

**Spatial Distribution of PM concentrations in Dhaka
City (January 2011-June 2012)**

Clean Air and Sustainable Environment Project

(নির্মল বায়ু এবং টেকসই পরিবেশ প্রকল্প)

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1. INTRODUCTION

Atmospheric pollution due to enhanced anthropogenic activities is now a global issue. During the last decades, a great awareness has been created among the public and the Government as to the impact of chemical pollutants on the quality of human life and in general the ecosystems. As a result, rapid progress is being made in different regions of the industrialized world to develop a better understanding on the issues related to various aspects of the environment and its pollution. Urban air pollution and its causes has been one such issue of great concern.

Air pollution has become one of the serious environmental concerns in urban areas, especially in view of the adverse health effects that have been associated with ambient fine particles[1-3]. In the middle of nineties (1993-96) air quality in Dhaka started deteriorating visibly. The increasing air pollution levels including lead in ambient air in Dhaka was a major concern for both public and the Government. To combat the air pollution situation in Dhaka, several policy interventions were undertaken by the Government. Although there is a visible improvement of the situation after some actions were taken by the GOB in recent years, further actions are needed to clean breathing air for the city dwellers.

Particulate matter (PM) is the term used for a mixture of solid particles and liquid droplets suspended in the air. These particles may originate from a variety of sources, such as power plants, industrial processes, and transports, brick kilns, biomass burning, windblown dust, sea spray, and also they are formed in the atmosphere by transformation of gaseous emissions. The chemical and physical compositions of these particles depend on characteristics of the emission sources located around the area, time of year, and prevailing weather conditions. Size distribution of the particles follows a bimodal distribution with a valley around 2.5 μm . The mass of the particles is proportional to the area under the distribution within each size range.

Prior to 1999, little effort was made to control vehicular and industrial emissions in Bangladesh. In an effort to improve air quality within the Dhaka city and to comply with the USEPA as well as the proposed Bangladesh national air quality standard, a number of control strategies have been developed and steadily implemented. To date, the old two-stroke engine, the three-wheelers, have been completely replaced by compressed natural gas (CNG) powered four-stroke three-wheelers in Dhaka city. New cars are equipped with air pollution control devices and CNG powered cars have been recently introduced. Industrial sources are being classified and slowly regulated. As a result of these implemented control strategies, the air quality of Dhaka city has slowly, but steadily improved[4].

The characterization of these fine particles is very important for the regulators, and researchers due to their potential impact on human health, their ability to travel thousands of kilometers across countries, and their influence on climate forcing and global warming[5]. In order to have an efficient Air Quality Management (AQM) system and also for regulatory purposes it is important to have reliable air quality data and its temporal and spatial distribution.

Air quality monitoring data is a key component to understand and reduce 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 in the air, where the air is most polluted, and some information about the types of air pollution.

In Bangladesh, the Department of Environment (DoE) is mandated by the Government for managing environmental issues including air pollution and its impact on human health, vegetation and structures, etc. Before 2002 the DoE used to measure total suspended particles (TSP) in a limited scale in different cities as part of their regulatory activity. With the inception of Air Quality Management Project (AQMP) in 2002 the DoE started measuring PM₁₀ and PM_{2.5} fraction of the PM and other criteria pollutants for regulatory purposes as mentioned in the New National Ambient Air Quality Standards[6].

The AQMP helped create an air quality network of five Continuous Air Monitoring Stations (CAMS) - two in Dhaka and one each in Chittagong, Rajshahi and Khulna. In addition, AQMP equipped with DoE with satellite Air Monitoring Stations (SAMS), laboratory equipment to weigh and process air samples. The capacity developed under AQMP has been utilized to collect air quality data.

2. FACTORS INFLUENCING GROWTH IN AIR POLLUTANTS IN DHAKA

In many developing countries like Bangladesh, a great proportion of urban air pollution has been due to uncontrolled emissions from motor vehicles. With very high population densities, increasing anthropogenic activities in the city centers also give rise to severe atmospheric and other forms of pollution. In the Dhaka city, the blackening of the ambient air and reduced visibility are observed in some areas, especially during dry seasons, even with unaided eyes. Episodes of choking smells and irritating eyes are quite common.

The main influencing factors for the emissions of pollutants and deterioration of air quality in Dhaka are:

- rapid urbanisation resulting in increased construction activities, requiring large volumes of brick production in hundreds of brick kilns in the neighborhood of the city, with limited or no emissions control measures, expansion of slum areas where biomass is often used for cooking, etc.
- increasing transportation demand, resulting in a growth in vehicle emissions and resuspended road dust,
- industrialisation often unplanned
- possible regional and transboundary movement of air pollution.

Major sources of air pollution in the Dhaka city are believed to be vehicular emissions and resuspended soil/road dust. Other sources of air pollution are the numerous brick-making kilns, mainly used in the dry season all over Bangladesh, biomass burning and emissions from industries, domestic

cooking, etc. Almost all of these kilns use coal and wood as their source of energy. This biomass/garbage burning process results in the emission of particulate matter (PM), oxides of sulfur (SO_x), and volatile organic compounds (VOCs). The emissions from this source sometimes exceed natural rate of purification of the local atmosphere, and thereby gives rise to severe episodes of local air pollution. Decomposition of solid wastes disposed on soil surface and accumulated over low-lying areas in and around the Dhaka city makes ambient air un-breathable.

It has been realized in recent years that air pollution in the Dhaka city is greatly associated with uncontrolled emission from motor vehicles and increasing anthropogenic activities related to increasing economic development activities, concentrated mainly in urban cities. Ambient air quality in urban centres is dependent on many factors like airflow pattern, traffic volume and congestion (Figure 1), emissions from motor vehicles and re-suspended dust particles, indiscriminate disposal of wastes, etc.

The automobiles on the roads are often very old, overloaded, and poorly maintained. Even 40-year old trucks and dilapidated mini-buses are also plying on the city streets emitting smokes and gases. According to an assessment made by DoE, a large cross-section of the vehicles that ply daily on the streets of Dhaka is faulty, and emits smoke far exceeding the prescribed limit. Diesel vehicles emit black smoke that is primarily unburned fine carbon particles.



Figure 1: Traffic congestion in the Dhaka city (September 2005)

Although the total number of vehicles in the city of Dhaka is not large, compared to its population, visual observation on the main arterial roadways indicates high levels of ambient pollutants due to the density of traffic, poor traffic flow and poor maintenance of the vehicles.

Aircrafts, railway engines, power plants, open-burning incineration, solid waste disposal sites, and dust particles from different sources also contribute to air pollution. Dust pollution due to road diggings, constructions and other development activities further aggravate the air pollution situation in cities. The construction of multi-storied buildings in the Dhaka city is increasing rapidly to accommodate the growing population, along with these construction activities; the number of slums is also increasing.

In the absence of adequate municipality services for clean environment, the tremendous pressure of population has made it almost impossible to maintain a clean environment in the capital city of Dhaka.

3. OBJECTIVES

As air quality monitoring is the baseline information of any air quality management program, hence one of the major objectives of the CASE project is to provide data on air quality to policy makers, stakeholders and the general public. Periodic reporting of air quality data requires evaluating, interpreting and making access for other stakeholders. Air quality reports provide important summary information to staff working to improve air quality, other stakeholders and the public on the state of air quality in Bangladesh. This process promotes better understanding of the data, may identify data quality issues and ensures that the data is used.

It is well recognized that air pollution due to fine particles are of serious concern due to its known adverse health impact. Periodic monitoring of particulate matter (PM10 and PM2.5) concentrations is carrying out at three different locations of Dhaka City through Satellite Air Monitoring Station (SAMS).

It is essential that these data are analyzed, reduced and reported in an appropriate format to be readily understood and meaningful to end users. This report describes the details of the PM concentration data. The main purpose of this report is to present, analyze and make available of these data to the general public, stakeholders, researchers and policy makers to develop effective air pollution abatement strategies.

4. SATELLITE MONITORING NETWORK

Given that fine particulate matter (PM) is important pollutant of concern, it is necessary to understand the spatial distribution of PM. The DOE was equipped with several portable Air Monitoring instruments, which enabled CASE to establish several PM based satellite air monitoring station (SAMS) at different locations of Dhaka city. Currently, samples are collected at three SAMS sites namely, Department of Environment (DoE) campus, Agargaon, Atomic Energy Centre, Dhaka (AECD) campus, Ramna and BITAC campus, Tejgaon.

4.1 Site Characteristics

Department of Environment (DoE) Campus

The DoE site also a semi-residential site located at Agargaon, northern part of Dhaka. The sampling location is within 20 m from a local road and about 100m from a secondary road with moderate traffic density. Agargaon is currently developing as administrative area of Dhaka and significant number Government Offices established and many other are in construction phase. Population density in this area is relatively lower than other parts of Dhaka. The Sampling location is on the roof of the DOE Building and the roof height is about 5m and the sampling intake is about 1.5 m above the roof surface. There is no significant local source except construction activities around the sites.

Atomic Energy Centre, Dhaka (AECD) campus

The Atomic Energy Centre, Dhaka (AECD) of BAEC is located at a semi-residential area in the southern part of Dhaka City. Since the site is in the Dhaka University Campus, the population density is moderate. In the semi-

residential area site, the sampler was placed on the flat roof of the Atomic Energy Centre, Dhaka (AECD) campus building. The roof height was 5 m and the intake nozzle of the sampler was located 1.8 m above the roof. The intake was about 80 m away from the roadside with moderate traffic. There is not significant local source around the site. The sampler was placed so that the airflow around it was unobstructed.

BITAC campus, Tejgaon

This site is located in an industrial area (BITAC) and a heavily trafficked road is 100 meter, away from the sampling location. Population density is lower compared to the other sampling sites. Both industrial and motor vehicle sources make an important contribution to long-term and peak concentrations. One of the busiest bus terminals is located within 1 kilometer of the sampling site. A big metal workshop is also located within the immediate vicinity of the sampling site. The sampling probe is 7 meter above from the ground.

The satellite sampling locations are shown in Figure 2.

4.2 Meteorological conditions

In Bangladesh, the climate is characterized by high temperatures, high humidity most of the year, and 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)[7]. Winter season is characterized by dry soil conditions, low relative humidity, scanty rainfall, and low northwesterly prevailing winds. The rainfall and wind speed become moderately strong and relative humidity increases in the pre-monsoon season when prevailing southwesterly (marine). During 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, so as the wind speed. The direction starts shifting back northeasterly.

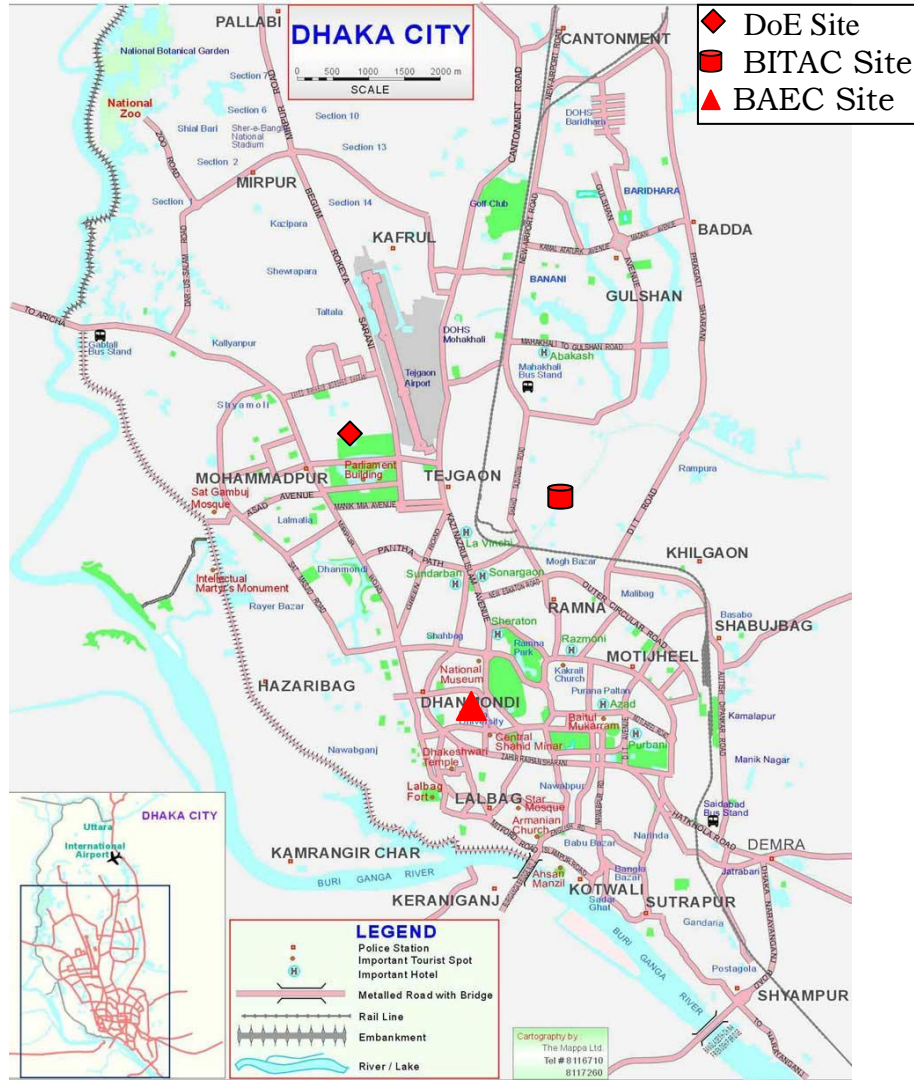


Figure 2: Map of Dhaka City Showing air Quality monitoring stations, industrial area and major network

Figure 3 shows the typical wind direction pattern calculated from wind direction data obtained from the Bangladesh Meteorological Department (BMD), Dhaka, in different seasons in Bangladesh.

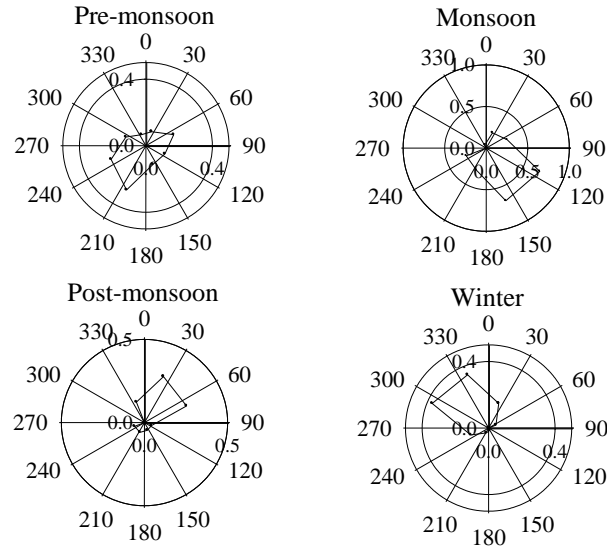


Figure 3: Seasonal wind direction at Dhaka based on wind speed data

5. METODOLOGY

5.1 Description of the sampler

The PM sampling were done by Airmatrics MiniVol sampler. The Airmatrics MiniVol sampler was developed jointly by the U.S. Environmental Protection Agency (EPA) and the Lane Regional Air Pollution Authority. The sampling technique is a modification of the PM₁₀ reference method described in the U.S. Code of Federal Regulations [8] and can be used for PM and gas sampling. The diagram of the sampling head for the unit is shown in Figure 4.

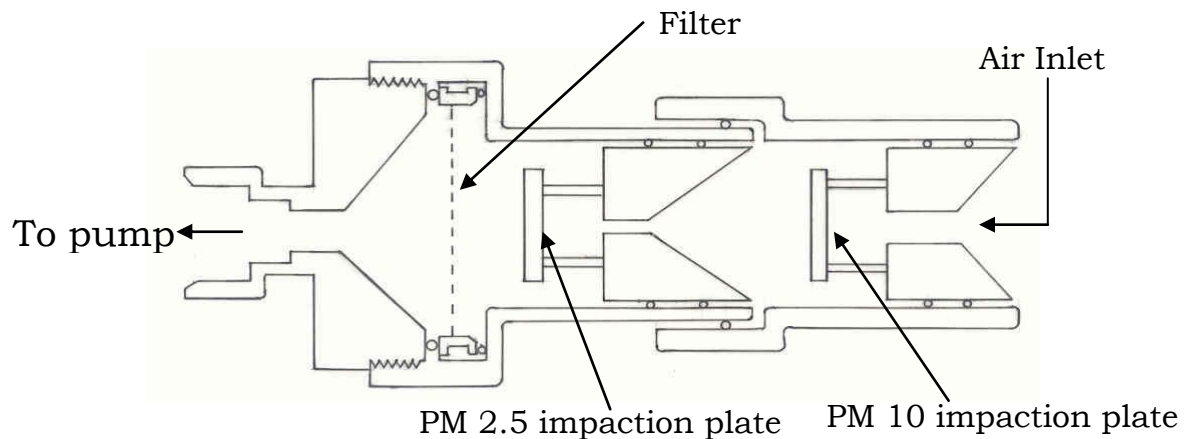


Figure 4: Schematic of the sampling head of Airmatrics PM Sampler

The MiniVol Airmetrics sampler is basically a pump controlled by a programmable timer, which can be set to make up to six runs within 24 hours or throughout a week. The sampler is equipped to operate from either AC or DC power sources. In the particulate matter (PM) sampling mode, air is drawn through a particle size separator and then through a filter medium. Particle size separation is achieved by impaction. The collection of correct particle size depends on volumetric flow rate. In case of MiniVol, the actual flow rate should be 5 lpm at ambient conditions. To assure a constant 5 lpm flow rate through the size separator at different air temperatures and atmospheric pressures, the sampler were adjusted for each sampling site.

The sampling technique used by the MiniVol is modification of the PM10 reference method described in the U.S. Code of Federal Regulations (40 CFR part 50, Appendix J). Under these criteria, a PM10 sampler must have: 1) a sample air inlet system to provide particle size discrimination, 2) a flow control device capable of maintaining a flow rate within specified limits, 3) means to measure the flow rate during the sampling period, and 4) a timing control device capable of starting and stopping the sampler.

The AIRmetrics MiniVol Portable Air Sampler meets all of these specifications and is equipped with:

- a) An inlet impactor capable of separating particulate matter to $\leq 10 \mu\text{m}$,
- b) A flow control device which maintains a specified flow rate,
- c) A flowmeter to measure the flow rate during the sampling period,
- d) An elapsed time meter, and
- e) A programmable timer that starts and stops the sampler unattended.

The MiniVol's flow rate is generally less than the flow rates used by reference method devices. The lower rate results in a greater deviation in accuracy at low concentrations of particulate matter where precision can be lost through the handling and weighing of a minute particulate sample. However, at high particulate concentrations the sampler produces results that are precise and comparable to reference method samplers.

While the MiniVol's sampling method is not a reference or equivalent method, it has proven to be an excellent indicator of absolute ambient PM10 and PM2.5 concentrations[9]. Although the method used by portable PM10 and PM2.5 sampling does not wholly conform or comply with the reference method, the data collected by the sampler still serve as a useful supplement to data generated by PM10 and PM2.5 reference methods.

5.2 Particulate Matter Sampling Mode

In the particulate matter (PM) sampling mode, air is drawn through a particle size separator and then through a filter medium. Particle size separation is achieved by impaction. Critical to the collection of the correct particle size is the correct flow rate through the impactor. For the MiniVol, the actual volumetric flow rate must be 5 liters per minute (5 lpm) at ambient conditions. To assure a constant 5 lpm flow rate through the size separator at differing air temperatures and atmospheric pressures, the sampler must be adjusted for each sampling project.

Impactors are available with a 10-micron cut-point (PM10) and a 2.5-micron cut-point (PM25). Operating the sampler without an impactor allows for collection of total suspended particulate matter (TSP). PM10 Preseparator and filter holder assembly is shown in

Figure 5.

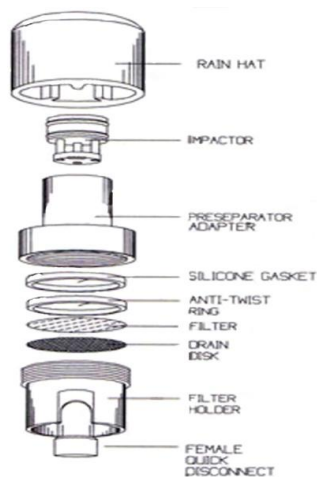


Figure 5: PM Pre-separator and Filter Holder Assembly

The inlet tube downstream from the filter takes the air to the twin cylinder diaphragm pump. From the pump, air is forced through a standard flowmeter where it is exhausted to the atmosphere inside the sampler body.

The programmable timer will automatically turn the pump off at the end of a sampling period.

5.3 Sampling

The MiniVol was positioned with the intake upward and located in an unobstructed area. PM₁₀ and PM_{2.5} were collected simultaneously for 24 hrs at every sampling site with two MiniVol samplers and the inlets of the samplers were kept 1 m apart from each other. The pre-weighted conditioned clean filters were loaded to respective filter holder assembly at the central conditioning room at DoE and were carried to sampling sites in separate clean polyethylene bag. After sampling, filter holder assemblies (keeping the exposed filters inside) were brought to the conditioning room of the DoE directly from the sampling site for conditioning and PM filter retrieval. Care was taken in transporting the exposed filter holder assemblies, so that there should be no PM loss.

5.4 PM mass determination

PM masses were measured in the central weighing laboratory of the Department of Environment developed under the CASE project. The PM samples having both PM₁₀ as well as PM_{2.5} were determined by weighing [10] the filters before and after exposure using a micro balance (SATORIOUS Model MT5) maintaining room temperature approximately at 22°C and relative humidity at 50%. The air filters were equilibrated at constant humidity and temperature of the balance room before every pre and post weighing. The difference in weights for each filter was calculated and the mass of each PM_{2.5} or PM₁₀ sample can then be determined. Details of the sample handling protocol is given in Annexure – I.

6. RESULTS

PM samples in two size fractions (namely, PM₁₀ and PM_{2.5}) were collected from February 2011 to June 2012 at three satellite PM sampling sites. One or two samples collected in each week. The samples were collected in weekdays only. A total of 60 - 70 sample pairs were collected in each sites. The PM concentration data obtained from the sampling campaign were analyzed and presented in the following sections.

6.1 Particulate Matter Trends in Dhaka City

PM concentrations measured in three sites are summarized in **Error! Not a valid bookmark self-reference.**. The table presents monthly average, maximum and minimum PM concentrations in those sites. It was observed that both PM₁₀ and PM_{2.5} monthly average concentrations at three sites monitored are lower in monsoon season compare to dry winter months. In general it is seen that PM concentration levels in both the size fractions are highest in BITAC site, whereas lowest in BAEC site. The observed higher PM concentrations at BITAC may be attributed to the emissions from small industries around the site and vehicular emissions from the adjacent road in the proximity of the sampling site. While BAEC site is located in a semi-residential area and the emissions in this area expected to be low.

The daily PM₁₀ and PM_{2.5} concentrations as measured at three sites in Dhaka are plotted and are given in Figure 6. It may be seen from the figure that during wet season (May – September) the both PM₁₀ and PM_{2.5} concentrations levels at all three generally meet the 24 hour average Bangladesh National Ambient Air Quality Standard (BNAAQs) for PM, which is set at 150 µg/m³ for PM₁₀ and 65 µg/m³ for PM 2.5. PM levels during rest of the period in the year usually exceed the BNAAQs, which is of serious concern from health hazard point of view.

It is observed from Figure 6 that both PM₁₀ and PM_{2.5} showed similar seasonal pattern as observed in previous studies. During monsoon the PM

levels were found lowest at all three sites. Observed lower PM concentrations are due to washout of particles by rainfall. During dry season (November – March) the PM levels reach highest levels, because there is hardly any rainfall during this time period. Moreover, brick kilns at northern side of Dhaka city, a significantly large source of air pollution, in Dhaka city also would have influence on the pollution levels.

It was also observed several spikes of PM levels, especially for PM10 at BITAC site PM2.5 at BAEC site. There were some construction activities going on nearby the BITAC sampling site and coarse particles (diameter between 10 and 2.5 μm) generated could have influence on the increased levels of PM10. Higher levels of PM2.5 on 03 March and 16 April 2012 at the BAEC site could be linked with episode of open burning of garbage around the sampling location.

Table 1: PM concentration levels ($\mu\text{g}/\text{m}^3$) in three satellite air monitoring stations (SAMS)

Month	BAEC						DoE						BITAC					
	PM10			PM2.5			PM10			PM2.5			PM10			PM2.5		
	AVG	MAX	MIN	AVG	MAX	MIN	AVG	MAX	MIN	AVG	MAX	MIN	AVG	MAX	MIN	AVG	MAX	MIN
Feb-11	264	331	215	155	213	110	-	-	-	-	-	-	301	330	260	148	177	99.7
Mar-11	228	293	146	117	164	83.2	237	346	96.3	119	199	32.5	301	411	206	133	191	64.2
Apr-11	178	261	110	116	176	51.7	190	266	86.4	132	200	27.6	312	403	120	161	226	45.9
May-11	99.2	128	72.3	56.5	95.1	38.8	138	170	107	94.1	128	70.8	236	312	120	113	261	31.2
Jun-11	23.9	39.5	13.4	19.2	31.9	6.9	123	171	67.2	45.9	72.6	16.5	97.8	143	52.1	42.4	47.3	37.4
Jul-11	57.7	60.4	22.1	16.5	16.5	16.5	83.1	155	22.1	36.0	72.6	11.3	92.7	150	55.1	20.5	27.0	13.9
Aug-11	37.8	60.4	24.9	15.6	24.0	9.6	42.4	43.3	41.2	21.9	24.7	16.5	45.3	82.8	17.9	27.2	47.5	13.2
Sep-11	84.4	125	44.0	61.3	90.9	31.6	130	158	75.9	80.8	143	18.1	81.9	118	36.9	41.3	64.1	17.0
Oct-11	272	355	155	77.0	79.8	74.2	165	201	130	98.8	128	54.7	167	201	125	111	160	57.7
Nov-11	210	218	210	92.5	116	69.6	234	325	176	123	172	83.0	175	202	150	97.0	122	66.7
Dec-11	264	309	195	195	206	185	264	309	195	195	169	152	189	203	172	117	147	68.4
Jan-12	299	528	153	186	305	140	299	528	1523	186	248	109	283	440	181	132	203	84.5
Feb-12	347	410	227	204	214	190	347	467	252	191	275	68.5	371	467	266	266	371	163
Mar-12	354	418	256	189	301	70.3	341	460	89.9	111	138	87.0	431	460	393	144	185	109
Apr-12	309	320	298	162	309	61.2	99.2	227	45.1	29.6	53.9	13.1	200	384	82.9	84.3	151	50.0
May-12	188	263	158	90.2	122	65.3	110	185	63.8	64.5	123	24.8	132	162	76.8	60.5	116	11.1
Jun-12	159	159	159	92.3	92.3	92.3	60.4	60.4	60.4	38.5	38.5	38.5	88.7	171	14.3	35.0	73.3	6.9

BAEC: Bangladesh Atomic Energy Commission
 DoE: Department of Environment
 BITAC: Bangladesh Industrial Technical Assistance Centre
 AVG: Average value
 MAX: Maximum value
 MIN: Minimum value

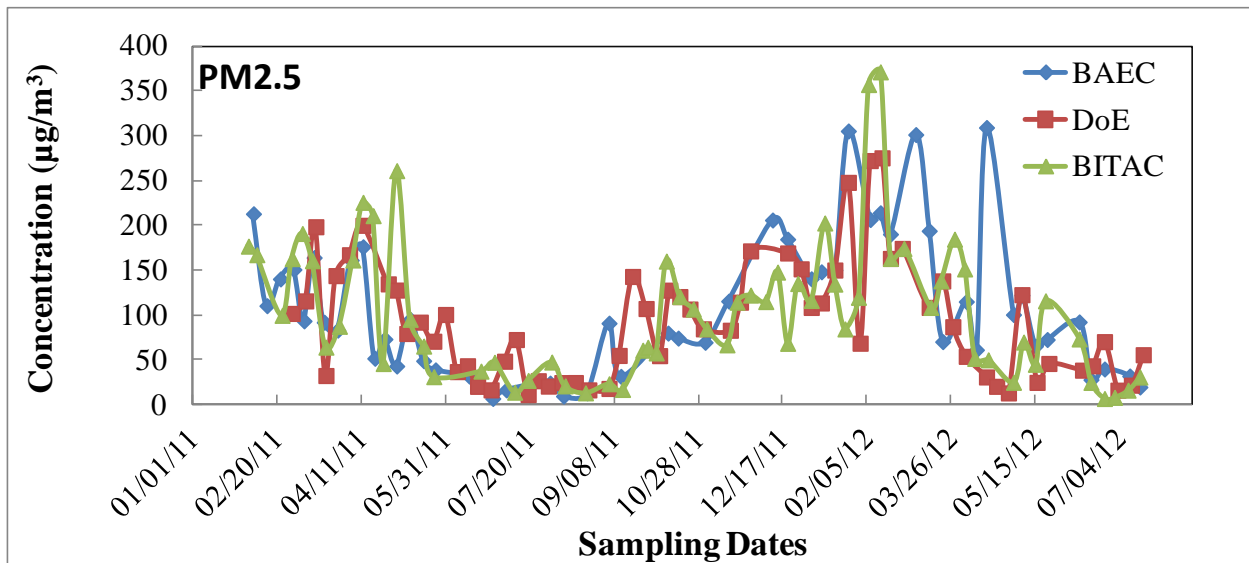
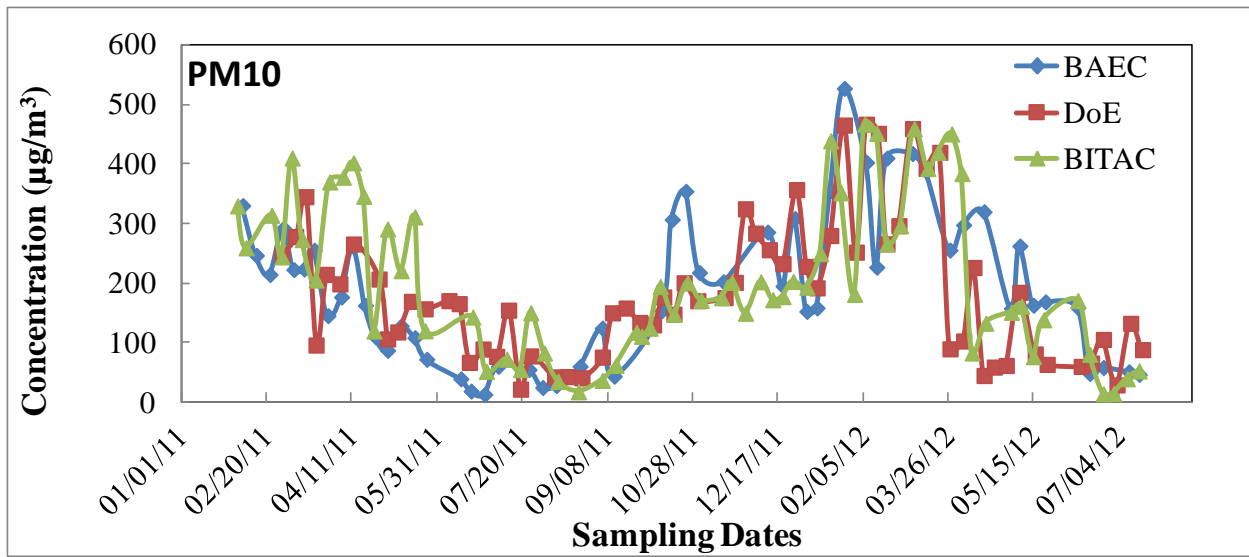


Figure 6: Time series plot of PM10 and PM2.5 concentration at three sites

6.2 Spatial Distribution of PM Levels in Dhaka City

Fine particulate matter is recognized as most important criteria pollutant in cities because of its potential impact on human health. In view of this, it is important know spatial distribution PM concentration level over the Dhaka city to assess the exposure levels to population living around the city. Since the topography of Dhaka city is almost flat, it is expected that PM concentration levels over the city would not vary significantly. But PM concentration levels may have some influence based on the heterogeneous distribution of different local sources. Monthly average PM levels measured at three sites are plotted for comparison and given in Figure 7. Data at all three sites showed the expected seasonal variation.

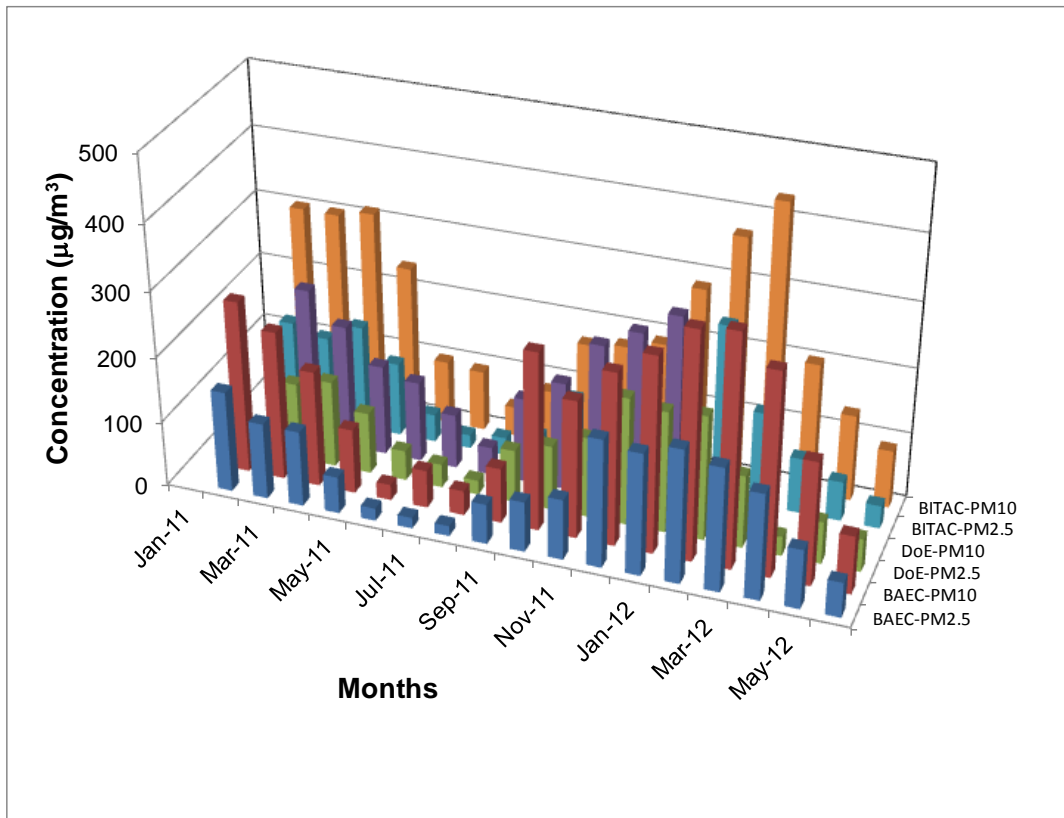


Figure 7: Spatial distribution of PM10 and PM 2.5 in Dhaka city

In general it is observed that monthly average PM concentration levels in both size fractions are higher in BITAC site with few exceptions. It was observed that during March-June 2012 the PM_{2.5} levels are high at BAEC site. The BITAC site is located in the industrial area of Dhaka city and also a major road with heavy traffic situated nearby. Therefore the emission from industries and automobiles possibly explain the higher observed PM levels. Moreover, construction work was underway nearby by the sampling site, which also could influence the PM levels, especially during month of February-April 2011.

Among the three sites PM levels in both size fractions found to be lower than other two sites. DoE site located in Agargaon, is currently developing as an administrative centre and basically Government offices are situated around this area. A large residential area, where lives mainly middle income group population, starts about 50m north of the site. Only a secondary road with moderate traffic runs about 100m south of the sampling location. There is no other significant local source that can influence the PM levels at this site. Therefore, absence of local source of pollution could be a reason for relatively observed lower PM concentration levels at this site.

6.3 PM₁₀/PM_{2.5} Mass ratio

The ratio of PM₁₀/PM_{2.5} has been calculated for all three sites and plotted against sampling dates (Figure 8). It is observed from Figure 8 that PM₁₀/PM_{2.5} ratios for all three sites randomly varied and no significant seasonal variation was seen. Mean value along with maxima and minima for the ratios were also calculated and summarized in Table 2. The mean PM₁₀/PM_{2.5} ratios were around 2.0, which suggest that on an average 50% of the PM₁₀ is PM_{2.5}. The lowest ratios were found around 1.0 and in those cases most of the PM₁₀ are PM_{2.5}. These could be due washout of coarse particles (PM₁₀-PM_{2.5}) by rain. The highest ratios were found be between 4.58 and 6.11. The PM₁₀/PM_{2.5} ratios could be related to prevailing dry days when resuspended coarse particles were dominated in the total PM mass.

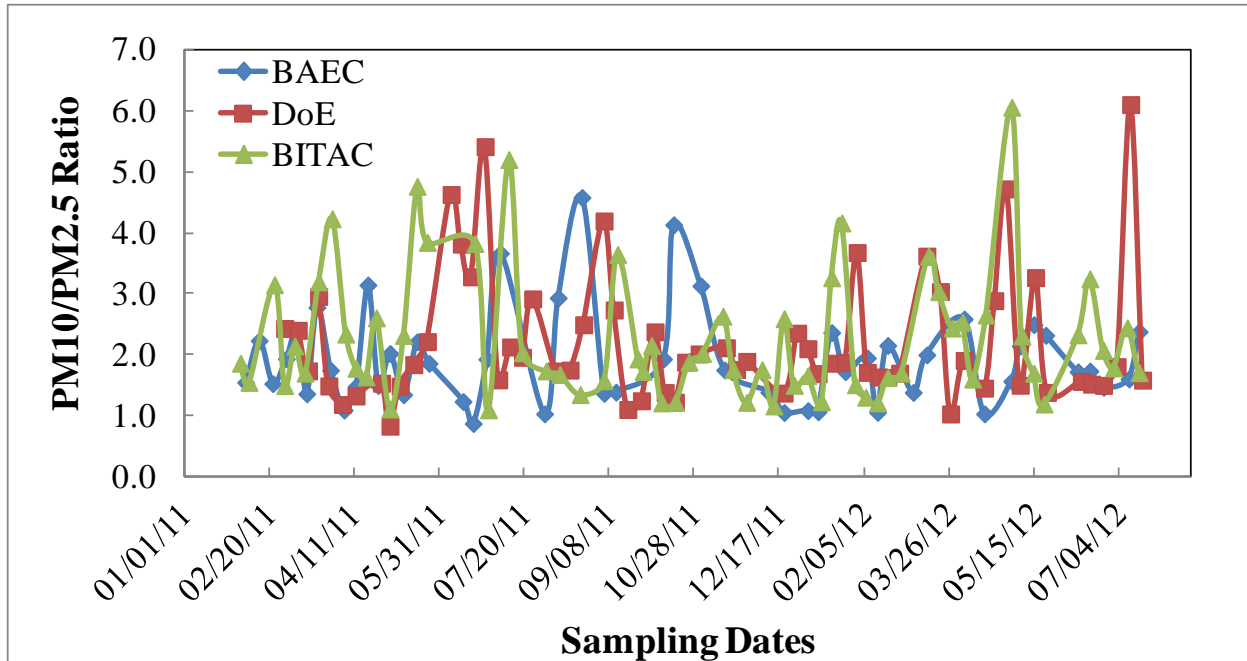


Figure 8: Calculated PM10/PM2.5 ratios at three sampling sites

Table 2: Summary of PM10/PM2.5 ratios for three sampling sites

SITE Location	PM10/PM2.5		
	Average	Maximum	Minimum
BAEC	1.95	4.58	1.04
DoE	2.25	6.11	1.03
BITAC	2.30	6.06	1.10

Figure 9 shows the frequency distribution of the daily PM10/PM2.5 mass ratios at three sampling sites during the sampling period. The maxima were found to be around 2.0 for all sampling sites. The findings are comparable with previous study in Dhaka city [11]. This indicates that for the majority of days about 50% of the PM mass concentrations are fine particles with aerodynamic diameter less than 2.5 μm , which are mainly of anthropogenic and urban activities. In Dhaka, there are significant emissions from automobiles and other anthropogenic activities related to the extremely high population density. Biomass/coal burning for cooking and in the brick kilns around the city contribute significantly to these emissions [7].

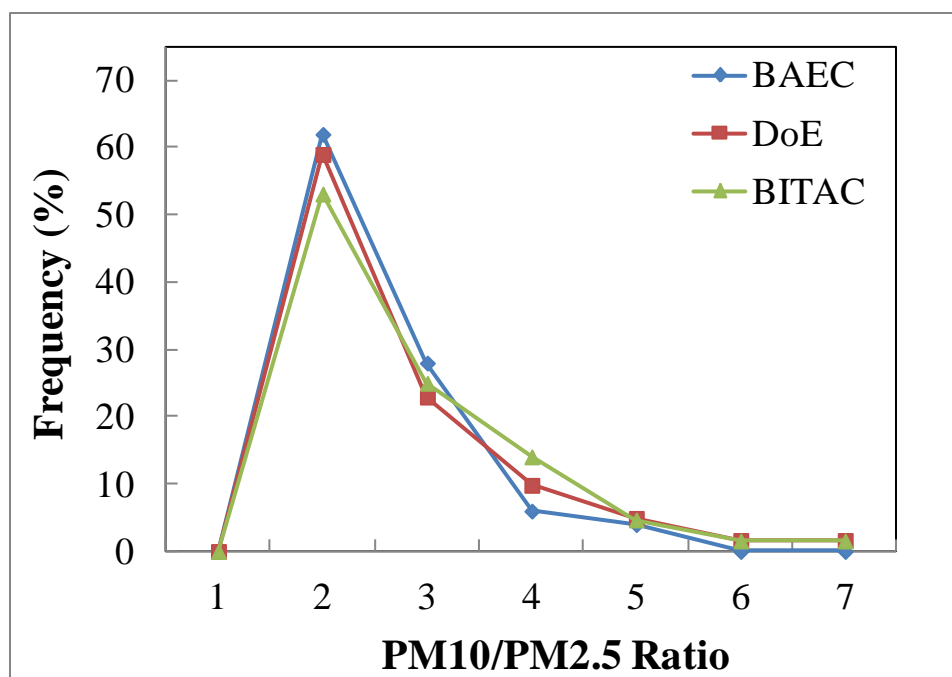


Figure 9: Frequency distribution of PM10/PM2.5 ratio at three sampling sites

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8. ANNEXURE – I

Low Volume Suspended Particulate Matter Sampling Protocol

A. Equipment and Supplies

1. Airmatrix Sampler – MiniVol
2. Microbalance – Sartorius ME5-F
3. Filters--Teflon.
4. Filter Holders--Nuclepore Corp. Aerosol Holder, 47 mm
5. Multiple holder adapters, 47 mm Nuclepore
6. O-Rings, Nuclepore
7. Quick disconnect air hose fittings-- male, attached to the filter holders
8. Plastic caps for protecting filters-60 mm ID
9. Drain discs--Nuclepore 47 mm
10. Plastic Sandwich Bags to protect loaded filters.
11. Petrislides--Millipore Corporation, 47mm

B. Filter Handling and Weighing

1. Set up and calibrate balance as described in the manual
2. Carefully weigh the first three filters (control filters: C_{123}) of each new lot as controls, then set aside in slotted petri-dishes. These filters are to be weighed at the beginning (control filter masses: $C_{1ca,2ca,3ca}$) and end (control filter masses: $C_{1cb,2cb,3cb}$) of each weighing session for any filters from the same lot. The average difference between their original weights and current weights is used to adjust the tare for the group weighed at the time.

Changes in the weight of the control filters over time are most readily explained by assuming that water adsorbs on the surface of the filter substrate. The fact that the changes in filter masses follow the changes in relative humidity is most evident. Because the sample filters (both clean and exposed) are “conditioned” in the same room as the control filters, we assume that the relative humidity affects the sample filters to the same extent as the control filters.

12. Note: the Sartorius ME5-F Microbalance mass units are in milligrams. All filter masses are, therefore, recorded in milligrams.
3. Handle filter (sample filters: **F**) with stainless forceps and spatula. Pass filter through field of static eliminators for a few seconds, then center on balance pan. Close door.
4. Read and record the clean sample filter weight (clean masses: F_c) only when

microbalance readout remains steady for a minimum of 20 seconds. If filters have been equilibrating amid the room relative humidity amid temperature have been fairly constant for a few hours, this should not require over a minute or two. If the readout continues to drift for excessive time, it may be necessary to put off weighing until equilibration of the filters is complete or the room conditions stabilize.

5. After recording the weight, load the filter in a holder above a drain disc, fasten a numbered label to the holder, then cover with a sandwich bag topped by a plastic cap. Loaded holders are stored upright in racks to prevent contamination.
6. Generally, filters are sent to the field loaded into a tackle box fitted with quick disconnect fittings. Field sampling reports or data sheets are sent with each filter or set of filters.
7. Filter heads or Petrislides received from the field are first checked against the accompanying field sampling report for correct numbers, site amid flow information, then the plastic bags are removed and holders are placed upright on racks for equilibration. The receiving date is logged on the field report.
8. After a minimum of 24 hours equilibration, weigh each exposed sample filter (exposed masses: F_e) as in 1, 2, and 3 above, making certain the three control filters for each pertinent lot are reweighed (control filter masses before weighing exposed sample filters: $C_{1ea,2ea,3ea}$, and after sampler filter weighing: $C_{1eb,2eb,3eb}$) at the same time.
9. Store weighed samples in 47 mm Petrislides with ID number attached.

C. Calculations and Reporting

1. The gross mass of particulate matter on the sample filter (W_g) is found by subtracting the exposed filter mass from the clean filter mass:

$$W_g = F_e - F_c$$

The change in the weighs of the control filters between the clean and exposed sample filter weighing (ΔC) is calculated:

$$\Delta C = \frac{\sum_{i=1}^n [(C_{ica} + C_{icb}) - (C_{iea} + C_{ieb})]}{2 \times n}$$

where n is the number of control filters used. While it is recommended that three control filters be used, on occasion a control filter will become unusable (soiled, torn, or otherwise damaged). In these instances the number of available control filters will be less than three.

The net mass of particulate matter on the filter (W_n) is obtained by correcting the gross mass for the mass change of the control filters:

$$W_n = W_g + \Delta C$$

These calculations and W_n , the filter sample or loaded weight, are recorded in the appropriate filter weighing log book.

2. The field sampling report is used to calculate the air volume and sample time using the lab portion below the dashed line. Start and stop air flows are read from the latest calibration plot for the orifice used for the vacuum reading. Average flow in liters per minute is the mean of the start amid stop flow conversions.

The sample time (t) is ordinarily the difference between the start and stop readings from a time totalizer. It is convenient to record time in minutes, the unit used for flow, to simplify the calculations.

Sample air volume (V), in cubic meters, is then the average flow (Q), in liters per minute, times the sample time, in minutes, times 0.001, the conversion from liters to cubic meters.

$$V_{m^3} = 0.001 \frac{m^3}{l} \times Q_{l/min} \times t_{min}$$

3. The information from the field sampling report and weights from the filter weighing book are entered in the sample log book. Data run assumes midnight-to-midnight samples; if otherwise, the times and dates must be clearly indicated. Date received is when logged into the lab. The station is indicated by AIRS/SAROAD number. Sampler and filter numbers are copied from the field report. Type refers to filter medium, in this case Whatman QM-A Quartz Microfibre. Configuration indicates the kind of sample, in this case TSP or PM₁₀. Orifice number, average flow, and air volume (V) are entered from the field report. Finally, the particulate matter concentration (PM) in micrograms per cubic meter is found by the formula:

$$PM_{\mu g / m^3} = 1000 \frac{\mu g}{mg} \times \frac{W_{n(mg)}}{V_{m^3}}$$

where the “1000” is the conversion factor from milligrams to micrograms.

4. Final concentration data is reported to AQC in the AIRS/SAROAD format for entry in the appropriate database.
5. A sample day station summary is compiled for all sites listing filter numbers amid air volume. The information is needed to cross reference samples by date amid station. The sheet is also used to record voids, sample losses amid other problems. Once this sheet is completed, the field sampling report may be filed.
6. The computer program used to calculate particulate matter concentration from portable saturation samplers has expanded data flagging and calculation features which allow for equipment limitations and data quality assumptions appropriate for survey sampling.
 - a. Concentration calculations can be performed, amid flagged with a codes denoting data limitations or assumptions included in the calculations. A listing of commonly used codes is presented below.

M: Missing field data

B: Battery failure

F: Flow differential

T: Tinier malfunction

S: Sampler malfunction

D: Damaged filter

- b. The sampler flowrate differential flag (F:) is computer-generated, and is attached to the calculated concentration if the pre- and/or post-flows are outside $\pm 15\%$ of the samplers "ideal flow set point". In this case the pre-flow is used to calculate the particulate matter concentration.
- c. Sometimes, a final flow is not available due to battery failure of the portable sampler. In this case, a "B:" code is assigned to the data, and a post flow equal to the pre-flow is used to calculate the concentration. This provides some assurance that the actual flowrate will be overestimated, and the resultant concentration biased lower.
- d. The other codes are assigned based on comments made on field data sheets, or observations of the filters during post weighing procedures. Flagged data and comments are included in the printed calculations, and printed in tabular form appended to the project data summary.

D. Quality Control and Assurance

1. At least a 7% level of blanks shall be set aside during preparation of filters for sampling. The blank is weighed, assigned a number in sequence with the other filters being tared, then placed in a labeled petri dish. The code letter B is prefixed to the filter number in the weighing book and on the petri dish label. The blanks serve several functions:
 - a. As a quality control on the gravimetric procedure, each blank is reweighed at least one day after the initial weighing. At least 50% of reweighs should be performed by someone other than the original technician. The weight variations in a statistically significant number of such audits are then used to establish control limits for the variation at three standard deviations (see Quality Assurance Handbook for Air Pollution Measurement Systems, Vol. 1, Appendix H). Control limits should be recalculated every six months from the most recent blank values. If a blank shows variation between weighing beyond the control limits, the weighing process must be rechecked and, if the discrepancy is not found to be associated with the second weighing, all the filters tared with the initial blank weighing must be rechecked.
 - b. Blanks are selected with samples of the same lot as analysis blanks for ion chromatography, X-ray spectrometry, or other tests.
 - c. Blanks may occasionally be needed to replace damaged control filters for temperature/humidity adjustments.
 - d. Unused blanks or portions thereof are stored in numerical order with their samples for at least two years before discarding.

2. Since it is known that humidity amid temperature introduce most of the variability in filter weights, chose control must be maintained on these factors. Any change of 1 % in humidity or of one degree Celsius in temperature during a weighing session necessitates die reweighing of die controls amid recalculation of the adjusted tare.
3. The three control filters furnish another quality check on die weighing precision and on the accuracy of the tare adjustment. The variations in ΔC between the controls are compared to control limits established from the past performance of the filters--such limits are set at three standard deviations as in 1a, above. When excess variation indicates au out-of-control condition, weighing must be suspended until the balance is checked and recalibrated and the control filter reweighed.
4. Zero the balance after every twenty filter weights. Reset the zero if needed. (Caution: Large position zero displacements may be caused by dirt on the pail. Remove the pan, clean it, and then recheck the zero in such cases. If the zero drift at any check is over one microgram, reset it and then recheck the calibration before continuing. If the zero drift is over five micrograms, correct the balance and reweigh filters back to the point where the difference is two micrograms or below.)