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A mathematical modeling for assessing air pollution (PM10) and public health effects- an alarming scenario over Dhaka city.

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Abstract
This study attempts to evaluate optimum cost of air pollution (PM10) (Particulate Matter with diameter less than or equal to 10 micrometer) control measures to attain an environmental standard of Dhaka city and to compare with health cost and thus to find out most economical way to achieve Bangladesh national standard of PM10 pollution. This study will also show which one is more feasible and economic between to reduce PM10 emission to national standard for avoiding respective health hazard and to invest in health care due to PM10 exposure. For this purpose at first various sources of PM10 emission of Dhaka city are identified and emission quantity for individual source is estimated. It is found that all emission sources use petrol, diesel, coal and biomass as burning fuel which can be easily replaced by CNG (Compressed Natural Gas).It is noted that natural gas (NG) has about zero PM10 emission . Besides, in Bangladesh natural gas (NG) is abundantly available. Cost of using CNG to every emission sources is estimated. A set of control measures to satisfy environmental standard with a minimum total cost is found by using Linear Programming (LP) method: the cost becomes US$ 353.53 million per year. On the other hand health cost due to PM10 exposure has been already estimated for Dhaka city. One of the latest studies (A.K. Azad, et. al. 2003) on health damage due to PM10 exposure shows the cost of US$ 1820 million per year. From these two studies it is showed that US$ 1466.47 million saving from health cost which is equivalent to 2.4 % of national GDP.

Keywords: *Particulate matter (PM10), Emission, Exposure, CNG, Linear Programming (LP)*

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I. INTRODUCTION:

Air is indispensable for the survival of all living organisms on earth, including human beings. It is even more important than water - without water a person can survive for days, but without air no more than a couple of minutes. Air pollution is one of a variety of manmade environmental disasters that are currently taking place all over the world. Air pollution may be defined as an atmospheric condition in which various substances are present at concentrations high enough above their normal ambient levels to produce a measurable effect on people, animals, vegetation, or materials. 'Substances' refers to any natural or manmade chemical elements or compounds capable of being airborne. These may exist in the atmosphere as gases, liquid drops, or solid particles. It includes any substance whether noxious or benign; however, the term 'measurable effect' generally restricts attention to those substances that cause undesirable effects. Recently, air pollution has received priority among environmental issues in Asia, as well as in other parts of the world. Exposure to air pollution is the main environmental threat to human health in many towns and cities. Particulate emission is mainly responsible for increased

death rate and respiratory problems for the urban population. This problem is acute in Dhaka being the capital of the country and also the hub of commercial activity. The other urban areas i.e. Chittagong, Khulna, Bogra and Rajshahi have much lesser health problem related to urban air pollution. The ambient atmospheric conditions have progressively deteriorated due to the unprecedented growth in numbers of motor vehicles, and continuous housing and industrial development. Bangladesh is one of the least developed agrarian nations in the world. However, since it's birth in 1971, there has been some growth in the industrial sector. Industries are mainly concentrated in major urban areas like Dhaka (the capital), the seaport cities like Chittagong and Khulna, the inland port city Narayanganj, and other divisional towns. Naturally, the air pollution problem is more acute in these areas. Apart from unplanned industrial development in these areas, the severity of the pollution is increased mainly due to exhausts from two-stroke engine and diesel-run vehicles. Dhaka city is facing serious air pollution and has become one of the most polluted cities in the world. A report by the World Bank indicates that concentration of particulate matter (PM10) is higher than the Bangladeshi ambient air quality standard and even

higher than the WHO guidelines. PM10 concentration is now about three times higher than national annual standard (2004). Recent study shows the annual average concentration of PM10 in Dhaka city is 137 µg/m3 (Murshid & Shimada et. al. 2004) . But Proposed Bangladesh average annual Standard is 50 µg/m3. So it is about 3 times higher than standard. Excess death per annum in Dhaka city due to PM10 exposure is 10,350 (A. K. Azad et. al. 2003). Both PM10 and PM2.5 levels are high, being much above the safety standards especially during the dry season. The increasing number of vehicles and their improper management, traffic congestion and operation are responsible for degradation of the air quality. The economic valuation of the air pollution revealed that between US$ 121 to 353 million per year (2003 estimate) can be saved in Dhaka as health cost if the PM10 pollution level is reduced by a modest 20% of the current level (Khaliquzzaman, 2005a). Air pollution is causing a serious threat to public health in most of the urban centers in the developing countries, according to experts. In the study, health impact of PM10 in Dhaka City for 2002 was evaluated. Risk assessment of PM10 has been performed and evaluation of economic loss due to adverse *health* effects has also been made. "Results from this analysis showed that the number of excess deaths per annum owing to PM10 pollution in Dhaka is 10,350." For PM10 pollution, this study predicts about 74,000 cases of chronic bronchitis, about 70 million cases of restricted activity days, about 14,000 cases of respiratory hospital diseases, over 286,000 emergency room visits, about 2.8 million cases of asthma attacks and over 220 million respiratory symptom days(A. K. Azad, et. al.2003).

PM10 composed of fully dispersed liquids and solids, including soot, dust and organic and inorganic substances are the most harmful. It is emitted in the atmosphere from various activity sources, such as transportation, fuel combustion, industrial process and solid waste disposal. Quoting other studies and research works, the study found a strong evidence of the relationship between PM10 and premature death as well as disease. Identifying the sources of particulate air pollution has been reported (Begum et al, 2005). Seven components have been found in the coarse PM (PM2.2-10) and six components have been found in the fine (PM2.2) particulate matter.

1.1 MAJOR SOURCES OF PM10 AIR POLLUTION

Dhaka is now one of the most polluted cities of the world. Especially the concentration of PM10 is very high in the air of Dhaka. It is about three times higher than the Bangladesh national standard and has become a great threat to public health. So, it is high time to take step to diminish the PM10 emission. Major sources of PM10 emission in Dhaka city are motor vehicle, re-suspended road dust, industries, brick kilns and construction dust. It is observed that the lion shares of PM10 emission comes from vehicular emission. It is about 45% of total PM10 emission. All the sources of PM10 use fossil and biomass fuel. Motor vehicles use diesel and petrol oil for their combustion which yields PM10. Besides, there are lots of two stroke engine motor vehicles in Dhaka city. They pollute the air more because of improper combustion. There about 4000 brick kiln around Dhaka city. These brick kilns use wood, coal and tyres as fuel. Although Industries around Dhaka are trying to use natural gas fuel, some industries are still using coal and diesel as fuel. Air of Dhaka city is very dusty because of re-suspended soil dust and construction dust. A brief conception about above five PM10 emission sources needs to deal with.

Table. 1 Total number of motor vehicles (except CNG converted two stroke 3-wheeler) plying in Dhaka city

Category of Vehicles	Number	Percentage
Two stroke engine vehicles (motor cycle)	140050	44 %
Four stroke petrol engine vehicles(Car, Jeep, Minibus, Microbus, taxi etc)	155749	48%
Four stroke Diesel engine vehicles (Bus, Truck, Tractor)	27004	8 %
Total	322,803	100%

Source: AQMP (Air Quality Monitoring Project, Dhaka- 2003)

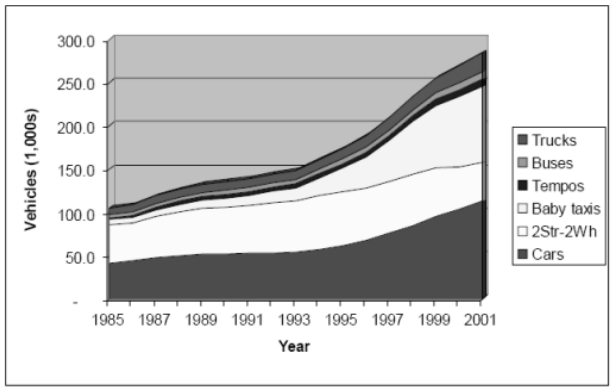

Fig. 3 Rate of increasing various motor vehicles

Fig.4 Mushroom growth brick kilns around Dhaka city emit particulate matter

II. OBJECTIVE OF THE RESEARCH:

Air pollution is causing a serious threat to public health in most of the urban centers in the developing countries. Dhaka, the capital of Bangladesh, is one of the most polluted cities in the world. Three pollutants- Particulate Matter (PM10), Sulfur dioxide (S02), and air-borne-lead pose significant air pollution problems, and have major public health impacts. Among the pollutants, PM10 whose levels are 3 times higher than Bangladesh Standard in the heavily polluted districts in Dhaka, the most harmful one. This study will attempt to reduce PM10 from Dhaka City to proposed national standard by applying various methods and technologies. As a result respective health hazard like asthma, chronic bronchitis and other respiratory disease will be prevented. The cost of applying various methods and technologies to reduce PM10 to standard value will be estimated and minimized by Linear Programming (LP) method. A cost function will be formulated subjected to constraint equations. After getting air pollution (PM10) cost solving by linear programming method it will be compared to health cost of Dhaka city due to PM10 exposure. If air pollution (PM10) cost is less than the health cost, this study will suggest the government to give more emphasis on air pollution (PM10) control than to invest in respective health care. If PM10 pollution is under control (Bangladesh standard annual standard average), respective health damage like asthma, chronic bronchitis and other respiratory diseases can be prevented. Then every year government need not to spent so large amount of money.

III. METHODS AND MATERIALS

Assumed methods and technologies for this research to reduce PM10 to Bangladesh standard level are given below:-

1. Conversion of all two stroke engine vehicles into four stroke engine and using CNG (Compressed Natural Gas) as fuel.
2. Incorporating CNG Kit to four stroke petrol engine for converting into CNG engine
3. Incorporating CNG Kit to four stroke diesel engine for converting into CNG engine
4. Using CNG in Industries and brick kilns as fuel.
5. Using street sweeping machines by CNG fuel to remove road dust.
6. Cleaning of construction dust by vacuum cleaner and cleaning of construction materials.
7. Estimating the cost for multi-year (two year) basis.

For obtaining item 1 to 7 at first emission of every source has been estimated. It is already pointed out that Dhaka city has five major emission sources. For five emission sources eight methods are set to reduce PM10 emission to standard level in two years' time period. The five emission sources and their technologies to control emission are given below:-

Table.2 Calculation of Emission per various types of vehicle is given below:-

Types of car	Number	Emission Factor (kg/vehicle.km) (a)	Traffic Volume (Vehicle.km/yr) (A)	Total PM10 Emission in ton /year(A*a)
Four stroke diesel vehicle	27004	0.0016	(27004*43,800)	1892.44
Four stroke petrol vehicle	155749	0.0001	(155749*14,600)	227.39
Two stroke engine vehicle	140050	0.0001	(140050*10,950)	153.35

Source: BRTA (Bangladesh Road Transport Authority-2003), AQMP (Air Quality Monitoring Project, Dhaka-2005)

Table 3: Cost of CNG Conversion engine and Four Stroke conversion per vehicle

Type of Conversion	Four Stroke Petrol Engine Vehicle(Unit Price in US$)	Four Stroke Diesel Engine Vehicle (Unit Price in US$)	Two Stroke Engine Vehicle(Unit Price in US$)
CNG Conversion	US$ 735	US$ 10,000	
Four stroke Conversion			US$ 322

Source: slate.newagebd.com / greencarcongress.com

Table-4: Summary of gaseous and particulate emission factor

	Particulates (g kg^{-1})	**CO (g kg^{-1})**	**HC (g kg^{-1})**	**NO_x (g kg^{-1})**	**CO_2 (g kg^{-1})**
Grass	1.5	41.7	3.2	2.2	322.4
Leaves	32.3	70.7	2.4	3.0	1064.6
Twigs	4.3	70.9	0.2	4.6	897.3
Leaves and twigs (1:1)	2.2	42.8	11.4	2.8	1403.3
Grass, leaves and twigs (1:1:1)	4.4	57.3	1.8	1.7	456.2

Source: (G. Kamalak Kannan, Minakshi Gupta et. al. 2004)

IV. DATA PREPARATION

This study has attempted to estimate optimum cost of air pollution (PM10) based on Linear Programming (LP) method and then compare the cost with health cost. For this purpose at first PM10 emission sources of Dhaka city are identified and emission data are collected from various organizations of Dhaka city and various research papers and website. A Continuous Air Quality Monitoring Station (CAMS) has been established in Dhaka city, at the campus of the Parliament House (Sangsad Bhaban), and is operational since April 2002. Six criteria pollutants namely, PM10 and PM2.5 NOx, S02, O3 and CO have been monitoring in the CAMS. Uncontrolled emissions from motor vehicles and other economic activities give rise to air and other forms of pollution. High levels of emission of air pollutants in a small area exceed the processes of dilution and dispersal, leading to severe episodes of ambient air pollution. Fairly comprehensive air quality data are being collected for Dhaka nowadays (AQMP (2002- 04) and Biswas et al (2001, 2004)). The summary of air quality data for Dhaka obtained at the Continuous Air Monitoring Station (CAMS)

Table.7 Average values for Criteria Pollutants Measured at CAMS, Dhaka during 2003 along with Bangladesh Standards (Source-AQMP (2002-04).

Pollutants	Averaging Time	Who Guidelines	Bangladesh Standards	Annual average Concentration during 2003
CO	1 hour	30 mg/m^3	40 mg/m^3 (35 ppm)	---
	8 hour	10 mg/m^3	10 mg/m^3 (9 ppm)	1.0 ± 0.8ppm
SO_2	24 hour	125 mg/m^3	365 mg/m^3 (140 ppb)	----
	Annual	50 mg/m^3	80 mg/m^3 (30 ppb)	7±8 ppb
NO_2	24 hour	---	---	---
	Annual	40 mg/m^3	100 mg/m^3 (53 ppb)	59±58 ppb
Ozone	1 hour	---	235 mg/m^3 (120 ppb)	
	8 hour	120 mg/m^3	157 mg/m^3 (80 ppb)	28±20 ppb
PM_{10}	24 hour	---	150 mg/m^3	
	Annual	---	50 mg/m^3	133 ± 78mg/m^3
$PM_{2.5}$	24 hour	---	65 mg/m^3	---
	Annual	---	15 mg/m^3	76 ± 57mg/m^3

Sources of emission , total motor vehicle data, data of emission factor, data about re-suspended soil dust , construction dust and brick kilns data are obtained from AQMP (Air Quality Management Project, Dhaka), BRTA (Bangladesh Road Transport Authority), DOE (Directorate of Environment) , SOS (Save Our Soul) and from so many other website and research papers. According to AQMP there are about 322,803 motor vehicle plying in the Dhaka city.

V. MODELING APPROACH

As it is earlier mentioned that this research will estimate air pollution (PM10) cost and minimize this cost . For minimization of cost Linear Programming (LP) is a appropriate method. For this purpose a cost function (objective function) is established subjected to constraint equations. This study already has total seven emission sources (motor vehicles splitted into three categories) and total eight options (variables) to remove PM10 to standard level. Each option has total emission in ton and total cost in US million dollars to remove that emission has been calculated separately in this study. So, as per the calculation cost of unit ton of PM10 to remove is given in (Table-8).

Table-8: Cost of removal unit ton of PM10 by using the following technology (for first year)

System/Technology used for removal PM10	Possible total Cost of the method (Million US$)	Possible maximum Amount of PM10 removed (in ton/yr)	Unit Cost (Million US$) (to remove per ton PM10) (yj)
Street Sweeping machines for cleaning road dust (x1)	99.59	920	0.1083
Watering and broom in gutter area of street (x2)	15.21	80	0.1901
CNG conversion of four stroke petrol vehicles (x4)	202.08	227	0.8902
CNG conversion of diesel vehicles (x5)	371.30	1892	0.1962
Conversion of two stroke engine into four stroke CNG engine (x6)	123.89	153	0.8097
Cleaning of construction dust by vacuum cleaner and others (x3)	175.2	400	0.438
Using CNG in brick kiln for firing (x7)	143.51	623	0.2303
Using CNG fuel in industries (x8)	206.56	735	0.281
Total	1337.34	5030	

5.1 FORMULATION OF COST FUNCTION:

Let x i (i = 1,2,3.4……) is PM10 in tons to be removed by using the Method/ technology
So, total cost T = ∑(xi* yj) Where yj (j= 1,2,3……) is cost of per ton PM10 removal
So Cost Function T = x1y1 + x2y2 +x3y3+…

Table-9 Total PM10 (in ton) removal by applying various methods/technologies (for first years)

Source of PM10	Methods/Technologies used to remove PM10

(Xij)	Street sweeping machines i =1	Watering and to broom in gutter area in street (2)	CNG conversion of four stroke petrol vehicle (3)	CNG Conversion of four stoke diesel vehicle (4)	Conversion of two stroke petrol vehicle into four stroke CNG (5)	Cleaning of Construction dust by vacuum cleaners and others(6)	Using CNG as firing in brick kilns(7)	Using CNG in industry as fuel (8)
Re-suspended soil dust (j=1)	**x11**	**x21**						
Construction dust(2)						**x62**		
Four stroke petrol vehicles(3)			**X33**					
Four stroke diesel vehicles(4)				**x44**				
Two stroke engine vehicles(5)					**X55**			
Brick kilns(6)							**X76**	
Industries (7)								**X87**

So, Cost Function for first year $T_1 = 0.1083x_1 + 0.1901x_2 + 0.438x_3 + 0.8902x_4 + 0.1962x_5 + 0.8097x_6 + 0.2303x_7 + 0.281x_8$

Subject to Constraint Equations :-

1.Re-suspended soil dust:- $x_1 + x_2 \leq 1000$

2. Construction dust : $x_3 \leq 400$

3. Two Stroke Engine:- $x_6 \leq 153$

4. Four stroke petrol Vehicles:- $x_4 \leq 227$

5. Four stroke diesel vehicles:- $x_5 \leq 1892$

6.Brick Kilns :- $x_7 \leq 623$

7.Industry :- $x_8 \leq 735$

8.Total Emission:

$x_1+x_2+x_3+x_4+x_5+x_6+x_7+x_8 \geq (5030x0.64)$

$x_1, x_2, x_3, x_4, x_5, x_6, x_7, x_8 \geq 0$

Solution found ($x_1, x_2, x_3, x_4, x_5, x_6, x_7, x_8$)

(1000, 0 ,0 , 0 , 1892, 0 , 327.2, 0,)

So, Total minimum cost for first year T_1 = US$ 554.86 million

Similarly, total cost for the 2nd year is calculated T_2 = US$ 152.2 million as all the sources are equipped with CNG in 1st year, there is no need of equipment cost from 2nd year- only running cost is needed.

VI. ESTIMATION OF HEALTH COST

Health cost on Dhaka city due to PM10 exposure is already estimated. One of the latest studies (A.K. Azad, et. al ,2003) shows that valuation of health cost is Taka 124.184 billion per year which equals to US$ 1820 million per year. This paper (A.K. Azad, et. al ,2003) estimated health cost considering all kind of exposures, risk assessment for mortality. But at the same time, the number of occurrences of respiratory and other diseases and weakness (chronic bronchitis, emergency room visits, asthma attacks, restricted activity days etc.) are estimated following Ostro (1994).

VII. RESULT AND DISCUSSION

For air pollution cost minimization a linear programming is formulated consisting of a cost function for multi-year (two years). Multi-year (two years) is considered because once all the sources are equipped with CNG

from next year there is no equipment cost. It will be needed only running cost from next year. For this purpose objective function for five PM10 emission sources and eight variables (methods / technologies) are set to solve the linear programming (LP). From linear programming (LP) method it is showed that air pollution (PM10) cost is US$ 353.53 million per year whereas health cost for Dhaka city is US$ 1820 million (A.K. Azad, et. al ,2003) per year. So, air pollution cost is about one fifth of health cost. From the model following results are also achieved:

- 64% of total PM10 is reduced in Dhaka city which leads to achieve Bangladesh national standard level (50µg/m3, annual average)

- The annual saving from reduction of PM10 to proposed national standard is US$ 1466.47 million which is equivalent to 2.4% of national GDP

- 64% of PM10 reduction (i, e reduced to the proposed Bangladesh national standard) will save 1,213 deaths annually (Murshid and Shimada et.al. 2004)

Air pollution (PM10) control measure is a preventive method. If the PM10 pollution can be prevented, respective health damages (Asthma, chronic bronchitis and other respiratory disease) would be reduced considerably. So, in the light of this study government should pick up this preventive measure rather than to invest in mitigative method like respective health care and can save US$ 1149.74 million per year. The World Health Organization (WHO) estimates that about 700,000 deaths annually could be prevented in developing countries if three major atmospheric pollutants - carbon monoxide, suspended particulate matter, and lead - were brought down to safer levels. Among the pollutants, particulate composed of fully dispersed liquids and solids including soot, dust, and organic and inorganic substances are the most harmful one. It is emitted into the atmosphere from various activity sources, such as transportation, fuel combustion, industrial process and solid waste disposal. A number of studies show a strong evidence of the relationship between particulate matter less than 10 µg (PM_{10}) and premature death as well as disease. The associated costs are also estimated to be very large. For example, in Mexico City, such economic damages due to air pollution are estimated at $1.5 billion per year. In Jakarta, 14,000 deaths, which is about 2 percent of annual deaths in the cities, could be avoided every year if particulates could be kept at the level recommended by WHO (Ostro, 1994).

VIII. RECOMMENDATION AND FUTURE SCOPE OF THE RESEARCH

Limitation, Recommendation and Future Scope:

During this research no action is taken about old engine vehicles. Old engine vehicles (older than 10 years) are more polluting than new engine vehicles. In this study it is said that all motor vehicles, brick kilns and industries will use CNG as fuel. So all the demands of natural gas may not be met up from only domestic source although it seems at present that all demand can be fulfilled according to present reserve and exploration of natural gas. But after several years government may have to import natural gas which will create pressure on economy. Besides to maintain a continuous supply of CNG to all sector it needs to establish so many CNG stations. But at present Dhaka city has a few number of CNG station. In this research it is not considered traffic congestion in mathematical model. Traffic congestion is one of the main causes of air pollution (PM10) and Dhaka is a huge traffic congestion city. The presence of very low speed non-motorized vehicles (mainly rickshaws) with a maximum speed of 10 km/hour, and their interaction with motorized traffic presents a very special traffic problem. Rickshaws cannot be removed due to socio-economic constraints. Hence, creative measures are needed to limit the impact of non-motorized traffic. Some of these have already been tried sporadically, on a limited scale, but what is needed is a long-term commitment, and substantially scaled-up operations. A suggested measure for Dhaka city is that non-motorized traffic is restricted from arterial roads, with some exceptions for the circulation of such traffic. The exceptions would consist of non-interactive special lanes and crossings, to maintain non-motorized flow between different regions. Some expected effects from this measure that will reduce pollution would be that traffic flow-speed will increase, and fuel consumption will be reduced for the same vehicle-miles traveled. Banning of old engine vehicles and excluding these vehicles from calculation-a suggestion for future modification of this research. PM 10 emission from traffic congestion should also be included in mathematical model.

IX. CONCLUSION

The ultimate success of any decision is the extent to which it translates into action. It is apparent from the discussion above that it is possible to reduce emissions from various sources mentioned above to national standard if the model of the research is followed although there are some limitations are associated. Old engine vehicles should be banned from Dhaka city and its imports are also to be prohibited. Motor vehicles, especially two-strokes engine vehicles are an increasingly important source of air pollution emissions in Dhaka. Further understanding of

the sources of air pollution, the contribution of vehicles to air pollution emissions, and the characteristics of vehicular emission control measures is necessary to design a cost effective action plan. It is recommended that government will undertake actual measurement of emission factors, complete the emission inventory, and conduct an investigation on emission control measures. A continuous monitoring scheme is essential to evaluate air quality and for the development of any with the help of development partners. However, the acuteness of the problems caused by air pollution, and awareness campaigns organized by different mass media, have made the government aware of the necessity of monitoring ambient air quality. In Dhaka city, there is only one Continuous Air Quality Monitoring Camp (AQMP) at the campus of the Parliament House (Sangsad Bhaban). More air quality monitoring stations should be established in vulnerable areas like Tejgaon, Farmgate, Gulshan , Mohakhli. DoE Should conducts vehicular emission measurement some sensitive locations like Tejgaon, Farmgate, Manik Mia Avenue, Gulshan, Lalmatia, and Agargaon. These areas represent industrial, commercial, and residential areas of the city. The automobiles on the roads are often very old, overloaded, and poorly maintained. Other old vehicles, including 40-year old trucks and dilapidated mini-buses, are also plying the city streets emitting smokes and gases. According to an assessment made by DoE, 90 per cent of the vehicles that ply Dhaka's streets daily are faulty, and emit smoke far exceeding the prescribed limit. Black smoke which is primarily unburned fine carbon particles is emitted by diesel vehicles. So, if it is possible to ban old engine vehicles, reduction of traffic congestion, good traffic management, using of CNG instead of traditional fuel , PM10 pollution for Dhaka city may be reduced to national standard level.

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