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Research Article

# Real-time Air Quality Mapping and Its Implications on Air Pollution Management in Bangladesh

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## Abstract

This paper analyses the impact of recent developments of disruptive technologies in assessing air pollution, especially the real-time Air Quality (AQ) mapping at regional scale for Bangladesh. These technologies enable better delineation of local air pollution sources, as the local wind impact under suitable circumstances can strip away the contribution of transported air pollutants from long distance sources. The new understanding from disruptive technologies (i.e., real-time AQ maps and levels), can help reassessment of the existing data and better estimation of the contribution from local and pollutants transported from long distance. Such maps obviate the need for regional modelling using global data bases for air quality issues which provide static information and even the local emission inventory-based dispersion modelling can be dispensed with in some cases. The availability of the site-specific web-based AQ data provided by these new tools also reduces the need for the current practice of dense AQ monitoring (i.e., population-based physical monitoring stations). The potential application of the information available from the new technologies in Bangladesh is illustrated in this paper. The source apportionment studies for Dhaka so far, attributed the pollution due to coal burning in Brick kilns as 58 percent. These studies couldn't assess the contribution of the transboundary pollution. An inventory-based dispersion modelling work concluded that the contribution of local brick kilns to the ambient air pollution due to coal burning in the kilns to be only 13.6 percent on yearly basis. With this data and evidence from real-time AQ maps, it can be deduced that a large percentage of the pollution due to coal burning is contributed by the transboundary sources. The paper also illustrates the relevance of some air quality management measures implemented by the Government in the light of the findings and concludes that the local measures for air pollution control may not have a major impact in reducing overall annual average levels of Particulate Matter (PM) in Dhaka or in the country. These measures however can reduce population exposure in local airsheds; for example, by reducing the pollution from the brick kilns near urban population centers and also reduction of local pollution exposure from large point sources. The paper also discusses the evidence on the emerging threats of potential severe air pollution (as observed in the real-time AQ maps) from new large coal fired power plants in Bangladesh.

## Keywords

Air Pollution, Real-time Air Quality Maps, Source Apportionment, Transboundary Air Pollution, Pollution Exposure, Power Plants, Topsoil

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## 1. Introduction

The quality of Air in Dhaka city and Bangladesh in general has been a major public concern for many years. A number projects were undertaken, since early 2000s, to study, identify, quantify, and manage the local air pollution as part of the AQ management measures by the Government of Bangladesh (GOB), with support from the international agencies. While some of these efforts were successful in reducing the local pollution levels; but on the countrywide basis, these measures met with limited success. Studies carried out as part of these projects to identify air pollution sources in Bangladesh were based on source apportionment analysis. However, these analyses were biased by the high pollution levels during the dry season (November -April) when transboundary interactions in the airshed including Bangladesh and north Indian states are prominent [1-3]. The atmospheric inversions during the period further aggravate the situation by trapping the pollutants. Although, some of these studies on back trajectory calculations showed a general airmass movement from NNW [1], the impact of the movement on the pollution levels could not be quantified. A recent study by The World Bank team using Greenhouse Gas and Air Pollution Interactions and Synergies (GAINS) model has identified the airsheds and tried to identify the extent of the transboundary pollutions [3]. Another recent development is the availability of AQ data from several web-based sources [4-8]. In addition, the latest technique of developing real-time AQ maps based on integrated satellite and ground-based data with modelling is a disruptive development [4]. These maps provide information that allow visualization of the impacts of wind speed, direction and other factors on the pollution levels. Real-time Air pollutants concentrations for six criteria pollutants (i.e., pollutants regulated by law) in a given country/location are also available from several web-based sources [4-8], with the exception of Pb (Lead). The identification/quantification of local sources in Bangladesh using this newly available AQ information and techniques can help in the development of better plans for the management of air quality in the country. These aspects are discussed in the following sections based on available data to understand the inconsistencies in the existing information on the pollution levels, especially from brick kilns in Dhaka area.

## 2. Studies on Transboundary Movement of Air Mass and Pollution in Bangladesh

There are several studies in the literature on transboundary movement of air mass in the subcontinent including Bangladesh, which is responsible for long range pollution transport. One such study by Masud et al [1] reports ninety-six-hour backward trajectories for every 3-h interval for the period of November 2013 to April 2014 (i.e., high pollution season); calculated using Hybrid Single-Particle Lagrangian Integrated Trajectory (HYSPLIT) model [9] by Draxler and Rolph. Global 'Reanalysis of Meteorology Data' downloaded from the archive of the National Oceanic and Atmospheric Administration (NOAA) was used as input for equating the trajectories in this study. The receptor point for calculation was chosen as Gazipur (GZ) near Dhaka; which was assumed as being the sub-urban background station at the time of the study, to minimize the influences of local sources. Air mass trajectories grouped by months of the dry season (Nov-April) are shown in Figure 1. As depicted in the figure, most of the air masses during dry season except some periods of April, had come from the west but entered Bangladesh with various angular directions. Many of the trajectories in the figure are not clearly seen due to overlap. Majority of the trajectories in November proceeded behind the Himalayas and entered Bangladesh from the north-east direction. December trajectories flew over Middle East with comparatively high flights and entered the Bangladesh from the north. This study showed that sources in the eastern Indian region bordering Bangladesh, north-eastern Indian region bordering Nepal, and Nepal and its neighboring areas have high probability of contributing to the $PM_{2.5}$ levels recorded at GZ station.

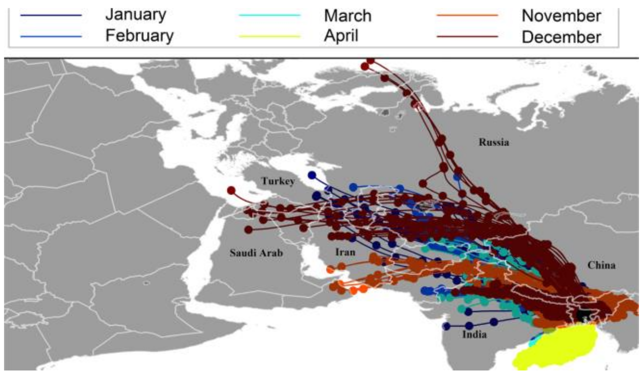


***Figure 1.*** *Ninety-six-hour HYSPLIT back trajectories centered on Gazipur (near Dhaka) for dry season in 2013–2014, shown grouped for each month and according to color key [1].*

Particulate matter from mid-Asia, northern Pakistan, far northern India, and southern China might too have contributed to the pollution at GZ station to some extent, as the air mass movement over these regions impact Bangladesh.

Another HYSPILT-4 back trajectory study [2] that used CWT (Concentration Weighted Trajectory) analysis showed that Bangladesh has a high probability of being affected by pollutants from North Indian territories, the India-Nepal border, India-Pakistan border and the Eastern Indian region bordering Bangladesh.

The recent study by the World Bank [3] used GAINS model, has identified major airsheds in South Asia where spatial interdependence in air quality is high and found that the air pollution spreads far in South Asia, but it does not uniformly disperse over the continent. Instead, the air pollution gets trapped in large "airsheds" that are shaped by climatology and geography. The study identified six major airsheds (Figure 2) in South Asia where spatial interdependence of air pollution is high. One of the airsheds i.e., the Central/Eastern Indo-Gangetic Plain comprising Bihar, West Bengal, Jharkhand, Bangladesh, is especially important for Bangladesh. The sources in this airshed appear to contribute significantly to the air pollution in Bangladesh. This aspect is further elaborated in the subsequent sections. Although air pollution levels vary strongly with seasons, such variations can't be predicted by the GAINS model.

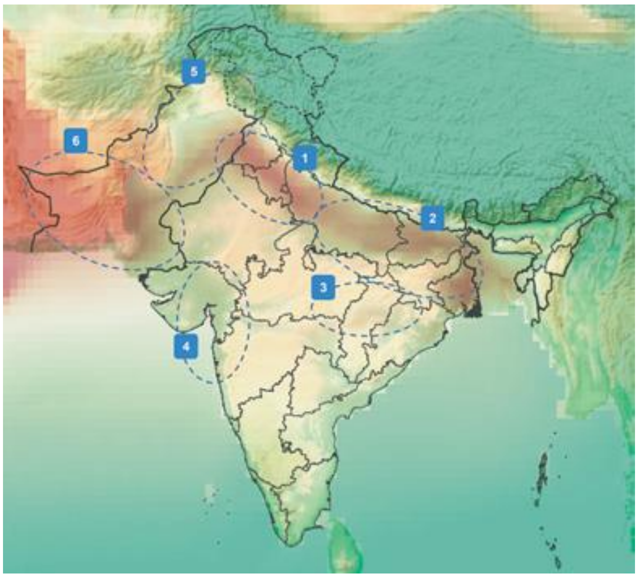


***Figure 2.*** *Six illustrative airsheds in South Asia based on fine particulate concentrations, topography, and fine particulate transportation between source regions [2].*

The study further highlights that current policy measures, even if fully implemented, may only be partially successful in reducing $PM_{2.5}$ concentrations across South Asia. Based on an analysis through GAINS model, the study concludes that *even if all technically feasible measures were fully implemented, due to spatial interdependence of air pollution, parts of South Asia would still not be able to meet the WHO Interim Targets on their own by 2030. Thus, regional cooperation through cost-effective joint air pollution strategies leveraging spatial interdependence in air quality is essential.* It is however important to note that 'GAINS' is not an emission inventory model and depends on global database and the uncertainties in the model parameters/data are not explicitly included. For cost effective actions, refinements based on area specific information especially on local sources (i.e., both large point and area sources) and dispersion modelling are required, so that the maps from GAINS Model are useful.

## 3. Determination of Local Pollution Sources Through GAINS Model

Although, the findings from the regional air pollution transportation model provide some understanding of the mesoscale transboundary pollution contributions, more detailed information that justifies and validates these findings is needed for policy decisions. The numerical finding from the GAINS model is available in an emission inventory work [10] which is presented in table 1. It can be seen that the ground-based determinations are quite at variance with the values obtained from GAINS model. Although, the GAINS model outputs are three years older (2010) than inventory study (2013), the air pollution trend during these years was similar. [11]. GAINS analysis hence is not useful for policy decisions due to such anomaly.

***Table 1.*** *Dhaka Annual Emissions per pollutant for all source sectors, with comparison to GAINS global emission inventory (tons/year). Dhaka.*

| Pollutant | Inventory (2013) | GAINS Model (2010) | % Difference |
|---|---|---|---|
| $PM_{10}$ | 58,524 | 44,950 | +23% |
| $PM_{2.5}$ | 20,819 | 35,300 | -70% |
| SOx | 60,216 | 34,300 | +75% |
| NOx | 14,862 | 32,800 | -121% |
| CO | 45,581 | 27,100 | +68% |

The outputs of GAINS City Model are reported to be more accurate. However, as the reported study provides only maps with no quantitative estimates [12], the results could not be compared with source-based inventory. This drawback of Global data-based modelling results can be addressed with the availability of web based real-time regional and local pollution data from the new disruptive technologies [4].

## 4. Latest Information on Air Pollution in the Regional Airshed and Its Implications

Due to various initiatives of the GoB and other agencies, the data on concentration of criteria pollutants are now available on daily basis on several government and private websites [4-8]. The data from the Department of Environment (DOE)'s Continuous Air Monitoring Stations (CAMS) is also available [7], although not on a regular basis. These CAMS (i.e., 31 in total) cover most of the high population areas (i.e., cities) in the country (figure 3). More recently, satellite based

AQ data is also available on the web. With this, the utility of traditional dense ground-based monitoring stations (i.e., population based) becomes a bit limited. and further expansion of current CAMS network in Bangladesh can be avoided. However, ground-based monitoring can't be completely dispensed with, as these stations are required for ground truthing of satellite/ web-based data and monitoring of other criterial pollutants such as Pb (Lead)). In addition, ground-based monitoring stations will also be required for collecting filter-based samples for source apportionment studies. Considering these factors, the AQ and weather data from one of the websites [4] is discussed in some detail below, with an objective to assess its utility for AQ planning and management. The real-time AQ maps are produced by integrating satellite-based data with ground-based data and through modelling. Dynamic changes with time of the AQ levels can be observed in these maps. Such maps provide information on the extent the airshed, air mass movement that cause pollution transport due to the impacts of local wind (i.e., speed/ directions and other factors) on the pollution levels in the airshed.

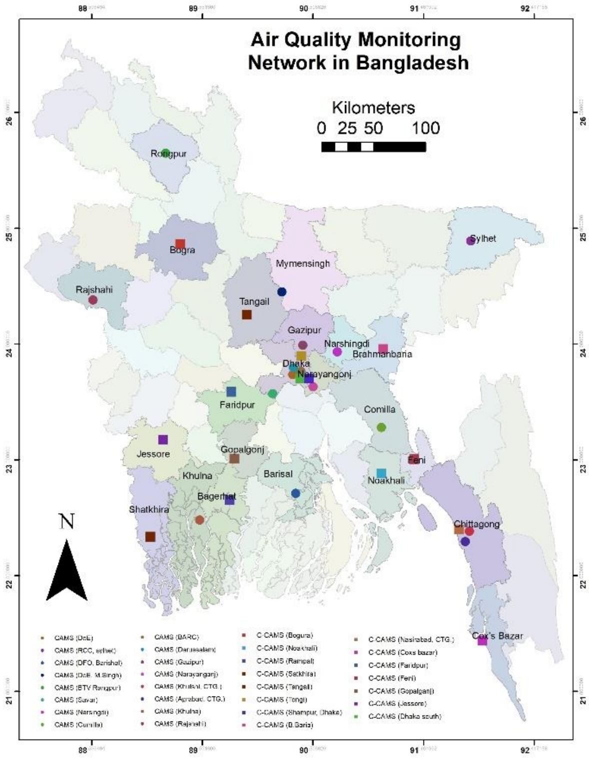


***Figure 3.*** *Location of the thirty-one CAMS in Bangladesh (DOE CAMS consist of monitoring equipment of USFRM standard or traceable to it.).*

The local wind factors in some cases lead to separation and visualization of the transboundary and local pollution sources, which is very important for air quality management decisions for specific areas. Figures 4 and 5 below show both the regional and local air pollution levels in Bangladesh, for nearly the same period of the year with similar weather, except for the local wind speed and directions (Table 2). The regional air pollution maps show the extent of the regional airsheds also. Local wind direction and speed largely determine the levels of local air pollution, as source emission profiles do not change over a short period. Figure 6 shows an opportune situation when the regional pollutions are almost pushed away from Bangladesh, showing local air pollution levels (i.e., the yellow patches corresponding to AQI of 51-100 in figure 6). These figures are equivalent to maps from dispersion modelling but without need for emission inventory inputs and these also come at no cost.

In addition, Figures 4 to 6 are illustrative and identifies the airsheds with high interactions. The models used for the preparation of the maps [4] account for all the parameters that determine air pollution levels. Air quality is the product of complex mechanisms which involve long-distance transport phenomena, physico-chemical transformations, and their variations on a local scale. Weather is intrinsically linked to the air quality. This means that pollution is dispersed or transported from one place to another depending on the wind. To add to this, sunshine induces a chemical transformation of certain pollutants, heavy rains cause the particulate matter to fall to the ground (i.e., reduced suspension time), and a difference of temperature between air layers (i.e., less than adiabatic lapse rate) can trap pollutants near ground level. The models use calculation tools based on atmospheric sciences (i.e., similar to those used to predict weather) [4]. These are combined with millions of pollution data points measured in real time by satellite, and at ground level. These data allow the models to produce an estimate of pollution levels on a large scale and over several days.

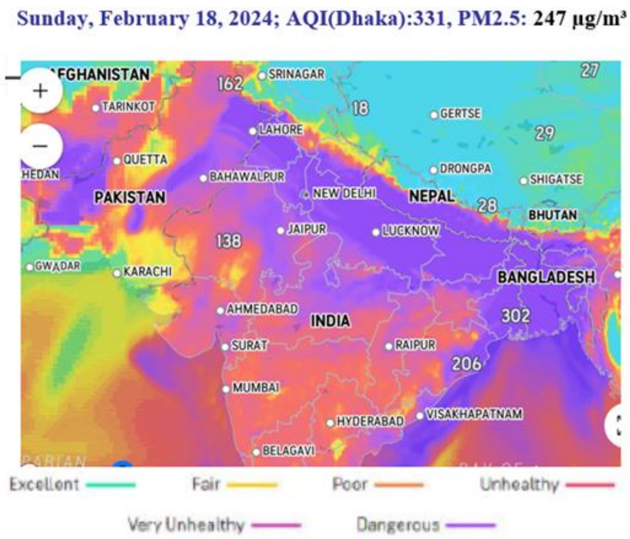


***Figure 4.*** *Regional and Bangladesh AQ Map on February 18, 2024 (Dhaka AQ: Dangerous); Prevailing wind is WSW 5 km/h. Pollution Level Color Scale: The six levels of pollution being: Excellent (AQI 0-20), Fair (AQI 21-50), Poor (AQI 21-50), Unhealthy (AQI 51-100), Very Unhealthy (AQI 101- 250) and Dangerous (AQI 251+).*

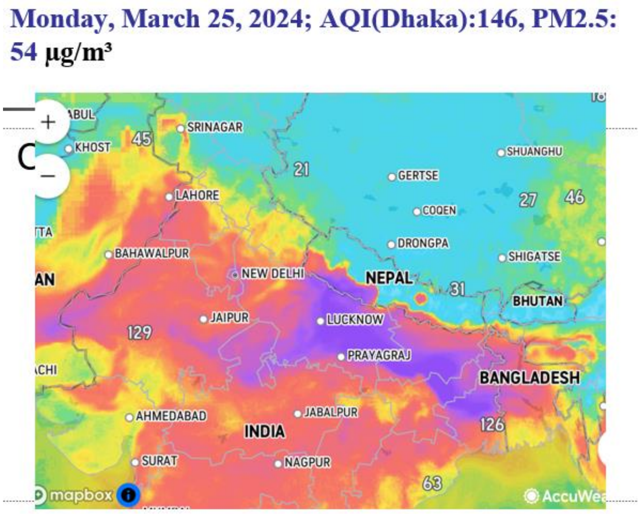


*Figure 5. Regional and Bangladesh AQ Map on March 25, 2024 (Dhaka AQ: Very Unhealthy). Pollution levels reduced by SSE 9 km/h wind.*

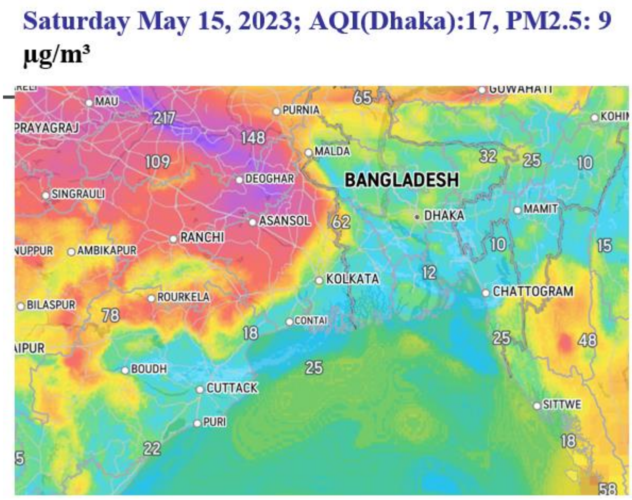


*Figure 6. Bangladesh AQ Map on May 15, 2023 (Dhaka AQ: Excellent) when regional pollution is pushed away by the local wind (SE 14 km/h).*

The pollution map for the regional airshed for Feb 18, 2024 is shown in Figure 4. The figure shows that on this particular day, the $PM_{2.5}$ concentration in Dhaka was 247 $\mu g/m^3$ with corresponding AQI of 331 (Dangerous), the wind direction being WSW with speed of 5 km/h. It can be clearly seen that the high pollution airshed consists of the north Indian coal belt and Bangladesh. Since the airshed is totally engulfed by high level of transported pollution, it is not possible to identify the local (i.e., point or area) sources in Bangladesh from this map.

The pollution map for the regional air shed for March 25, 2024 is shown in Figure 5. This figure shows that on this day, the $PM_{2.5}$ concentration at Dhaka was 58 $\mu g/m^3$ with corresponding AQI of 146 (very unhealthy); the local wind direction being SSE (9 km/h) partially reduced the movement air pollutants from north India into Bangladesh. Although, the pollution level is reduced, it is still not possible to identify the local (i.e., point or area) sources in Bangladesh from this map as well. The sources in Bangladesh can be identified if the transboundary pollution from the north-west can be peeled off by the wind. This is exactly what happened on May 15, 2023 morning (Figure 6) due to existing weather condition on the day with low AQI of 17 (Excellent). The SE (14km/h) wind stopped the pollution from the north Indian coal belt reaching Bangladesh and the local pollution sources (i.e., yellow patches corresponding to the AQI in fair category with AQI (21-50) can be seen in the map, that indicate the locally produced pollution. It appears from the visual analysis of air pollution level on this date that the local non-point sources of air pollution (yellow patches) of importance are the brick kilns in most cases and the cities. The lime kilns may also be important sources in the greater Sylhet (Sunamganj) area in the north-east, where reportedly more than two hundred such lime kilns are operational. Two large cement factories are also located in the area and one of these produces cement clinker from limestone, which involve high temperature process, and it is a copious source of $PM_{2.5}$ pollution. The comparison of the AQ levels and important weather parameters on the three days analyzed in figures 4 to 6 is summarized in in table 2 [4], along with a comparison with recently revised Bangladesh Ambient Air Quality Standards (AAQS), 2022 and WHO AAQS (Tier-1). It is to be noted that CO level which of local origin is similar in all the three cases. As already discussed in chapter-1, the availability of site specific criteria pollutants data, dense monitoring is no longer required.

*Table 2. Air quality and weather parameters for the dates of the three AQ maps.*

| S. No. | Parameter | 18-Feb-24 | 25-Mar-24 | 15-May-23 | BD AAQ Standards* | WHO Interim Target 1 |
|---|---|---|---|---|---|---|
| SNSn | | Value | Value | Value | Value | Value |
| 1 | $PM_{2.5}$ | 247 $\mu g/m^3$ | 58 $\mu g/m^3$ | 9 $\mu g/m^3$ | 35 $\mu g/m^3$(Annual)<br>65 $\mu g/m^3$(24 Hour) | 35 $\mu g/m^3$(Annual)<br>75 $\mu g/m^3$(24 hours) |
| 2 | $PM_{10}$ | 414 $\mu g/m^3$ | 88 $\mu g/m^3$ | 16 $\mu g/m^3$ | 50 $\mu g/m^3$(Annual)<br>150 $\mu g/m^3$(24 Hour) | 70 $\mu g/m^3$(Annual)<br>150 $\mu g/m^3$(24 hour) |

| S. No. SNSn | Parameter | 18-Feb-24 Value | 25-Mar-24 Value | 15-May-23 Value | BD AAQ Standards* Value | WHO Interim Target 1 Value |
|---|---|---|---|---|---|---|
| 3 | $O_3$ | 120 µg/m $^3$ | 24 µg/m $^3$ | 27 µg/m $^3$ | 100 µg/m $^3$(8 Hour) | 160 µg/m $^3$(8 Hour) |
| 4 | $SO_2$ | 12 µg/m $^3$ | 5 µg/m $^3$ | 6 µg/m $^3$ | 80 µg/m $^3$(24 hour) | 80 µg/m $^3$(24 hour) |
| 5 | $NO_2$ | 30 µg/m $^3$ | 14 µg/m $^3$ | 8 µg/m $^3$ | 40 µg/m $^3$(Annual) | 40 µg/m $^3$(Annual) |
| 6 | CO | 315 µg/m $^3$ | 260 µg/m $^3$ | 267 µg/m $^3$ | 5 mg/m $^3$(8 hour0 | 7 mg/m $^3$(24 hour) |
| 7 | $NH_3$ | - | - | - | - | 0.25 µg /m $^3$(Annual) |
| 8 | Pb | - | - | - | 0.25 µg /m $^3$(Annual) | 0.25 µg /m $^3$(Annual) |
| 9 | AQI | 331 | 146 | 17 | | |
| 10 | Temp | 28C | 26C | 27C | - | - |
| 11 | Wind | WSW 5 km/h | SSE 9 km/h | SE 14 km/h | - | - |
| 12 | Humidity | 34% | 75% | 60% | - | - |

*Bangladesh (BD) AAQ Control Rules, 2022 (Standards compatible to WHO Interim Target 1 only)

The upcoming large five coal fired power plants of total capacity of about 6,500 MW at Rampal, Payra, Kalapara, Banshkhali and Matarbari in Mahesh Khali will add to the major point sources of air pollution in Bangladesh. Considering the large capacity of these plants and as they are to be operated throughout the year, the contribution of these plants to the ambient air pollution in the country could even be worse than the contribution from the transboundary pollution, as transboundary pollution is limited to only dry season (Nov-April) as seen in figure 7.

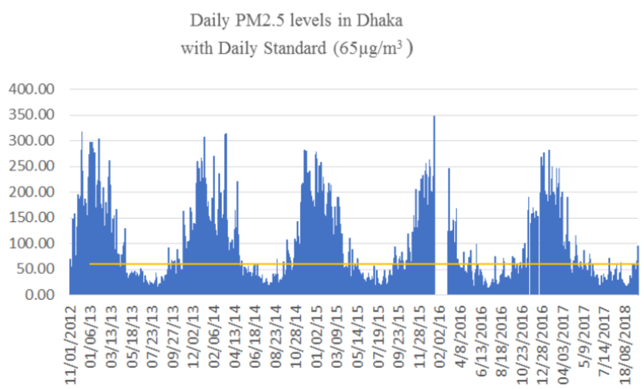


***Figure 7.*** *$PM_{2.5}$ levels in Dhaka during 2012-2018.*

According to available information, all these plants are ready but are not operating on regular basis as yet. While these plants are equipped with appropriate emission control systems, the pollution levels observed from two plants (Rampal at 22°35’37.69’’N and 89°33’21.50’’E and Payra - 21°54’37.69”N and 90°18’20.98”E) are quite high as seen in the AQ map on 1st October, 2024 in Figure 8. It is also important to note that such information can’t be obtained from the global data-based models like GAINS.

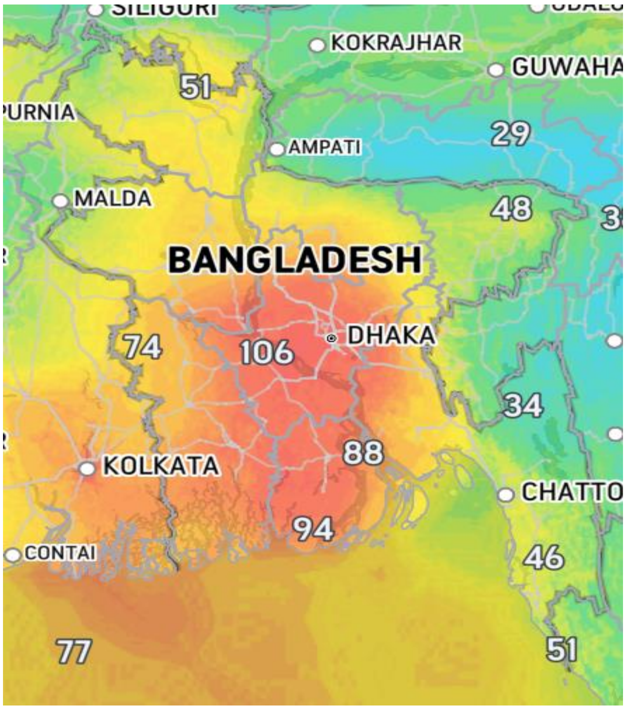


***Figure 8.*** *Bangladesh AQ Map on October 01, 2024 (Dhaka AQ: Unhealthy (AQI 51-100)) when regional pollution is mostly pushed away by the local wind (SSE 3 km/h). The emission from the two coal fired power plants at Payra and Rampal can be seen.*

Due to local wind (SSE 3 km/h), the transboundary pollution was low on October 1, 2024 and thus the pollution levels seen are due to the emissions from these two plants. High emissions from these plants can be attributed to the use of low-quality coal and/or ineffective emission control systems. While these are new plants, information on the quality of coal used or the performance of emission control systems is not known, but air emissions from these plants need significant improvement. In addition, switching to natural gas (instead of coal) may also be explored, as the increased cost of fuel can offset by the savings on health costs on people. Economic feasibility analysis of fuel change will need further studies.

In addition, continuous AQ monitoring should be carried out at these plants and the CAMS should be linked to the national CAMS system operated by DOE, GoB. This will enable regular monitoring of emission control systems and may help ensure their proper performance.

Further, analysis of data in table 2 shows that the AQIs in all the three cases (i.e., before the month of October), the levels of air pollution in Dhaka is largely determined by the local wind direction/speed (as emission source profiles do not change over short periods) and the air quality changes from dangerous and very unhealthy to excellent with the shift of wind direction/speed from WSW and SSE to SE.

The low level of local air pollution observed when there is low transboundary pollution (i.e., during May to October as seen in figure 7 and in the absence of local pollution from the new coal power plants) is due to low fuel use in Bangladesh. It is also important to note that, the $PM_{2.5}$ particulates are produced largely in the high temperature processes (i.e., due to fuel burning) and subsequent physical and chemical transformations of gaseous phase pollutants. Thus, the low level of local $PM_{2.5}$ pollution can be attributed to the low energy use in Bangladesh, which is also manifested by the low $CO_2$ emission of about 0.5 tons per capita per year for Bangladesh in 2020 [12-17]. The CO data in table 2 is seen to be quite low (i.e., <10% of the standard), which is also an indication of the low pollution from motor vehicles with internal combustion engines (ICE). This can be largely attributed to the conversion of almost all the passenger vehicles, small busses and goods vehicles to CNG (Compressed Natural Gas) fuel.

The policy implication of these findings is that overall annual air pollution in Bangladesh can't be appreciably reduced through local measures as a large fraction of air pollution during high pollution season (i.e., during November to April) is not of local origin. In order to reduce health impacts, measures to reduce emissions from local area sources (e.g., brick kiln clusters and industrial areas) and point sources (e.g., Coal power plants, cement plants, steel mills without Air Pollution control etc.) near high population centers may be more cost effective.

## 5. Implications of Latest Data and Its Implications on Source Apportionment Data

The contribution of different sources in the air pollution from source apportionment studies (carried out during 2010-12) in the four major cities of Bangladesh and during 2001-2 for Dhaka is presented in Table 3 [18, 19]. The data in the table indicate large contributions from the brick kilns for all the four large cities (ranging from 36.1 to 58 percent for 2010-12). The methodology to assess the contribution of various sources usually involves collection of two samples (i.e., for PM2.5 fraction) per week for about a year and analysis for concentrations of about 20 components including elemental contents, black carbon and organic carbon etc. The number of samples and time period can be adjusted, depending on actual availability of samples. The data is then analyzed with codes using Positive Matrix Factorization (PMF) methodology [18]. Different components with concentration signature for the sources are then identified by looking at the source signatures. The component with coal burning signature is identified with the brick kiln emission as this is the only sector locally that uses coal.

***Table 3.*** *Source Apportionment (%) of PM2.5 in four large cities in Bangladesh [18, 19].*

| Source | Dhaka | | Chittagong | Khulna | Rajshahi | Comments |
|---|---|---|---|---|---|---|
| | 2001-2 | 2010-12 | 2010-12 | 2010-12 | 2010-12 | |
| Soil dust | 1.0 | 7.6 | 2.59 | 9.0 | 8.39 | |
| Road dust | - | 7.70 | 1.54 | 7.7 | 2.91 | |
| Brick Kilns | 37.5 | 58.0 | 36.2 | 36.1 | 40.2 | Largest source since 2010-12, which also include transboundary component. |
| Biomass Burning | 2.4 | 7.4 | 19.1 | 23.5 | 35.4 | |
| Motor vehicles | 43.0 | 10.4 | 33.0 | 13.7 | 9.8 | Reduced in 2010-12 due to removal of 2 stroke 3 wheelers and CNG use in MVs. Chittagong level stayed high due to diesel trucks serving the port. |
| Fugitive with Pb content | 3.3 | 7.63 | 7.44 | 8.05 | 3.28 | Identified as Industrial emission |

With the availability of $PM_{2.5}$ pollution levels from real-time pollution maps (i.e., Figure 6) illustrated earlier, it is apparent that much of what was previously identified as emission from local brick kilns are largely from transboundary pollution, as these also come mostly from coal burning in power plants in north India. Thus, the actual contribution from the brick kilns could be much lower than what was found in the source apportion studies shown in Table 3, as these studies couldn't separate contribution from the transboundary sources. The total contribution in the source apportionment studies also did not add up to 100% as some components are missed in the analysis and mass closures were not achieved.

There was telltale indication of this lower contribution from the local brick kilns from a dispersion modelling study for brick kilns near Dhaka [20]. This study, modeled $PM_{2.5}$ ($\mu g/m^3$) concentrations averaged over the brick manufacturing season and over the year for the Greater Dhaka region. The results of this study are presented in Figure 9 and the range of modeled $PM_{2.5}$ concentrations ($25^{th}$, $50^{th}$ and $75^{th}$ percentile concentrations over one standard deviation) in the designated cluster regions of the Greater Dhaka in Figure 10.

***Table 4.*** *Sources of PM2.5 in Dhaka according to reanalyzed source apportionment data and prospects for pollution abatement with Trans-boundary contribution for 2010-12.*

| Sources | Contribution (%) | Generation, mitigation measures implemented and potential Mitigation prospects |
|---|---|---|
| Soil dust | 7.60 | Soil dust is mostly produced locally from construction activities in the city and from windblown dust from agricultural activities in the surrounding areas. Covering up open dusty materials piles at construction sites and spraying water can reduce fugitive soil dust. |
| Road dust | 7.70 | These are mainly produced and spread through vehicular movements (i.e., friction of tires with the road surface) and consists of a mixture of dust from tires, friction with road surfaces and deposition of vehicular emission products. This source may be mitigated to some extent through kerb to kerb carpeting, road sweeping and water spray. Decentralized measures usually do not work and can be expensive. Only minor improvements are possible/likely. |
| Brick Kilns | 13.60 | Pollution from brick kilns can be substantially reduced by moving to non-fired bricks, especially for large clusters near major population centers with good health outcomes. This move has already been mandated by GOB. Attempts for emission reduction through incremental technology change for pollution reduction met with rather limited success. Move to non-fired brick technology (e.g., AAC, LSB) can have major contribution and will have the co-benefit of topsoil conservation for maintaining agricultural productivity. |
| Trans-boundary | 44.40 | Emission reduction from Trans-boundary sources is a difficult proposition to achieve in the short term. This requires, high level discussions/ conensusof neighboring countries for coordinated and time-bound measures aimed air emission reduction. Although some discussions have been going on for quite some time, but tangible results have not been achieved and any progress could take long time. |
| Biomass Burning | 7.40 | Pollution from this source is already in decline due to rapid spread of LPG use as cooking fuel and ICS (Improved Cookstoves) dissemination (e.g., already about 9 million households have moved to ICS) which reduce mainly wood fuel use to almost by half. Available estimates indicate that about 5 million households either have natural gas connection or have adopted LPG for cooking and these are rapidly spreading. The processes for higher LPG use and ICS adoption are likely to accelerate leading to pollution reduction from this source but progress may be limited by affordability of LPG in the low-income households. |
| Motor vehicles | 10.40 | Removal of two-stroke 3-wheelers from Dhaka contributed to the major reduction of air pollution level. Most vehicles with ICE except for heavy duty trucks and busses have been converted to CNG/LPG fuel. Low sulfur diesel (500 ppm) has already been introduced for diesel vehicles, which was around 2500 ppm in 2010. By 2012 the contribution of vehicular pollution fell to 10.4% compared to 43% in 2002. Most of the low hanging fruits have already been picked and further progress is likely to be slow. In rural areas three wheelers are mostly battery (Pb-Acid) operated now and Pb pollution may increase due to unauthorized recycling of Pb-acid batteries from these vehicles and also from Solar home systems. |
| Fugitive pollution with Pb content | 7.63 | This component can be identified as industrial emission, and this is likely to increase with more industrialization. Emission control for large/Medium industries (i.e., point sources) and cluster of smaller industries may provide local relief, but this may not lead to large overall ambient pollution reduction. Previously leaded gasoline use was discontinued in July, 1999, which reduced the air lead level substantially. |

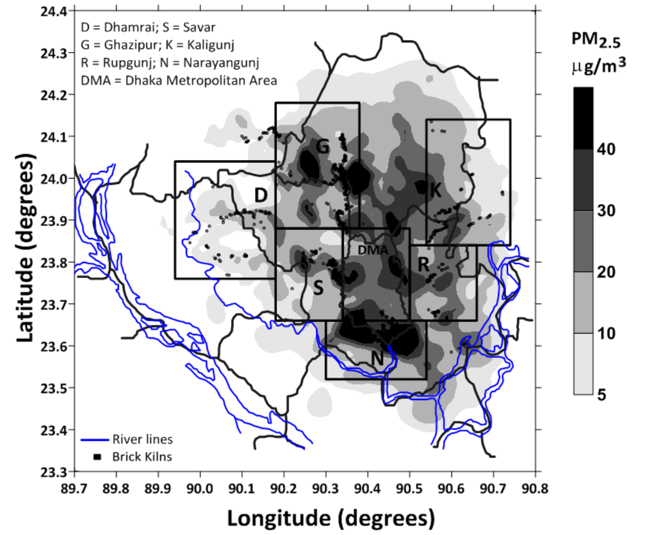


***Figure 9.*** *Modeled $PM_{2.5}$ ($\mu g/m^3$) concentrations averaged over the brick manufacturing season for the Greater Dhaka region [20].*

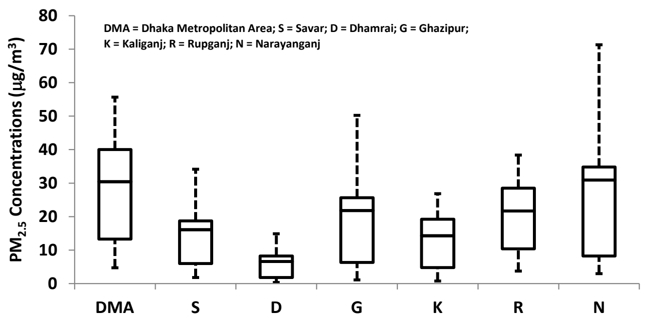


***Figure 10.*** *Range of modeled $PM_{2.5}$ concentrations ($25^{th}$, $50^{th}$ and $75^{th}$ percentile concentrations over one standard deviation) in the designated cluster regions of the Greater Dhaka region [20].*

These figures indicates that the modeled $PM_{2.5}$ concentrations over Dhaka Metropolitan Area (DMA) ranged from 4 to 56 $\mu g/m^3$ over the brick manufacturing season. The range indicates the $5^{th}$ and $95^{th}$ percentile concentration per model grid over the grids covered by the designated DMA and an average of 30 $\mu g/m^3$ 20]. Considering that the average brick-production period in Bangladesh is about five months in a year, the average yearly contribution can be estimated as 12.5 $\mu g/m^3$, compared to 53.4 $\mu g/m^3$ from DOE reported data (2013) when calculated considering 58 percentage contribution from brick kilns1. It can be concluded from the data used in Figure 9 that the contribution of transboundary pollution is about 40.9 $\mu g/m^3$ (about 44.4 percent of the total 58 percent contribution from coal burning) This further implis that the contribution of brick kilns to ambient air pollution is only 13.6 percent. Accordingly, the re-estimated source apportionment based on the analysis of dispersion model is presented in table 4.

1 DOE, Ambien Air Quality report, 2018. This report shows yearly average ambient $PM_{2.5}$ in Dhaka for 2013 as 92 $\mu g/m^3$.

# 6. Air Pollution Abatement Experience in Dhaka and Potential Options

## 6.1. Air Pollution Abatement Experience in Dhaka

The findings from the deliberation in the previous sections would mean that pollution reduction for airsheds with large population should be prioritized through local airshed based mitigation measures. The question naturally arises is there any example to show that such measures work. Indeed, such a case was the removal of two stroke 3-wheelers commonly referred to as Baby Taxis or Auto-rickshaws from Dhaka city by an executive order effective on $31^{st}$ December, 2002. The number of this class of vehicles was estimated to be between 30,000 and 65,000 in Dhaka. Emission inventory at that time [29, 30] indicated that these vehicles contributed about 40% of the vehicular air pollution for the particulate matter (i.e., PM10). Main reason for high emission was the mixing of lubricants with gasoline in the two stroke engines in these vehicles and excessive use of lubricants due to perceived notion that more lubricant protects the engines. Emission-wise these little vehicles were gross emitters, with one baby-taxi emitting as much as 10 times more particulate matter (PM) and hydrocarbons (HC) compared to regular sedan cars. For example, typical HC emissions were about 8000 ppm for baby taxis compared to 500 ppm for cars [30].

After the removal of baby taxis, an assessment of the improvement in air quality was analyzed based on data obtained at the CAMS located at the Shangshad Bhaban area was done. As presented in Figure 11, average weekly $PM_{10}$ and $PM_{2.5}$ levels just before the removal of the baby taxis were 386±90 and 238±51 $\mu g/m^3$ respectively. Next week after the removal of baby taxis, the emission levels came down to 266±46 and 141±12 $\mu g/m^3$, a decrease of about 31 percent and 41 percent $PM_{10}$ and $PM_{2.5}$ levels respectively, as a result of the removal. This demonstrates the effectiveness of a policy action towards successful improvement in local air quality.

Some measures were also implemented by GoB, in addition to the removal of baby taxis. One of the most important measures among these was the introduction of Compressed Natural Gas (CNG) fuel in the transport sector. By thermal value, CNG was cheaper by as much as 50-70% than gasoline. Initially most ICE passenger cars and 3-wheelers converted to CNG fuel. Local workshops progressively learnt to convert the small diesel engines to use CNG fuel by the reduction the compression ratio to about 11 and fitting spark plugs in the engine cylinders. Most diesel fueled vehicles i.e., light duty diesel trucks and busses were gradually converted to CNG/LPG (Liquefied Petroleum Gas) fuel.

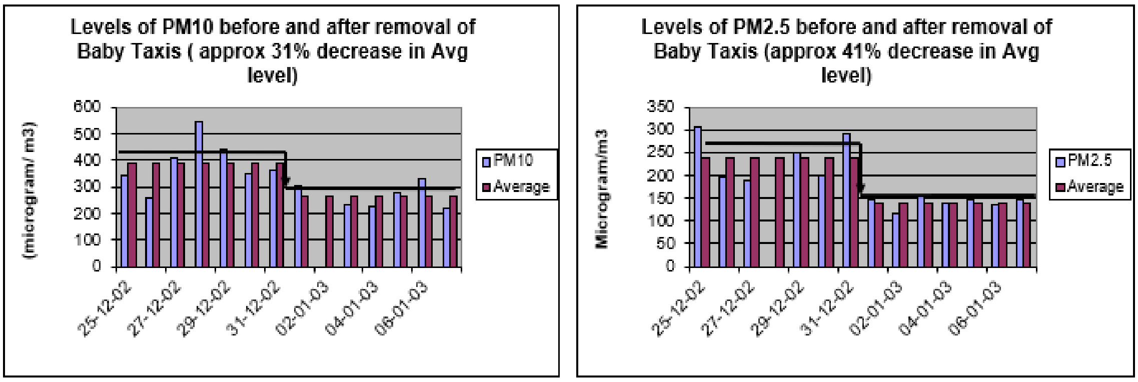


***Figure 11.*** *PM2.5 concentrations in Dhaka (from DOE CAMS at Shangshad Bhaban) during last week of December, 2002 and 1st week of January, 2003 along with the averages (for one week each before and after the removal of baby taxis). The data show 41% decrease in the PM2.5 levels [DOE Data].*

In addition, GoB reduced sulfur content in diesel from 2500 ppm to 500 ppm. This reduced heavy duty diesel vehicle emissions. Thus, the vehicle emission reduction measures up to the year 2010 were quite successful, which reduced vehicular emissions from 43 percent (2002-03) to 10.4 percent (2012). This has been documented by a number of studies carried out during 2000-2010 [29-38]. The success was primarily driven by stakeholders buy-in due reduced CNG fuel cost.

On the contrary, GoB's move to lower emission from brick kilns in Dhaka was not very successful. The traditional Fixed Chimney Kilns (FCK)) were banned in 2013 and new improved fuel efficient and lower emission kiln designs were introduced by the DOE. These kilns offer 30 to 40 percent reduction in coal use and up to 90% reduction in Total Suspended Particles (TSP) emissions. According to a DOE survey 62.6% of the FCK kilns moved to cleaner technologies by 2018 [19] but the quality and level of emissions from the converted kilns is not known. There was no statistically significant reductions in PM2.5 level in Dhaka, although about 500 brick kilns around in Dhaka were converted to improved designs.

The lessons here are that in the absence of effective enforcement and monitoring, technology demonstrations are unlikely to be successful, especially in the case of decentralized implementation. The kiln owners had low interest in the new design of kilns and these were not properly implemented and supervised, which again proved that stakeholders' buy in is an essential element in environmental policy implementation.

Bangladesh Government also took the landmark decision of providing only unleaded gasoline in the country form 1st July, 1999. The problem of lead pollution in the capital city Dhaka was identified as early as 1980 [23-26]. In view of the high public concern, in early 1999, the decision was made to make gasoline lead free in Bangladesh from 1st July, 1999 by the Energy Ministry. Measurements after the date showed that the gasoline dispensed at the pumps became largely lead free. Some residual lead however was found in gasoline for some time due to contamination in the distribution system. The average monthly Pb/BC% ratios showed progressive decline in PM2.5 [27]. This is another example of successful policy action at source that was successfully implemented at national scale.

## 6.2. Potential for Emission Reduction Opportunities in Bangladesh

The potential for emission reduction and mitigation measures undertaken are briefly summarized in Table 4. As summarized in section 6.1, GoB has implemented number of policy actions to improve AAQ (Ambient Air Quality) in Bangladesh, there are however only limited possibilities for success due overwhelming transboundary pollution during dry season (i.e., November to April), which also coincides with the brick burning season.

A program of transboundary pollution was initiated under the umbrella of South Asia Co-operative Environment Program (SACEP) in 1981, with the participation of member countries (Afghanistan, Bangladesh, Bhutan, India, Maldives, Nepal, Pakistan and Sri Lanka). One milestone of this program 'Malé Declaration' [21] which is on the control and prevention of air pollution and its likely transboundary effects for South Asia. The Male declaration encourages intergovernmental cooperation to combat the transboundary air pollution problem. Following on the Male declaration, a CAMS was established at Shyamnagar (22 ° 19′N, 89 ° 6′E) under Satkhira coastal district located near the border with India. The only output from this CAMS was a paper on PM/BC emissions during 2012-2013 for about three months [22] and no specific prevention/ mitigation measures were implemented. Such data and monitoring stations are no longer relevant with the availability of real-time regional AQ maps and data. Thus, a time bound action program with participation of all the regional countries is critical for air pollution reduction in the airshed. In the meanwhile, Bangladesh is on the threshold of a large expansion of coal-based power production with five new plants of a total capacity of around 6,500 MW. Hence, the discussion on Regional Action Plan for AQM (RAPA) should urgently be initiated with all the countries in the airshed. SACEP and Male declaration may be used as the basis for re-activating these discussions probably with support from agencies such as International Centre for Integrated Mountain Development (ICIMOD), Clean Air Asia, etc.

International development partners such as World Bank and Asian Development Bank are also actively advocating the need for regional co-operation in tacking the challenge of air pollution in South Asia Region. These agencies can also play an important role in facilitating the regional dialogue and support implementation of clean air programs.

## 7. Discussions and Conclusions

This paper analyses the impact of the recent development of disruptive technologies in assessing air pollution, especially the real-time Air Quality (AQ) mapping at regional/local scale for Bangladesh. Based on the analysis of AQ sources and their contribution to AAQ in Bangladesh, this paper concludes that the real-time AQ maps based on integrated satellite and ground-based data with modelling is a disruptive development which can replace global data-based modelling providing static information with less effort and no cost. The main conclusions from the study are summarized here.

(i) The information from these tools allows visualization of the impacts of wind speed, directions, and other factors on the pollution levels. Seasonal variation of air pollution level can also be followed by using such maps. The wind factors in some cases lead to separation and visualization of transboundary and local sources. The identification/quantification of local sources using the newer AQ information can help in the development of better plans for the management air quality.

(ii) The real-time air pollution data and maps also help to understand the inconsistencies in the existing information on pollution levels and can help in identifying emerging pollution issues also, thus leading to more realistic management measures. The need for local emission inventory-based dispersion modelling can also be dispensed with in some cases with the availability of the real-time AQ maps.

(iii) In addition, with the availability of real-time site specific quantitative air pollution data for the criteria pollutants (i.e., in many locations), the need for dense monitoring of AQ is no longer required and making tracking air pollution levels more affordable for the poorer countries. Existing data can be reinterpreted to separate the contributions of the local and transported long distance transboundary pollution in suitable situations. The qualitative observations from the real-time AQ maps can also show contribution from local point/area sources (i.e., namely from urban and transport sectors and coal fired power plants in Bangladesh). The analysis also indicates that AQ management measures in Bangladesh will not lead to major overall improvement in the yearly AQ ($PM_{2.5}$) levels, which is the major reason for health impacts. However, small airsheds (i.e., areas) with high pollution should be addressed for the reduction of $PM_{2.5}$ levels for cost-effective maximization of health benefits. This would also mean that the *major city areas should be targeted for air pollution reduction measures because of their high population, through local management measures.*

(iv) This study also emphasizes the importance of addressing the issue of brick kiln pollution in the Dhaka and other city airsheds, where kilns are clustered, on priority basis. The move away from fired brick kilns is also justified and necessary for topsoil conservation to sustain long-term agricultural productivity. This has already been mandated by the GOB. Some private entrepreneurs have started non-fired AAC (Autoclaved Aerated Cement) bricks manufacturing recently. The policy measures to support AAC and other non-fired brick technologies (e.g., Lime Sand Bricks (LSB)) would yield the double benefits of pollution reduction and topsoil conservation and should be supported.

(v) Another significant emerging air pollution issue in Bangladesh is the emissions from 5 large coal-fired power plants of about 6,500 MW capacity for which telltale evidences are provided in this paper. This emission is a round the year problem and it must be carefully monitored and managed. If emission controls do not work, fuel change to NG should be considered as studies show that the NG fueled power plants have low emissions[2].

(vi) The transboundary air pollution issue is a serious one during the dry season, which should be addressed with active co-operation among the governments of countries in the airshed. This can be facilitated through already existing programs such SACEP (i.e., Male Declaration) and agencies such as ICIMOD, Clean Air Asia, and international development partners such as The World Bank, Asian Development Bank, etc.

## Abbreviations

| | |
|---|---|
| AAQ | AAQ (Ambient Air Quality) |
| AQI | Air quality Index |
| BC | Black Carbon |
| DOE | Department of Environment |
| FCK | Fixed Chimney Kilns (Brics) |

2 SFG1208-v1-EA-P128012-PUBLIC-Disclosed-7-23-2015-Box393169B-2.pdf (worldbank.org)

| | |
|---|---|
| GAINS | Greenhouse Gas and Air Pollution Interactions and Synergies Model |
| HYSPLIT | Hybrid Single-Particle Lagrangian Integrated Trajectory Model |
| ICE | Internal Combustion Engines |
| ICIMOD | International Centre for Integrated Mountain Development |
| RAPA | on Regional Action Plan for AQM (RAPA) Should Urgently |
| SACEP | South Asia Co-operative Environment Program (SACEP) |

## Author Contributions

**Mohammed Khaliquzzaman:** Conceptualization, Data curation, Methodology, Formal Analysis, Writing – original draft and final editing

**Iqbal Ahmed:** Conceptualization, Methodology, Writing – review & editing

**Appalarajugari Sesha Harinath:** Conceptualization, Writing – review & editing

**Ziaul Haque:** Data curation, Writing – review & editing

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## Data Availability Statement

Most of the data are from published literature for which references have been provided and from the DOE archive. The data from the DOE archive are available from the corresponding author upon reasonable request.

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## Disclaimer

The work was undertaken at the individual initiative of the authors considering the importance of the subject matter and conducted in their own time. The findings, interpretations, and conclusions expressed in this paper are solely attributable to the authors and are not related in any way to World Bank or the Department of Environment, Governments of Bangladesh. The WB address used is for communication only.

## Conflicts of Interest

The authors declare no conflicts of interest.

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