Policy Implementation and its Impact on Ambient Air Quality

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Abstract

The scientists of Bangladesh Atomic Energy Commission (BAEC) are monitoring air particulate matter in ambient air, both PM_{10} and $PM_{2.5}$ concentrations since 1996. It was found that the annual average of Pb was 265±549 and 121±209 in 1997 and 2012 respectively. In 1997, the main source of Pb was Pb-gasoline. In July 1999, the Government banned the use of Pb in gasoline. As a result, Pb concentration in air has decreased. On the other hand, the government has introduced compressed natural gas for vehicles instead of diesel and banned two-stroke baby taxi from Dhaka city in January 2003. So, the annual $PM_{2.5}$ and BC concentrations were decreased almost more than half when the data sets were compared between 1997 and 2012. So it can conclude that the concentration of fine PM and BC do not increase linearly with the economic development due to policy implementations. These are positive achievements of policy implementations. Now the government is trying introducing nuclear power plant for power generation and more cleaner and energy efficient technology for brick production.

Keywords: PM, CNG, Pb, diesel

1. Introduction

More than one-third of the population of Bangladesh lives in cities. It is projected that, by the middle of the century, more than half of the population of Bangladesh will be urban-based. Most of the population growth is concentrated in and around Dhaka, the capital of Bangladesh. Since 1970, it has seen an eightfold increase in population which stands at more than 12 million, making it the eighth largest city in the world. It is projected to become the third largest city by 2020 with a population of approximately 20 million.

Air pollution has become an important environmental concern globally, especially in urban areas, in view of its adverse health effects [1]. The concentration of the key air pollutant mainly Particulate Matter or PM in Dhaka and other major cities has been steadily increasing in recent years, with an annual average higher than the World Health Organization (WHO) guidelines [2].

Air quality monitoring data is a key component to understand extent of problem and to develop strategies for reducing air pollution. Ambient air quality monitoring data provides measurement of concentrations of pollutants in the air at a specific place over a specified time. This provides valuable information about how much pollution their is in the atmospheric air, where the air is most polluted, and some information about the types of air pollution.

The problem of lead pollution in the capital city Dhaka was identified in 1980 [3] (by a research group at the Atomic Energy Centre, Dhaka. They carried out a survey of trace elements in the whole blood of the adult population of Dhaka. An average lead level of 550±180 $\mu g\ l^{-1}$ was found in a selected group of 100 adults. The high level of blood lead could not be understood as the automobile population was rather low in Dhaka at that time. The group looked for lead in food and drinks but no abnormally high levels were found [4-5]. The problem remained an enigma until 1991 when the same group noticed high levels of lead in 24 samples of total suspended particles (TSP) in air [6]. A study of the size fractionated ($PM_{2.5}$ and PM_{10}) airborne particulate matter was carried out again at the Atomic Energy Centre, Dhaka during 1993-95 [7-10]. The chemical analysis of the samples clearly identified the presence of high levels of lead and their origin in gasoline. Correlation between lead and bromine and source apportionment analysis clearly proved that most of the fine particle ($PM_{2.5}$) lead were of gasoline origin.

The results of the 1993-96 studies were highlighted in the IAEA News Bulletin [11]. This news item was widely reported both in national and international press. These reports and work by other groups helped to raise the national awareness at Government level which ultimately led to total phase-out lead in gasoline in 1999.

Lead is an environmental toxicant that affects virtually every system in the human body [12]. In children, lead decreases intelligence, growth and hearing; cause anemia and can cause attention and behavior problems [13]. High levels of exposure to lead can cause severe brain damage or death. Leaded gasoline is the primary source of lead exposure in cities in most developing countries. It accounts for 80-90% of airborne lead pollution in large cities where it is still used [14]. The removal of lead from gasoline in the single most effective way to preventing lead poisoning in children and the key to rapidly eliminating childhood lead poisoning on a large scale. The successes achieved in many countries have demonstrated that lead elimination is feasible and can be carried out through cost-effective, relatively short-term programs [15].

Gasoline engines contribute to air pollution by emitting high levels of particulate matter (especially two-stroke engines), carbon monoxide, nitrogen oxides and volatile organic compounds. Diesel engines also emit high levels of particulate matter, nitrogen oxides, volatile organic compounds and sulfur oxides (sulfur in diesel fuel is high). The other sources of particulate matter emissions are brick kiln around Dhaka which mainly operate during the winter period, resuspension from all the dusty unpaved roads and

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refuse burning by slum dwellers. From source apportionment studies [16], it was found that about 50% of particulate matter smaller than 2.2 micron ($PM_{2.2}$) comes from vehicular emissions (Data source 2001-2002)[17]. Thus, vehicles are believed to constitute the dominant source of air pollution in Dhaka [16-17]. There are no power stations, significant industrial sources of emissions, or nearby desert that may produce particulate pollution. Therefore, much of the governmental actions to date have focused on vehicular emission control [18]. Two pollutants of concern in the 1990s were lead and particulate matter. Lead was phased out of use in 1999 [19]. With respect to particulate matter, the government has been active in addressing significant contribution from two-stroke engine powered three-wheel vehicles, commonly known as baby taxies. These little vehicles were gross emitters, with one baby taxi emitting as much as 10 times more particulate matter (PM) and hydrocarbons than a comparable four-stroke vehicle [20-21].

Emissions were normally higher in two-stroke engines because of the design of the engine. Moreover, the lack of proper maintenance of these vehicles and the use of low-grade lubrication oil contribute to higher PM emissions. Thus, the baby taxies were believed to be a very significant contributor to air pollution in Dhaka. The effect of removing baby taxies from the roads and adaptation of compressed natural gas (CNG) as fuel resulted in a step reduction in PM pollution.

Prior to September 2002, a large number of two-stroke engine three-wheelers were used in Dhaka. The number of vehicles in this class was estimated to be around 65,000, providing useful point-to-point transportation, but emitting significant black smoke and hydrocarbons. Emission inventory calculations showed that these vehicles contribute to about 40% of the vehicular air pollution for the particulate matter smaller than 10 micron (PM_{10}) [22].

Since mid of 1999, Bangladesh Government has taken the initiatives to reduce air pollution through urban air quality management plan and strike the carbon market through the Clean Development Mechanism (CDM). In this report we will discuss about the correlation between the policies adaptation and ambient air quality in the city air.

2. Materials and Methods

2.1 Sampling

Samples were collected on 47 mm and 37 mm diameter Polycarbonate/Teflon filters using GENT/Thermo Andersen dichotomous samplers through Bangladesh Atomic Energy Commission (BAEC) from one site and Department of Environment (DoE) from four sites. BAEC has been collecting PM samples since 1996 and DoE has been collecting samples since 2010 [23]. The samplers in each station were positioned with the intake upward and located in an unobstructed area at least 30 cm from any obstacle to air flow and the sampler inlet was placed at a height of 10 m above ground level. BAEC does sampling twice in a week and DoE does sampling in every third day in a week.

2.2 Site description and measurement period

Being the capital city of the country, Dhaka is congested with a large number of motor vehicles, including both public and private. Many small factories are also located in and around the city. The CAMS-2 site is at Farm Gate in Dhaka (latitude: 23.76°N; longitude: 90.39°E). Farm Gate is characterized as a hot spot site due to the proximity of several major roadways, intersections and large numbers of vehicles plying through the area [16]. The site is surrounded by commercial and semi industrial area. The other sampler was placed in a semi-residential area (SR) area of Dhaka. The sampler was placed on the flat roof of the Atomic Energy Centre, Dhaka (AECD) campus building. It was found from the source apportionment study that the main pollutant sources are road dust, soil dust, sea salt, Zn source, motor vehicle and brick kiln in this site [24].

Chittagong (latitude 22.22°N, longitude 91.47°E) has the largest port in Bangladesh and has heavy traffic, especially the central city area covering about 10 km^2. A Continuous Air Monitoring Station (CAMS) is operated in Chittagong to measure criteria pollutants. The location of the CAMS-3 is in the Chittagong Television Station Campus at Khulshi, which is on a hilltop about 2.5 km northwest of the Chittagong downtown area and about 100 meters above the surrounding area. The major sources were biomass burning/brick kiln, soil dust, road dust, Zn source (including two-stroke motorcycles), motor vehicle, CNG vehicle, and sea salt in the Chittagong aerosol [25].

Rajshahi, a metropolitan city, is situated in the northern region of Bangladesh (latitude 24.37°N, longitude 88.70°E) and near the border with India. The location of the CAMS-4 is in Sapura at the Divisional Forest Office. There are few small industries surrounding the sampling site. The climatic conditions are very similar to Dhaka. As there is a low number of industries, apart from brick kilns in Rajshahi city, it has been found that the contribution of biomass burning at this site is highest [17]. This biomass burning contribution may originate from both brick industry, domestic burning/residential combustion (cooking with low grade fuels) or from transboundary transport.

Khulna, the third largest city of the country, is situated in the southern region of Bangladesh (latitude 22.48°N, longitude 89.53°E) and near the Bay of Bengal. Being located in a large river delta, it is the second port area of Bangladesh. The CAM station, CAMS-5, is located at Samagic Bonayan Nursery and Training Center in Baira which is about 3 km north of Khulna main town. There are many small factories near the sampling site (both west and south sides), which are producing Touchwood, a special type of fuel, which is made by rice husk and used as fuel for cooking.

2.3 PM mass and BC analysis

PM mass was measured both in the laboratory of AECD and the Department of Environment. The $PM_{2.5}$ masses were determined by weighing the filters before and after exposure using a microbalance [26]. The filters were equilibrated for 24 h at a constant humidity of 50% and a

constant temperature (22°C) in the balance room before every weighing. A Po-210 (alpha emitter) electrostatic charge eliminator was used to eliminate the static charge accumulated on the filters before each weighing. The difference in weights for each filter was calculated and the mass concentrations for each $PM_{2.5}$ and $PM_{2.5-10}$ samples were determined.

Black carbon (BC) measurements were conducted with a two-wavelength transmissometer (model OT-21, Magee Scientific, Berkeley, CA) (In case of DoE). The two-wavelength transmissometer measures the optical absorption of the ambient PM sample at 880 nm (BC) and 370 nm (UVBC) [27]. Certain organic aerosol components of wood combustion particles have enhanced optical absorption at 370 nm relative to 880 nm. A calculated variable, Delta-C signal (UVBC(370nm) – BC(880nm)), has been suggested as an indicator of wood combustion particles, but is not a direct quantitative measurement of their mass concentrations [28-29]. The concentration of black carbon (BC) in the fine fraction of the samples is determined by reflectance measurement using an EEL-type Smoke Stain Reflectometer (In case of AECD laboratory). Secondary standards of known black carbon concentrations are used to calibrate the Reflectometer [19].

2.4 Meteorological Conditions

In Bangladesh, the climate is characterized by high temperatures and high humidity for most of the year, with distinctly marked seasonal variations in precipitation. According to meteorological conditions, the year can be divided into four seasons, pre-monsoon (March-May), monsoon (June-September), post-monsoon (October-November) and winter (December-February) [30]. The winter season is characterized by dry soil conditions, low relative humidity, scanty rainfall, and low northwesterly prevailing winds. The rainfall and wind speeds become moderately strong and relative humidity increases in the pre-monsoon season when the prevailing direction changes to southwesterly (marine). During the monsoon season, the wind speed further increases and the air mass is purely marine in nature. In the post-monsoon season, the rainfall and relative humidity decreases, as does the wind speed. The wind direction starts shifting back to northeasterly [31]. The meteorological data used in this study were obtained from a local meteorological station, located about 2 kilometers north of the CAMS in Dhaka.

3. Results and Discussion

3.1 Decision on banning of leaded gasoline and its influence on air quality

Air pollution in Bangladesh occurs due to the significant emissions of toxic matter introduced into the atmosphere from the use of leaded gasoline. These particles were situated in agglomerates of auto exhaust emissions [19]. Before 2000, there is substantial amount of Pb in air of Dhaka city [6, 32]. It was observed particles containing Pb-halides, most typically Pb-bromide [19]. They indicated the primary emissions of auto exhausts from vehicles using leaded petrol. However, Pb was often associated in the particles with high sulphur content, which indicated Pb-sulfates [19]. There is a good relationship between Pb and Br before banning of Leaded gasoline [19]. There is also a good correlation between BC and Pb which also support the emission of Pb from motor vehicles (Fig. 1 & 2). As the association of Pb in fine fraction is high, it observed that these relationships show much better in fine samples.

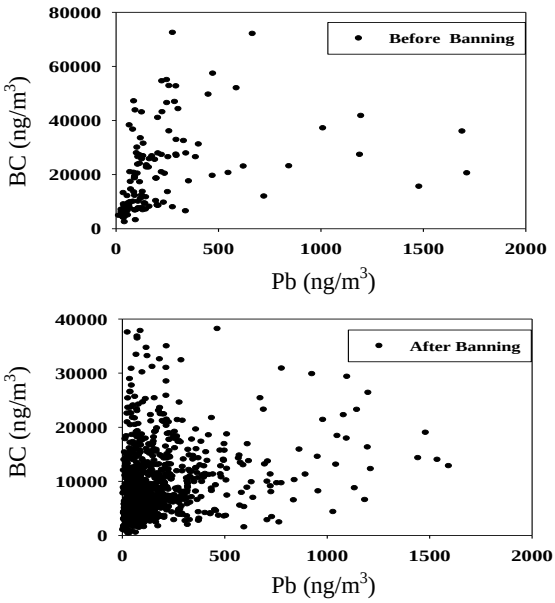

Fig. 1. The relation between BC with Pb before and after banning of Pb-gasoline

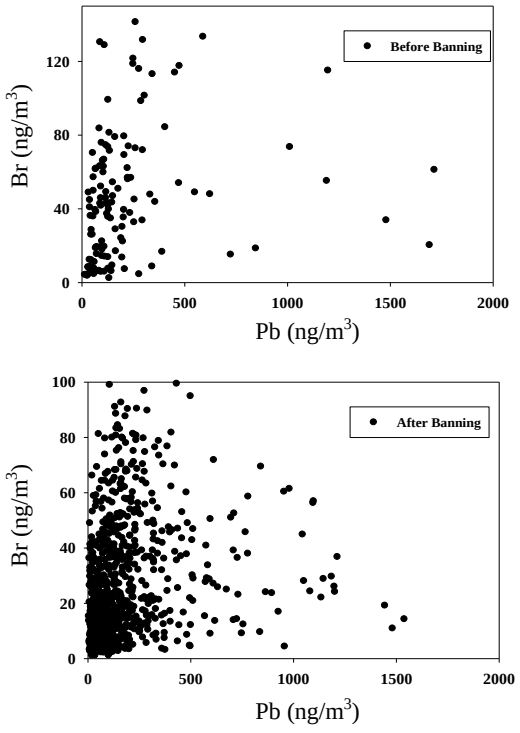

Fig. 2. The relation between Br with Pb before and after banning of Pb-gasoline

After the banning of use of Pb-gasoline, the ambient air quality has improved. There is a sharp decrease of Pb/BC ratio [19] during that period which proved that the primary source of Pb was Pb-gasoline. It would be found that there is no relation between Pb vs Br after the banning of Pb-gasoline (Fig. 2).

Table 1 shows the annual average of Br, and Pb with standard deviation. It also contains the ratio of Br/Pb, Pb/BC and $PM_{2.5}/PM_{10}$. It was observed that there is a decreasing trend of $PM_{2.5}$ because of several policy interventions within Dhaka city [33]. It would also be found that after banning of leaded gasoline in July 1999, the concentration of Pb has decreased and it continued up to 2000. After that this concentration has increased. This might be due to use of Pb in the manufacture of pesticides, fertilizers, in paints and dyes and in batteries and explosives [34].

Table 1. The yearly mean with standard deviation (ng/m^3) of Br and Pb and the ratio of Br/Pb, Pb/BC and $PM_{2.5}/PM_{10}$

Year	Br	Pb	Br/Pb	Pb/BC	PM2.5/PM10
	ng/m^3			%	
1997	23.5±21.1	265±549	17.3	1.69	47.5
1998	71.3±44.9	370±644	47.1	1.44	52.0
1999	28.7±34.5	225±370	21.4	1.64	56.2
2000	7.76±5.39	106±179	13.1	0.80	56.1
2001	9.33±7.97	130±163	19.6	1.64	41.6
2002	12.8±14.6	227±784	24.5	2.81	38.2
2003	20.0±39.0	166±467	48.9	2.26	41.5
2004	13.8±14.1	198±611	45.0	2.57	35.6
2005	26.7±20.7	342±732	38.4	3.63	42.6
2006	18.1±17.9	139±180	28.3	1.87	36.1
2007	21.7±17.6	123±137	59.5	1.38	37.7
2008	32.2±39.8	100±141	55.3	1.51	37.4
2009	46.5±34.4	237±214	30.5	2.41	36.9
2010	45.6±15.0	178±113	33.7	1.90	34.9
2011	48.2±21.4	240±204	35.8	3.90	34.3
2012	16.5±20.5	121±209	41.8	2.71	23.1

It would found that Pb has a tendency to be associated more with the fine fraction than the coarse fraction [35]. This is because the Pb particles were formed at high temperature as part of the vehicle exhaust. However, handling of lead batteries in preparation for the reclamation of the lead produces coarse particle lead [36]. It would be found that after the banning of Pb-gasoline (Fig. 1), there are two different sources from where Pb may originate. From the ratio of Pb/BC, it is confirmed that Pb comes from the discrete sources such as Pb smelter. There is a bit correlation with the BC (Fig. 3) after banning of leaded gasoline. As BC also originates from the Pb- smelter, it may also come from there. There are also Pb-battery recycling plants in Dhaka. Although, Pb was eliminated from the gasoline in Bangladesh beginning in July 1999, there may be substantial accumulated lead in the dust near roadways because lead has a very long residence time in surface soil [35]. In addition, there are Pb weights used on tires to balance the wheels [37]. They get thrown off and crushed in traffic, which is also a significant source of coarse Pb.

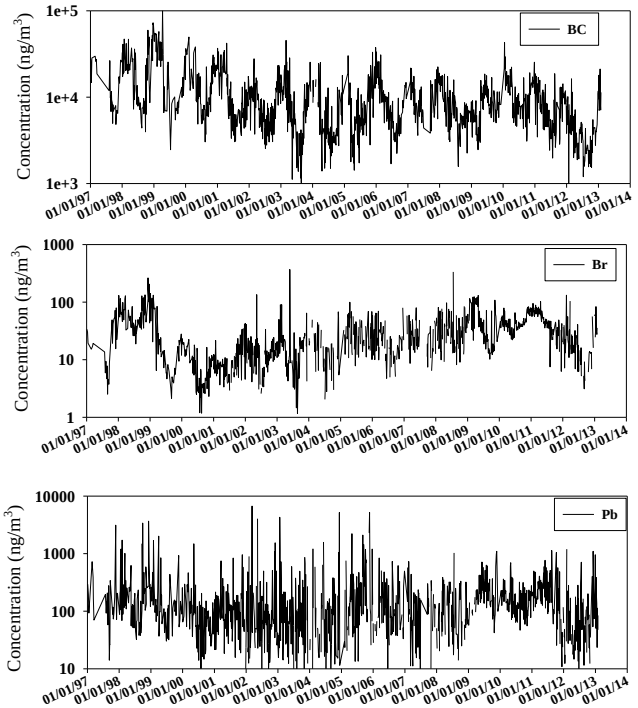

Fig. 3. Time series of Br, BC and Pb during the study period

Unfortunately, the story of environmental lead in Bangladesh is still an unfinished story and further decline is likely to be very slow. There is a substantial amount of accumulated lead in dust from earlier depositions. Elevated lead concentrations in the soil reflect this [34]. On the other hand, Pb is still being used in an uncontrolled manner in paints and there are also fugitive emissions from battery and other industries. Therefore it could be found that after 2000 year, the Pb level has shown an increasing tendency (Fig. 3) and needs to be controlled. It is, therefore, essential to continue the fight for lowering lead level in air through the removal of lead in paints and through the control of emission from suspected industries especially lead based battery industries by regulatory measures.

3.2 Decision on banning of Two-stroke engine, adaptation of CNG engine and its influence on air quality

To address air pollution from baby taxies, several activities were undertaken by the Bangladesh Government under the air quality management project (AQMP). This project included auto clinics, promotion of 2T lube oil, and finally, phased replacement of two-stroke engines with four-stroke and compresses natural gas (CNG) technology engines. To implement this phase out, the Ministry of Communications announced an order banning all two-stroke engine baby taxies in Dhaka by December 31, 2002. The first phase that

included most 1995 vintage vehicles or older were to retire on September 01, 2002. The remaining estimated 6,500 vehicles were retired on December 31, 2002. However, administrative and other problems led to an unsuccessful first stage of the phase out of the older vehicles. However, because of firm Government action, it was possible to remove all the two-stroke three wheelers from Dhaka city at the end of December. As a result, there was a dramatic change in the air pollution situation in Dhaka (Table 2).

Prior to 1999, little effort was made to control vehicular and industrial emissions. There was no air quality management system in Bangladesh to tackle air pollution. Only recently has the government begun to establish regulatory and institutional frameworks to address urban air quality problems. In an effort to improve air quality within the Dhaka city and to ultimately comply with the U.S. EPA as well as the proposed Bangladesh National Air Quality Standards, a number of control strategies have been developed and implemented. To date, the old two-stroke engine three-wheelers have been completely replaced by CNG powered four-stroke three-wheelers. New cars now are equipped with air pollution control devices, CNG-powered cars have been recently introduced, and industrial sources are slowly being regulated. As a result of these implemented control strategies, air quality in Dhaka has slowly, but steadily improved [38]. It is necessary to sustain these efforts until the measured air quality is in compliance with the National Air Quality Standards.

Table 2. Average suspended air particulate matter (APM) mass and Black carbon (BC) (μg m^{-3}) during 1997-2005 in urban areas of Bangladesh.

Year	PM_{10}	$PM_{2.5}$	BC ($PM_{2.5}$)
1997	99.1±65.1	44.4±26.9	15.6±9.4
1998	105±69.7	51.9±33.3	24.9±17.8
1999	126±86.9	64.1±40.0	21.5±18.3
2000	94.9±65.0	47.2±28.1	14.7±8.9
2001	85.2±76.7	30.7±21.7	10.7±7.6
2002	73.4±47.3	26.0±17.8	8.59±4.84
2003	80.0±45.6	31.7±19.1	9.10±7.30
2004	72.4±50.2	23.5±15.3	7.68±6.18
2005	80.9±64.2	29.5±16.1	9.39±7.61
2006	103.3±75.6	35.1±30.4	9.08±5.78
2007	95.5±50.3	32.8±15.7	9.71±4.67
2008	106.7±66.3	38.4±28.6	7.59±3.54
2009	119.5±82.6	38.6±21.5	9.41±5.87
2010	116.0±80.5	37.3±27.8	10.9±5.00
2011	118.8±70.2	36.7±18.9	7.70±3.75
2012	86.5±60.9	19.2±20.7	4.20±3.11

It has been observed that fine particulate matter is slowly decreasing from the previous years due to other Government policy interventions. The first step was to reduce emission through the proper tuning and repairing of vehicles. This process was begun in 2000. For this purpose, a series of auto clinics were conducted in which three-wheelers were checked for emissions free of charge, drivers were given a simple health examination, and information was provided to the drivers on how to operate their vehicles in a manner to minimize emissions. In 2001, the government took few steps to minimize the smoke emissions from vehicles by prohibiting the production, blending, import, and marketing of mineral oil without additives and set minimal standards for lubricants for two-stroke and four-stroke engine vehicles. Finally, on January 1, 2003, two-stroke engines, old buses (20 years), and trucks (25 years) were taken off of the roads.

The results of the source apportionment are given in Table 3 in order to understand the influence of policy adaptation on motor vehicles. The earliest source apportionment results (Data sets are 2001-2002) [17] showed that vehicles normally produced about 50% of fine particles ($PM_{2.5}$ particles). The most recent source apportionment data [31] (Table 3) shows that the contribution of BC from motor vehicles has decreased following CNG adoption in 2003. It has also found that the highest contribution of BC was from motor vehicles including two stroke engines in 2001 to 2002 [17]. Air quality policy actions were taken for PM as well as BC emission reductions from motor vehicles. The source results for the 2005-2006 data showed the reduction of PM as well as BC. However, the results from 2007-2009 data set shows that the contribution of PM emission has increased from the previous years. The emission of black carbon has been reduced compared to previous years. This result is a positive achievement for the policies adopted by the Government.

Table 3. Average source contributions derived from the PMF modeling

Source	Fine PM samples (μg/m^3)					
	2001-2002		2005-2006		2007-2009	
	Mass	BC	Mass	BC	Mass	BC
Motor vehicle	7.16	2.50	5.62	0.38	13.1	1.33
Brick kiln	2.23	1.37	11.1	4.14	5.63	1.53
Metal smelters	1.87	0.00	1.94	0.53	-	-
Sea salt	0.19	0.00	0.60	0.00	2.2.06	0.96
Two Stroke/Zn	1.75	1.11	1.94	1.07	1.43	0.87
Soil dust	1.92	0.0	2.74	0.18	4.14	0.35
Road dust	3.63	1.63	5.14	1.09	4.09	1.00
Compressed Natural Gas			-	-	2.30	0.03
Reconstructed Mass	18.7	6.61	29.1	7.38	32.6	5.67
Measured Mass	22.1	7.90	30.5	9.23	36.0	8.26

The GDP growth in Dhaka has been stagnant, but the growth of motor vehicles continued [39]. As a result the PM emissions from motor vehicles have increased, but the

BC emissions have decreased from vehicular sources. CNG activities is keeping positive role in economy of the country. Average CNG usage is 92.19 MMCM per month which is equivalent to 0.065 million liters of petrol/octane. Bangladesh imports about 1.2 million metric tons of crude oil along with 2.6 million metric tons of refined petroleum products per annum. Major consumer of liquid fuel is transport followed by agriculture, industry and commercial purpose. Since the price of CNG is much lower than other fuels, it has been widely adopted. The Government has also decided to ban motorized rickshaws in many parts of Dhaka, without improving public transport, walking, and bicycle riding facilities. As a result, the demand for private cars has increased. The population growth in Dhaka of more than 7% per year with an economic growth of about 6% and vehicular growth of more than 10% [40]. There have also been changes in the nature of the vehicles including the reduction in new two-stroke vehicles, conversion of buses to compressed natural gas, and retirement of old vehicles.

Now Bangladesh Government is trying to reduce the BC emission from Brick production sector by adopting green technology and it is in process now.

4. Conclusion

Bangladesh is a heavily populated country. The Scientists of BAEC (Bangladesh Atomic Energy Commission) first found that Pb in the air is due to uses of tetra methyl Pb in gasoline. Hence the government of Bangladesh decided to ban use of Pb in gasoline from July 1999. The natural resource in Bangladesh is very limited (only Gas). With the increase of the population growth, the cultivation land has been decreasing. Therefore, people are moving towards the industry. The most prominence industries are brick industry and Garment factory where 1/16 people (Total population) are engaged. The main fuels of brick industry are coal and wood and for Garment is diesel. Hence particulate matters (PM) including black carbon (BC) are very high in ambient air. On the other hand, as diesel emits lots of PM and BC. Hence Government of Bangladesh promoted use of compressed natural gas (CNG) in vehicles (Light and Heavy duty) and run off two stroke three wheeler vehicles from January 2003. As a result, the concentration of fine PM and BC does not increase linearly with the economic development. This is a positive achievement of policy implementations. Now the government is trying introducing nuclear power plant for power generation and more cleaner and energy efficient technology for brick production.

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