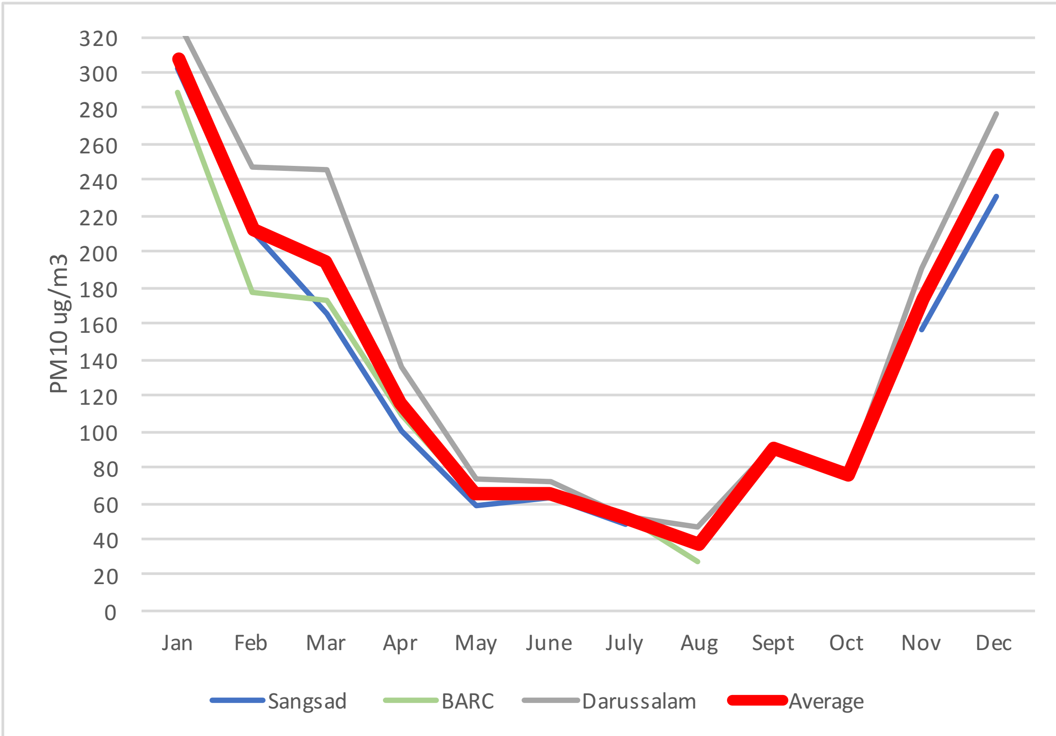


Figure 3: 2013 Observational $PM_{2.5}$ Concentrations from Three Stations in Dhaka City, Bangladesh

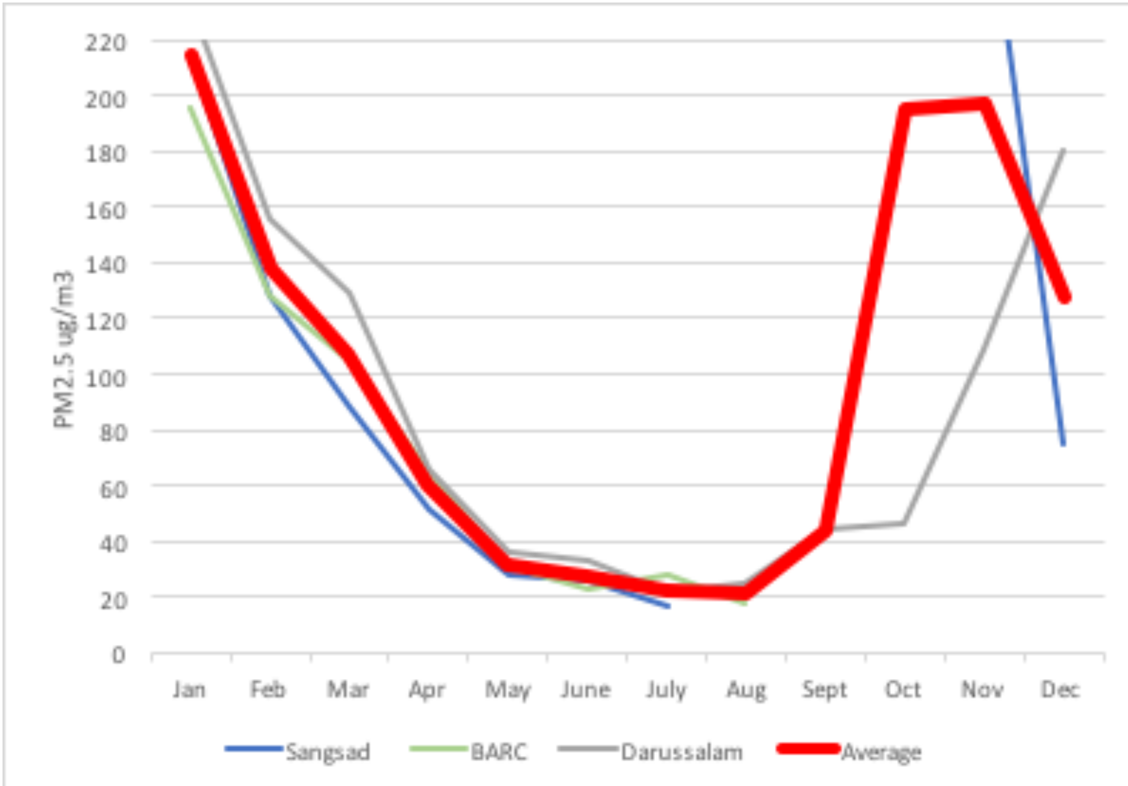


Figure 4: PM_{10} and $PM_{2.5}$ Attributable to Brick Kilns in Dhaka, Bangladesh, 2013