

Wintertime Air Quality in Megacity Dhaka, Bangladesh Strongly Affected by Influx of Black Carbon Aerosols from Regional Biomass Burning

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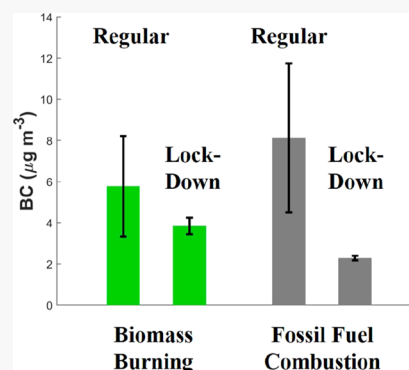
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Supporting Information

ABSTRACT: Clean air is a key parameter for a sustainable society, and currently, megacity Dhaka has among the worst air qualities in the world. This results from poorly constrained contributions of a variety of sources from both local emissions and regional influx from the highly polluted Indo-Gangetic Plain, impacting the respiratory health of the 21 million inhabitants in the Greater Dhaka region. An important component of the fine particulate matter ($PM_{2.5}$) is black carbon (BC) aerosols. In this study, we investigated the combustion sources of BC using a dual carbon isotope ($\delta^{13}C$ and $\Delta^{14}C$) in Dhaka during the high-loading winter period of 2013/14 (regular and lockdown/hartal period) in order to guide mitigation policies. On average, BC ($13 \pm 6 \mu g m^{-3}$) contributed about 9% of the $PM_{2.5}$ ($145 \pm 79 \mu g m^{-3}$) loadings. The relative contribution from biomass combustion under regular conditions was $44 \pm 1\%$ (with the rest from fossil combustion), while during periods of politically motivated large-scale lockdown of business and traffic, the biomass burning contribution increased to $63 \pm 1\%$. To reduce the severe health impact of BC and other aerosol pollution in Dhaka, mitigation should therefore target regional-scale biomass/agricultural burning in addition to local traffic.

KEYWORDS: wintertime air quality, black carbon, dual carbon isotope ($\delta^{13}C$ and $\Delta^{14}C$), source apportionment, biomass burning



1. INTRODUCTION

More than seven million people die prematurely each year due to particulate air pollution.¹ The World Health Organization (WHO) 24 h average standard for fine particulate matter ($PM_{2.5}$) health recommendation of $25 \mu g m^{-3}$ is frequently surpassed in South Asia, which hosts 14 of the world's 15 most polluted cities.² With high population density and poorly regulated emissions, Bangladesh is the country with the largest frequency of premature deaths (on average 96,000/year due to air pollution).^{3,4} In addition to this grim record, the largest city, capital Dhaka, is among the most polluted cities in the world.^{5,6} During the winter period, $PM_{2.5}$ concentrations may increase 4–5 times compared to the rainy season, due to the combined effects of anthropogenic activities and meteorology.^{7–9} The annual average $PM_{2.5}$ concentration in Dhaka is about $90 \mu g m^{-3}$ with strong seasonal variations. The seasonal average $PM_{2.5}$ concentrations were 169 ± 55 (winter), 87 ± 41 (pre-monsoon), 33 ± 13 (monsoon), and $65 \pm 32 \mu g m^{-3}$ (post-monsoon) in Dhaka.^{8,9} Local sources include motor vehicles, brick kilns, metal smelters, two-stroke engines, road dust and compressed natural gas, and fugitive lead.^{10,11} Long-range transported air mass also significantly contributed to the very high $PM_{2.5}$ concentrations in Dhaka especially during the winter period.¹⁰

Black carbon (BC) is an especially toxic component of $PM_{2.5}$, derived from incomplete combustion of fossil fuel and biomass.¹² BC is also a climate forcer, with a strong regional warming effect, perturbing regional hydrological cycles, affecting fresh water supply and agriculture.^{13,14} The levels of BC in Dhaka are highly elevated, ranging between 8 and $40 \mu g m^{-3}$, often reaching above $20 \mu g m^{-3}$.^{15–17} BC mass in Dhaka city on occasion accounted for up to 50% of the total $PM_{2.5}$ mass.¹⁸ It has been suggested that the contribution of motor vehicles was less than that of fossil coal-fueled brick kilns to BC emission and that transboundary contribution to BC loadings is also significant in megacity Dhaka.¹⁸ In addition, varieties of biomass (e.g., agricultural waste, residential cooking, winter heating, crop residue, fuel wood, cow dung, etc.) burning emissions are contributing to the BC loadings.¹⁹ However, the relative contribution of different emission sources to the adverse loadings of BC in Dhaka air remains uncertain,

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hindering the development of effective policies toward air pollution mitigation.

A powerful tool for BC source apportionment is dual-carbon isotope ($\delta^{13}\text{C}$ and $\Delta^{14}\text{C}$) characterization of the ambient BC compared with that for different key sources, for example, biomass burning and fossil fuel combustion.^{20–23} In this paper, we present dual-carbon isotope signatures for BC collected at an urban location in Dhaka during the winter period of 2013/14. During this period, politically motivated large-scale lockdown/hartal events of business and traffic occurred sporadically. We use the isotope signatures to calculate the relative source contributions from major source sectors: traffic; biomass burning; and coal combustion. Furthermore, we use the lockdown periods as a tool for differentiating between local and regional source profiles. This source forensic information provides quantitative guidance toward mitigation efforts and a development toward sustainable and healthy air quality in megacities such as Dhaka.

2. MATERIALS AND METHODS

2.1. Sampling Location. Dhaka is the biggest city (about 21 million inhabitants) of Bangladesh and the center of business, administration, and industry. It is growing rapidly and has the multiple environmental, social, and economic problems associated with a megacity. The exact sampling location is situated on the roof of the Mukarram Hussain Science Building, Department of Chemistry, University of Dhaka, Bangladesh,^{23,24} located at latitude: 23.72839° north, longitude: 90.39819° east with a sampling system elevation of 34 m above the sea level (Figure S1). The sampling site is an urban background site, with limited local impact. As the site is located near the city center, local emissions include emissions from a mixed traffic fleet with buses, trucks, private cars, and nonmotorized vehicles. There are no heavy industries (e.g., power generation) within few kms from the sampling locations, while chemical and other small industries are in old Dhaka within 2–3 kms from the sampling location. Several big industries, brick kilns, tanneries, and so on are far from the sampling location, about 5–20 kms.

2.2. Particulate Matter (PM_{2.5}) Sampling. Fine particulate matter (PM_{2.5}) was collected with a high-volume (30 m³ h^{−1}) sampler with a PM_{2.5} inlet (Digitel DH-77, Switzerland) from November 6, 2013 to February 1, 2014 including several lockdown (hartal) events. The winter sampling period (Nov 2013–Feb 2014) was chosen, as it represents the highest pollution episode of the year among four seasons in Bangladesh contribution from IGP haze on top of the local pollutions already reported by some earlier studies.^{8,9} However, we collected 20 filter samples, with a 24 h collection time. During periods of strong societal lockdown/hartal, the number of motor vehicles was reduced to 10%, while most of the industries and shopping malls were shut down. We managed to specifically capture three such strong lockdown events within our sampling routine.

The PM_{2.5} samples were collected on pre-combusted Quartz filters. The mass of PM_{2.5} is defined as the difference of the humidity- and temperature-controlled weight between loaded and unloaded filters. In addition, blank filters were collected. Loaded filter samples were stored in a refrigerator in the Department of Chemistry, University of Dhaka, prior to shipment to Stockholm University for gravimetric, elemental, and isotopic analysis.

2.3. Organic and Elemental Carbon (OC and EC)

Analysis. The mass-based concentrations of OC and EC were measured using a Sunset thermal–optical transmission (TOT) instrument using the NIOSH 5040 protocol.²⁵ To ensure the performance and stability of the Sunset instrument, a running log of the analysis of reference materials (e.g., NIST SRM 987) is kept. Prior to each analysis, the instrument was calibrated using a sucrose standard solution. The uncertainties for the OC and EC measurements (e.g., from triplicates) are typically less than 5%. For OC and EC, the blanks were below detection limits for the Sunset instrument ($\sim 0.2 \mu\text{g cm}^{-2}$ filter area), while PM_{2.5} contributed to on average 13% of the weight. The concentrations of BC are operationally defined, and EC is the carbon mass-based analogue.²⁶

2.4. Carbon Isotope Analysis. For carbon isotope analysis ($\delta^{13}\text{C}$ and $\Delta^{14}\text{C}$) of BC, a specifically designed cryo-trap coupled directly to the Sunset instrument was deployed, capturing CO₂ evolving from the filter after the OC/BC split time.^{21,27,28} To remove interference from other gases, for example, water vapor and halogen gases, a water trap with Mg(ClO₄)₂ and a heated (505 °C) silver trap are installed in the cryogenic line. The CO₂ was collected in glass vials prepared with CuO and Ag, which were sealed and sent to the National Ocean Sciences Accelerator Mass Spectrometry (NOSAMS) facility, Woods Hole, MA, USA, for $\delta^{13}\text{C}$ and $\Delta^{14}\text{C}$ analysis. The uncertainties for $\Delta^{14}\text{C}$ are typically <50‰ (typically 20–30‰). However, the ^{14}C data can be used to differentiate between fossil and biomass sources. However, it is clear that each of these consists of many different subcategories, which to some extent may be resolved by $\delta^{13}\text{C}$. For Dhaka, we consider one major biomass source: burning of C₃ plants (e.g., woody plants) and two major fossil sources: coal combustion (e.g., coal power plants and brick kilns) and liquid fossil fuel (e.g., traffic) combustion. Certainly, there may be other sources (e.g., gas flaring), but these selected ones are consistent with a previous regional study.¹⁷ Liquid fossil fuel contains traffic as a key source but may also include other sources of liquid fossil sources. However, such sources are expected to be less contributing for downtown Dhaka.

2.5. Carbon Isotope-based Source Apportionment. The fractional contributions from biomass burning (f_{bio}) and fossil fuel combustion ($=1 - f_{\text{bio}}$) can be directly computed from the $\Delta^{14}\text{C}$ signature, using an isotope mass balance

$$f_{\text{bio}} = \frac{\Delta^{14}\text{C}_{\text{sample}} - \Delta^{14}\text{C}_{\text{fossil}}}{\Delta^{14}\text{C}_{\text{bio}} - \Delta^{14}\text{C}_{\text{fossil}}} \quad (1)$$

$\Delta^{14}\text{C}_{\text{sample}}$ is the value of the investigated sample. $\Delta^{14}\text{C}_{\text{fossil}}$ is the signature of the fossil endmember. As fossil fuels are completely depleted in ^{14}C , $\Delta^{14}\text{C}_{\text{fossil}} = -1000\text{‰}$ per definition. The biomass endmember is more complicated, depending on the biomass material involved. For annual plants (e.g., rice and wheat), this reflects the isotope signature of CO₂ during the specific measurement year. However, for multiyear plants (e.g., wood), we need to consider the evolution of ^{14}C during the growth time of the tree, including the sharp increases in ^{14}C during 1960's nuclear bomb tests. Taken together, we here use $\Delta^{14}\text{C}_{\text{bio}} = +70 \pm 35\text{‰}$ as a biomass endmember estimate as elaborated upon in detail in Dasari et al.¹⁷ for this regional system and time.

The source information from $\Delta^{14}\text{C}$ may be further refined using $\delta^{13}\text{C}$ signatures. Here, we follow the approach by Andersson et al.²¹ to resolve between the following: biomass;

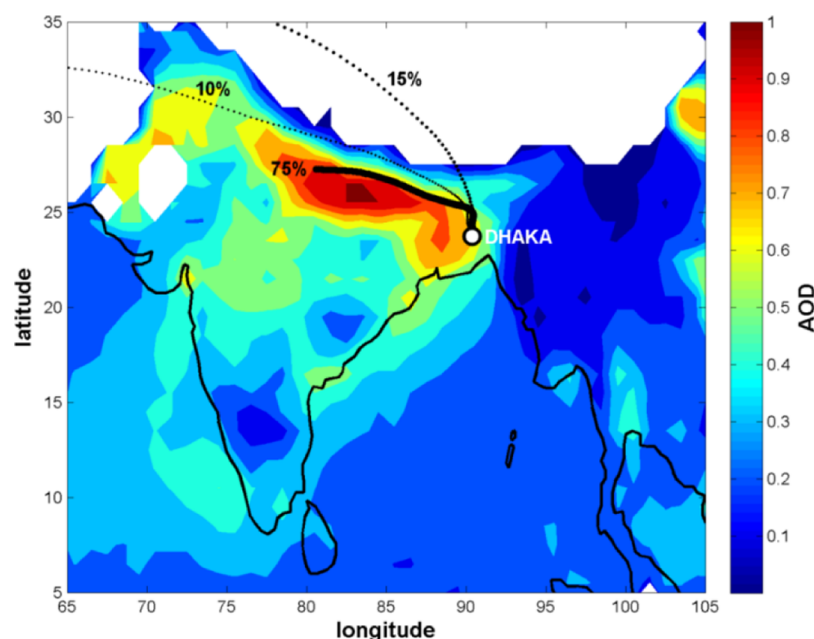


Figure 1. AOD from the MODIS (550 nm) from October 2013 to February 2014. The lines represent back-trajectory clusters arriving at Dhaka (black and white circle), where the thick line is the IGP cluster, contributing with 75% of air masses during the sampling period.

traffic (liquid fossil); and coal combustion, by solving the isotope mass balance equation

$$\begin{pmatrix} \Delta^{14}C_{\text{sample}} \\ \delta^{13}C_{\text{sample}} \\ 1 \end{pmatrix} = \begin{pmatrix} \Delta^{14}C_{\text{bio}} & \Delta^{14}C_{\text{traffic}} & \Delta^{14}C_{\text{coal}} \\ \delta^{13}C_{\text{bio}} & \delta^{13}C_{\text{traffic}} & \delta^{13}C_{\text{coal}} \\ 1 & 1 & 1 \end{pmatrix} \begin{pmatrix} f_{\text{bio}} \\ f_{\text{traffic}} \\ f_{\text{coal}} \end{pmatrix} \quad (2)$$

The $\delta^{13}C$ endmembers used for the different source categories were $\delta^{13}C_{\text{bio}} = -26.7 \pm 1.7\text{‰}$; $\delta^{13}C_{\text{traffic}} = -25.5 \pm 1.3\text{‰}$, and $\delta^{13}C_{\text{coal}} = -23.4 \pm 1.3\text{‰}$. This source differentiation was based on two overarching principles: (i) they include the main BC sources in the region and (ii) they are separable by the dual carbon signatures, as discussed in detail at Dasari et al.¹⁷ For Dhaka, we consider one major biomass source: burning of C_3 plants (e.g., woody plants) and two major fossil sources: coal combustion (e.g., coal power plants and brick kilns) and liquid fossil fuel (e.g., traffic) combustion. Certainly, there may be other sources (e.g., gas flaring), but these selected ones are consistent with a previous, regional study.¹⁷ The “traffic” source in principle includes “any liquid fossil source”, but for central Dhaka, traffic is expected to be the main source, and we use this term to be concrete.

To account for the endmember variability in the calculation of the relative source contributions, a Bayesian statistical model was used, and the results were calculated using Markov chain Monte Carlo (MCMC) simulations. The MCMC calculations were run in Matlab (ver. 2019b) using 10^6 iterations with a burn-in of 10^4 and a data thinning of 100, ensuring good convergence and robust parameter estimation.

2.6. Air Mass Back-Trajectory Analysis and Remote Sensing. Air mass back trajectories were calculated every 6 h during the sampling campaign (arrival height: 100 m above the ground level and 5 day duration of air mass back trajectories) using the Hybrid Single-Particle Lagrangian Trajectory Model (HYSPLIT). Cluster analysis suggests three main air mass transport pathways, where the main one is directly through the Indo-Gangetic Plain (IGP, 75%, Figure 1). The major 75%

“IGP” cluster is, besides the geographical domain, characterized by an overall lower wind speed, which is the explanation why these trajectories may appear short in comparison (Figures 1 and S3). Aerosol optical depths (AOD, 550 nm) were obtained using a moderate-resolution imaging spectroradiometer (MODIS) on board the Aqua and Terra satellites. Columnar absorption aerosol optical depths (AAOD) were measured using a CIMEL Sun-photometer at the measurements site, as a part of the NASA AERONET network (aeronet.gsfc.nasa.gov).

3. RESULTS AND DISCUSSION

3.1. Regional Aerosol Regime. Wintertime IGP, including Pakistan, India, Nepal, and Bangladesh, is characterized by highly elevated aerosol loadings, clearly visible from space (Figure 1). These loadings arise from massive and extensive regional emissions, topological dispersion constraints, and dry conditions. The regional-scale air pollution is continuously transported eastward into Bangladesh, amended by local emissions (e.g., brick kilns, traffic vehicles, indoor cooking, biomass burning, construction, industries, etc.), before the pollution haze is finally dispersed over the Bay of Bengal. In addition to in-city emissions, there is therefore also continuous influx of regional particulate matter into Dhaka. Measurements of columnar absorption aerosol optical depth (AAOD), a marker of light-absorbing aerosols such as BC in the atmosphere, show sustained and elevated levels, 0.05–0.12, during this period—representative of regional-scale levels—with values in the same range as some of the other most polluted IGP megacities such as Lahore,²⁹ Figure S2.

3.2. Concentrations of $PM_{2.5}$, OC, and BC. Elevated levels of 24 h average $PM_{2.5}$ levels were observed throughout the sampling period ($145 \pm 79 \mu\text{g m}^{-3}$), with a minimum of $43 \mu\text{g m}^{-3}$, continuously well above the WHO³⁰ health standard of $25 \mu\text{g m}^{-3}$ for 24 h average. It should be mentioned that the sampling height in this study is 34 m, and the regulatory air quality monitoring recommended height is 2 m. Therefore, it is likely that the $PM_{2.5}$ concentrations at 2 m height would be

significantly higher, especially during the wintertime temperature inversion period. However, the $PM_{2.5}$ steadily increased throughout the winter observational period (Figure 2). An explanation for this phenomenon may be the emission from brick kilns around Dhaka city (about 800 brick kilns) and rice parboiling industries, as they are only operating during the winter period, starting from November to April.³¹ Moreover, vehicular and dust emissions may also contribute to the high

$PM_{2.5}$, as no wet deposition happened during the winter period.^{7,10,11} However, it may also reflect buildup of air pollution in the IGP, which is then transported to the east and then the south during the winter. This temporal evolution is overall also present for OC but not for BC, suggesting differences in source dynamics and atmospheric processing for the different components.

The average BC concentration during the campaign was $13 \pm 6 \mu\text{g m}^{-3}$, which is among the highest in the world.³² Even so, it is somewhat lower compared to previous measurements in the same area^{33,34} but higher than what is observed at an IGP receptor site ($4.6 \pm 3.9 \mu\text{g m}^{-3}$) north of the Bay of Bengal.¹⁷ A reason for the lower values reported in this study compared to earlier studies for Dhaka may be that the present measurements were conducted in fine-mode aerosols, while previous measurements were in total suspended particulate matter. Nevertheless, the current estimates are in the same range as for some IGP cities, for example, Delhi,²² underlining the severity of both regional IGP and local Dhaka air pollution.

3.3. Ratio of Organic and Elemental Carbon (OC/BC).

The organic to elemental carbon ratio is a commonly used aerosol regime indicator. The present range, 3.4 ± 1.5 , is the same or slightly lower compared to reports for another IGP megacity, Delhi, during the winter period.²² Elevated OC/BC ratios are sometimes used as indicators for biomass burning, but the actual values strongly depend on the type of biomass burning, such as the smoldering conditions of typical rice paddy agricultural waste burning or flaming conditions such as during wheat residue burning and wood fuel combustion.²²

Furthermore, the OC/BC ratio may be strongly influenced by secondary formation of (organic) carbonaceous aerosols and substantially modulated by photochemical aging during long-range transport, perhaps particularly accentuated in the (sub)-tropics.³⁵ Taken together, it is clear that the OC/BC ratio is a highly nonconservative marker and should be interpreted qualitatively within each specific setting. Here, we find that the OC/BC ratio increases with time during the campaign, following an overall increase in OC, suggesting a shift in the aerosol dynamics (Figure 2b). Similarly, we see a continuously increasing $PM_{2.5}$ /BC ratio (decreasing BC/ $PM_{2.5}$; Figure 2b) during this campaign. This may suggest increasing contributions from secondary aerosols, including secondary organic carbon.

3.4. Carbon Isotope-Based Source Apportionment of BC Aerosols in Dhaka. Radiocarbon ($\Delta^{14}\text{C}$) is a powerful tool for quantitatively differentiating with high precision the fractional contributions to specifically BC from biomass burning and fossil fuel combustion, eq 1. For the winter period of 2013/2014, the $\Delta^{14}\text{C}$ signature varies significantly ($-517 \pm 107\text{‰}$), ranging between -655 and -303‰ , corresponding to 32–64% from the biomass combustion origin. These ranges are similar to what have been reported also for wintertime in the other end of the IGP, for megacity Delhi (-646 – -318‰).²² Using an isotopic mass balance, eq 1, these Dhaka values correspond to $48 \pm 4\%$ biomass burning for BC in Dhaka for the whole period, which is significantly larger compared to what has been reported for urban environments in Europe, East Asia, China, and North America, which tends to be in the order of 80% fossil fuels.^{15,16,35–38} On the other hand, these Dhaka values are in a similar range as for South Asian regional receptor sites and measurements conducted in the Himalayas, where the estimated fraction biomass is in the range of 50%.^{17,18,39–41}

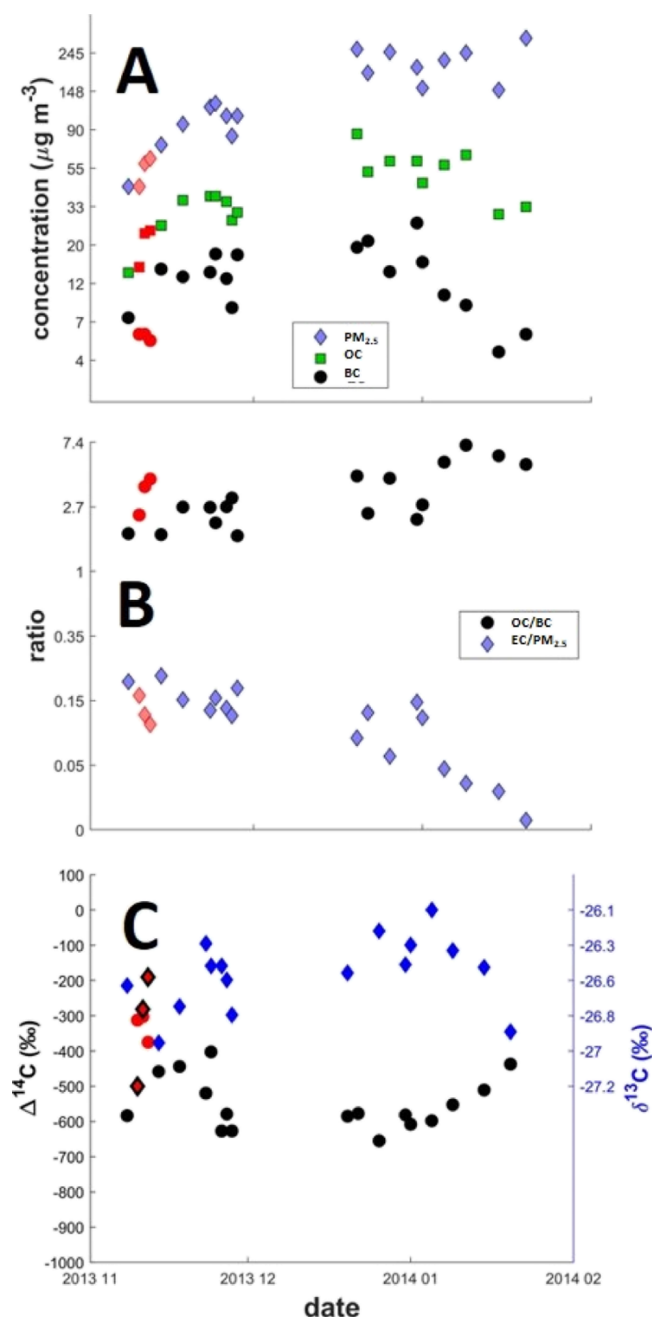


Figure 2. Aerosol component concentrations, ratios, and BC isotope signatures during November 2013–February 2014 in Dhaka. Panel A—log-scale concentrations: $PM_{2.5}$ (blue diamonds), OC (green squares), and BC (black circles). Panel B—log-scale ratios: OC/BC (black circles) and BC/ $PM_{2.5}$ (blue diamonds). Panel C—carbon isotope signatures of BC: $\Delta^{14}\text{C}$ (black circles) and $\delta^{13}\text{C}$ (blue circles). Periods with strike-induced societal lockdown conditions are marked in red in all panels.

To further constrain the sources, we add the stable carbon isotope, $\delta^{13}\text{C}$, signature. This dual-carbon isotope technique has proved useful for BC at multiple other locations, in South Asia and East Asia and in the Arctic.^{17,21,22,37,41,42} For the present dataset, we see little systematic variability in the $\delta^{13}\text{C}$ signature ($-26.4 \pm 0.3\text{‰}$) over time (Figure 2). Overall, the combined dual-carbon isotope cluster within the signatures is typical for traffic emissions and C_3 -plant biomass burning emissions. In a quantitative isotope mass balance for Dhaka, using both isotopes, eq 2, we indeed find biomass ($48 \pm 4\%$) and traffic ($46 \pm 5\%$) to be the major components, while coal combustion has a minor contribution ($6 \pm 5\%$). While the temporal variability of $\Delta^{14}\text{C}$ in Dhaka is high, these average results are similar to what we have found during the 2016/17 winter period at the Bangladesh Climate Observatory at Bhola (BCOB; $49 \pm 1\%$ biomass; $42 \pm 7\%$ traffic, and $9 \pm 7\%$ coal combustion)—a receptor site for the IGP outflow in southern Bangladesh.¹⁷

Dhaka is a rapidly growing megacity, including a high gross domestic product growth (between 6 and 8%), transferring the economic base from agriculture to industry. This process at present also brings very high pollution and stress on environmental and sustainability parameters, being the major cause for the severe health problem of about 21 million inhabitants of Dhaka. The severe air pollution is a central hindrance to achieve the sustainable development goals (SDGs). Therefore, the reduction of air pollution is essential not only in Bangladesh but also in the whole IGP including India, Nepal, and Pakistan. This study not only contributes quantitative scientific underpinning to guide policy efforts toward effective measures to reduce the air pollution from traffic emission but also highlights the need to control regional biomass burning including agricultural crop residue burning. However, to control air pollution in Dhaka and specifically for BC, local authorities should target fossil/traffic emissions, while regional emissions along the IGP should target biomass emissions.

3.5. Effects of Societal Lockdown on BC Aerosol Sources in Dhaka. In addition to the normal wintertime conditions in Dhaka, we investigated the BC sources during three periods with local politically motivated passive strikes (hartal), in which there was massive slowdown in Dhaka region business, industry, and traffic. During these periods of societal lockdown in the winter of 2013/2014, the patterns of BC emissions appear to have been substantially shifted (Figure 3). These events are characterized by lower BC ($6.1 \pm 0.3 \mu\text{g C m}^{-3}$ compared to $13.9 \pm 5.7 \mu\text{g C m}^{-3}$) and $\text{PM}_{2.5}$ ($54.5 \pm 10.3 \mu\text{g m}^{-3}$, compared to $160.6 \pm 74.6 \mu\text{g m}^{-3}$) loadings and significantly (as judged by heteroscedastic, double-sided *T*-tests, $p < 0.01$) higher $\Delta^{14}\text{C}$ -derived biomass contributions ($61 \pm 4\%$). These findings agree with a reduction of local traffic to 10% of normal intensity (Table 1). These reduced local concentrations accompanied by increased biomass burning contributions suggest a regional BC source, with elevated biomass contributions. Although this hartal period is not representative of the entire winter period, it does provide an important window of opportunity for capturing the source characteristics of the regional influx into Dhaka. These findings are similar to the regional influx of BC into urban Delhi, which significantly increased the ^{14}C signature due to countryside agricultural fires.²²

Taken together, this study shows that to minimize the impact of BC on the air quality in Dhaka, reduction of traffic

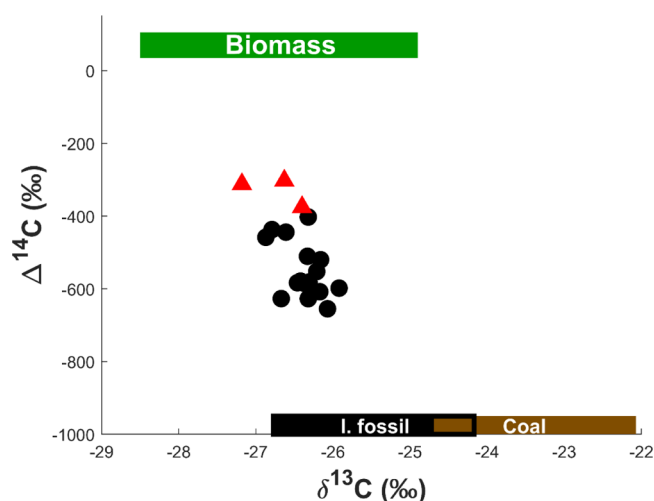


Figure 3. Dual-carbon isotope plot for BC. Black circles denote regular conditions, while red triangles denote periods with strike. The endmember values for the three major sources (mean $\pm$ stdev) are shown as boxes: biomass burning (green; C_3 plants), traffic (black; liquid fossil), and coal combustion (brown).

Table 1. Fractional Contributions (Mean $\pm$ Stdev) to BC from Biomass Burning, Traffic, and Coal Combustion in Dhaka during Normal and Politically Motivated Large-Scale Lockdown/Hartal of Business and Traffic Days in the Winter of 2013–2014 (n = Number of Days)

	normal (%) (n = 17)	lockdown/hartal (%) (n = 3)
biomass burning	44 ± 1	63 ± 1
traffic emission	50 ± 10	24 ± 5
coal combustion	7 ± 10	14 ± 5

emissions is a key measure. Furthermore, this study suggests also a large influence of regional IGP BC levels from biomass burning ($3.7 \pm 0.4 \mu\text{g C m}^{-3}$). Combined with an earlier study showing the strong local impact of countryside biomass burning inside megacity Delhi, the fact that the current study in megacity Dhaka, at the other end of the IGP, shows very similar results brings the wider implication that agricultural biomass burning may be an adverse contributor to the BC loading and poor wintertime air quality throughout the entire IGP, home to over 400 million people. This influence of biomass burning on the air quality in Dhaka and interference to large parts of the IGP, which by itself is much larger than the total loadings of BC from all sources combined, found in many metropolitan areas in Europe and North America, point the way for effective mitigative actions and guide measures toward a sustainable development for air quality and health of this densely populated region.

■ ASSOCIATED CONTENT

Supporting Information

The Supporting Information is available free of charge at <https://pubs.acs.org/doi/10.1021/acs.est.1c03623>.

Map of the sampling location, variation of the aerosol absorption optical depths in Dhaka, five days backward trajectories to the sampling location, and details of the sampling dates with individual values of $\text{PM}_{2.5}$, BC, OC, OC/BC, $\delta^{13}\text{C}$, and $\Delta^{14}\text{C}$ (PDF)

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<https://pubs.acs.org/10.1021/acs.est.1c03623>

Author Contributions

Ö.G. and A.S. conceived the scientific scope. A.S. and his group in Dhaka University, Bangladesh, performed the atmospheric sampling. F.J., M.D.H.K., and M.I.H. were conducting sampling in Dhaka, and M.I.H. was also involved in chemical analysis at Stockholm University. A.A. conducted the source apportionment calculations and the statistical analysis. A.S. and A.A. wrote the first version of the manuscript with the input of all co-authors.

Notes

The authors declare no competing financial interest.

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