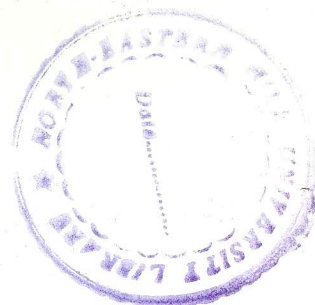


# **ASSESSMENT OF BREATHING LEVEL AIR QUALITY IN SHILLONG**

**(ABSTRACT)**



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Air Pollution is one of the most threatening problems inherited by the 21<sup>st</sup> century. It no longer remains a problem of urban centres alone as it has pervaded even to the remote areas. Air pollution is a global predicament since geographical dimensions cannot restrict the transport of air pollutants. In India, the problem of air pollution has been officially recognized in the early nineteen eighties. The promulgation of the Air (Prevention and Control of Pollution) Act, 1981 was the first major step by the Govt of India to contain the problem of air pollution in the country.

Awareness about the prevailing air pollution problems in the country is high which is evident from the fact that a large number of institutions and research groups have been working in this field since the last few decades. Even so, data with regard to total suspended particulates (TSP), soot (elemental carbon) and particle size distributions at breathing level for urban atmosphere is exceedingly scanty. Considering air pollution profile of a city, it becomes evident that pollutants predominantly come from a single source i.e. vehicular exhaust emissions released at the breathing zone of the people. Soot, a major component of the vehicular exhaust emissions, has been associated with health and amenity problems and certain European countries have already set standards for this pollutant. Concentration of oil-drops (OD) in suspended particulates is also of significant interest particularly in areas of high vehicular density and dense pine forests as the latter emanate natural terpenes in the form of OD.

In recent years, the aerodynamic size of suspended particulates has gained immense significance as various ailments of the respiratory tract and lungs are

found to be associated with it. A number of time-based studies have linked different levels of particles below the size of  $10\ \mu\text{m}$  ( $\text{PM}_{10}$ ) with increased incidences and durations of respiratory symptoms, increased hospitalization for respiratory diseases, increased lung dysfunction and increased cardio-pulmonary mortality. It is now also established that the number of fine particles or  $\text{PM}_{2.5}$  (particles below  $2.5\ \mu\text{m}$  in size) have much longer residence time in the atmosphere compared to the coarser particles and are most important from the human health perspective as they are also able to penetrate further into the respiratory system. Epidemiological evidence suggests that there may be no safe threshold limits for fine particulates and that the effects are linearly related to its concentration. The importance of the assessment of the concentration of toxic trace elements in air particulates has also been well accepted due to its serious negative health implications.

Until recently, National Ambient Air Quality Standards (NAAQS) for TSP were in use in India. The mass based standards for  $\text{PM}_{10}$  were introduced in the country only in the nineties. So far, no standards with respect to soot and  $\text{PM}_{2.5}$  have been set in the country despite the fact that the vehicular pollution in the urban atmosphere is of growing concern. Moreover, it is increasingly realized that the mass based standards for  $\text{PM}_{10}$  hardly provide the true characteristics of particulate size distributions and their associated health implications because the finer particles, though very high in number, account less for mass in comparison with the coarser particles, thus making it important to study the suspended particulate profiles and their number concentrations.

In the absence of any significant growth in the industrial sector, vehicular emissions remain as the main source of air pollution in Shillong. The per capita vehicular density of city is also quite high as it ranks 4<sup>th</sup> in the country (almost 1 vehicle amongst 10 persons). Shillong is not connected with any rail-network and, as such, roads are the only mode of transport. It also acts as the conduit point for the north-eastern states of Mizoram, Tripura and parts of Assam through its national highways (NH 40 and NH 44) that further accentuates the problem of air pollution in the city.

To investigate air pollution levels in Shillong, the Meghalaya State Pollution Control Board has established two ambient air quality monitoring stations in 1989 under National Air Monitoring Programme (NAMP). These stations are located at Lumpynggad (a hill top away from vehicular movements) and at Police Bazar (city centre and main commercial activity area). While the Lumpynggad monitoring station is located at ground level, Police Bazar monitoring station is located on the rooftop of a building at an approximate elevation of about 10 meters, therefore, making it difficult to establish any meaningful relationships between the obtained air quality data. Moreover, only some criteria pollutants like Suspended Particulate Matters (SPM), Sulfur dioxide (SO<sub>2</sub>) and Oxides of Nitrogen (NO<sub>x</sub>) are monitored from these two stations.

Thus, there is an unambiguous dearth of requisite air quality data with respect to TSP loadings, soot concentrations, particle size distributions and elemental compositions at breathing level of the urban atmospheres particularly for Shillong. Moreover, the highly humid and temperate climatic conditions of Shillong

are quite different from the rest of the parts of the country and air pollution statistics for such urban atmosphere is hardly available.

To fill these gaps, the present study was undertaken to assess the air quality of Shillong with respect to TSP color, TSP and soot loadings, OD concentrations, aerodynamic particle size distributions for solid particles (PM) and OD and concentration of toxic trace and major elements of Pb, Ni, Cu, Cd, Cr, Fe, Zn, Mn, Co, Na, K and Mg in air particulates at breathing level of the population. In addition, traffic density patterns and meteorological characteristics were planned to be recorded throughout the sampling durations to obtain their relationships with the monitored concomitants. The objectives of the study also included Receptor Modeling for source apportionment of solid particles and toxic trace and major elements using Principal Component Analysis (PCA) technique with Varimax Rotation method. Particle size distribution analysis with Image Analysis System (IAS), morphology of solid particles with Scanning Electron Microscope (SEM), enrichment factors (EF) analysis of monitored elements to obtain the possible sources in aerosols and correlation analysis of elements to understand their sources and transport behaviour were also the part of the scope of the study.

The present work is summarized in 6 (six) Chapters. Chapter 1 covers aspects of introduction, major air pollutants and their sources, pollution controls laws and their objectives, status of air quality monitoring and motivation behind the present work. The planning, survey and experimental details are described in Chapter 2. Chapter 3 comprises of details regarding determination of mass loadings of TSP and soot at breathing level, OD concentrations, relationship of TSP and soot

with traffic density and meteorological variables, cluster analysis and category-wise representation of TSP in Shillong and relationship of soot with TSP. Determination of aerodynamic size and distribution patterns of PM, relationship with traffic density, meteorological factors and source apportionment of PM by PCA, aerodynamic size distribution of OD and relationship with traffic density, comparison of particle size distribution data obtained with optical microscope and IAS and determination of particulate morphology with SEM are discussed in Chapter 4. Chapter 5 includes the aspects of determination of the concentration of different elements, EF analysis of elements, correlation analysis of elements and source apportionment of elements using PCA. The summary of the results of the present study and future perspectives of work constitutes Chapter 6.

The study area covered the city of Shillong; headquarter of the East Khasi Hills district and capital of the state of Meghalaya, India. The city is positioned at Latitude  $25^{\circ} 35'$  N and Longitude  $91^{\circ} 53'$  E. Commonly known as the "*Scotland of the East*", it is situated on the Khasi Hills range at the varying altitudes of 1400 to 1950 meters above mean sea level.

The concept of spatial representation was considered for selection of sampling locations because monitoring from a fixed site is often influenced by nearby sources that may not represent the exposure of the community at large. Moreover, the varying urban conditions can hardly be specified with a single station. Siting criteria adopted for selection of sampling locations was such to get the realistic representation of the exposure of population to air pollutants. We selected sampling locations at NH 40 & 44 (within the city confines), major roads,

educational and commercial clusters, busy traffic intersections, highways and indoor environment, industrial estates/areas and at various elevations to have an overall air pollution assessment of the city and to evaluate the community exposures at various situations. Some locations were also selected as control sites (away from vehicular movements) to compare the difference in air quality with locations exposed to intense traffic and anthropogenic activities.

A total of 84 locations were selected for the purpose and classified into CB locations (control locations away from vehicular movements), MP locations (moderate traffic density with comparatively flat roads), MU locations (moderate traffic density with high gradient roads), HP locations (high traffic density with comparatively flat roads) and HU locations (high traffic density with high gradient roads), traffic intersections (three locations each in across directions at a distance of approximately 300 meters from each other), highways (H) and indoor environment locations (IN), industrial estate/areas (IE) and elevation specific locations (A). The sampling was performed twice for all the selected sampling locations during dry periods (November to mid May) of 1997-98 and 1998-99. One additional sampling for 23 selected locations of MP, MU, HP and HU only was also performed during Oct-Nov, 1998. To obtain the correlations between the obtained air quality data with meteorological variables, hourly ambient temperature (AT-°C), relative humidity (RH-%), wind speed (WS-km/h), wind direction (WD-° from north) and rainfall (mm) were recorded during sampling hours. To assess the vehicular traffic density and changes in the movement patterns of various petrol and diesel driven vehicles, viz., two wheelers (TW) - scooters, motor cycles; light vehicles (LV)- cars, jeeps;

heavy vehicles (HV)- buses, trucks etc. manual counting of the vehicles was performed on hourly basis during sampling period of 9.00 to 17.00 IST. On the basis of traffic density, the selected sampling locations are categorized into moderate (Total Traffic Density,  $\rho_T < 500$  vehicles/h) and high (Total Traffic Density,  $\rho_T > 500$  vehicles/h).

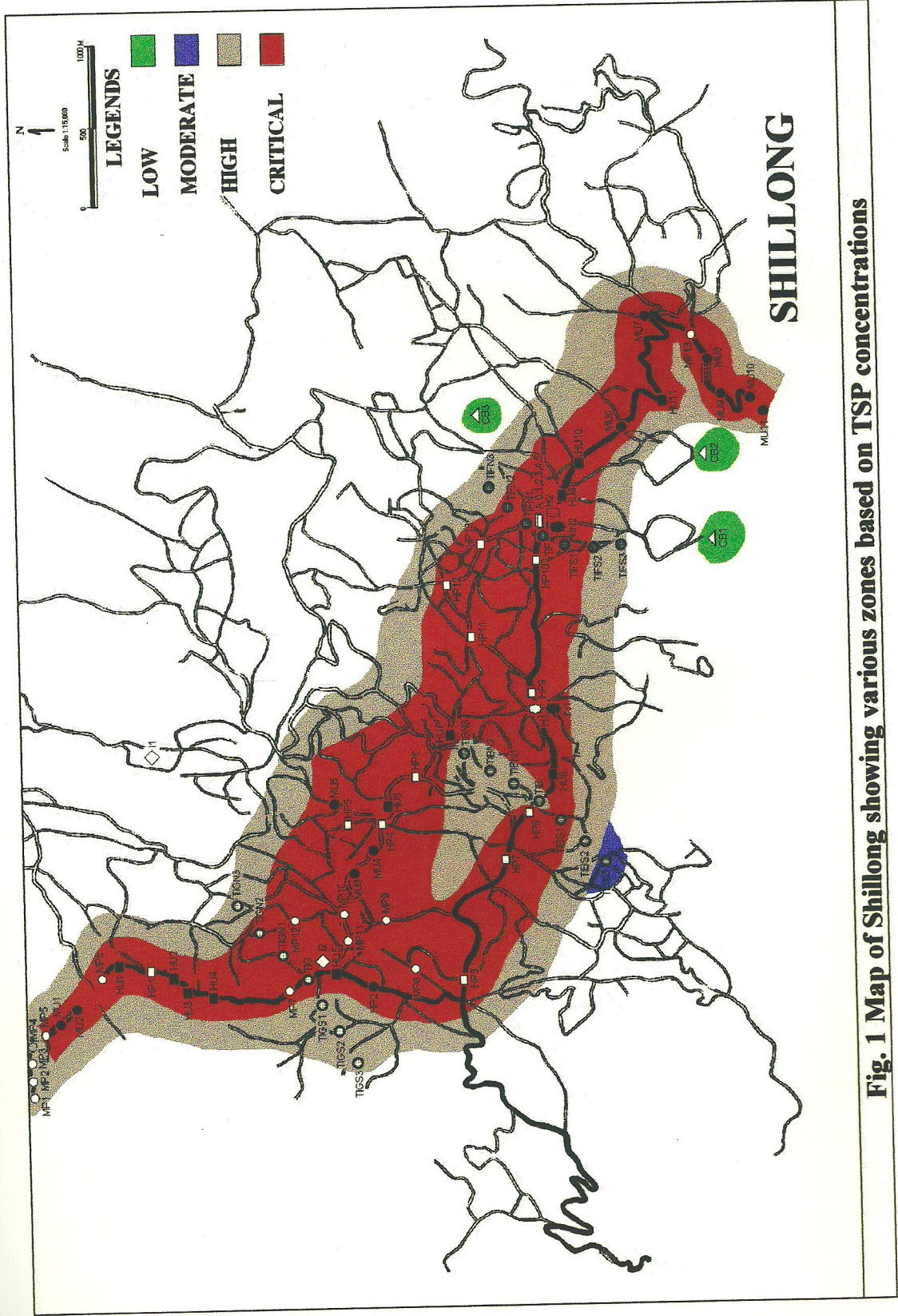
Low volume air samplers were used to collect airborne TSP. The basic feature of this equipment included a suction pump to draw air through the filter medium, a filter holder assembly, a flow meter to calculate the volume of air drawn, a time totalizing device and filter medium. Samplers were placed along the roadsides on pavements at breathing level (1.0 meter distance from road and 1.5 meter above ground level) during peak activity hours (9.00-17.00 IST) for all locations (excluding those at various elevations). The TSP and soot concentration has been calculated gravimetrically as per the Standard Methods of Air Sampling and Analysis. The concentration of OD in aerosols was determined using an optical microscope (Laborlux D, Leitz, Wetzlar, Germany) at a magnification of 1562X. Optical Microscope was also used for determination of particle size distributions and results were presented in % relative abundance. For each particle 'Ferret's diameter', the gauge of distance between two tangents at opposite end of the particle, was measured and recorded. The PM in the range of  $0.44 \mu\text{m}$  to  $\geq 10.5 \mu\text{m}$  and OD from  $0.44 \mu\text{m}$  to  $\geq 5.3 \mu\text{m}$  were measured. The results were pooled in two broad size groups viz.- fine particle size group of  $\text{PM}_{2.5}$  that contain particulates of  $\text{PM}_{0.44}$  ( $0.44 \mu\text{m}$ ),  $\text{PM}_{0.88}$  ( $0.88 \mu\text{m}$ ),  $\text{PM}_{1.77}$  ( $1.77 \mu\text{m}$ ), and  $\text{PM}_{2.6}$  ( $2.6 \mu\text{m}$ ), and another size group that contain particle spectrum of cumulative  $\text{PM}_{2.5}$  ( $0.44 \mu\text{m} - 2.6 \mu\text{m}$ ),  $\text{PM}_5$

(3.5  $\mu\text{m}$  - 5.3  $\mu\text{m}$ ),  $\text{PM}_{10}$  (6.1  $\mu\text{m}$  - 10.5  $\mu\text{m}$ ), and coarse PM (>10.5 $\mu\text{m}$ ) for solid particles. The OD were also grouped in similar size ranges of fine oil-drops of  $\text{OD}_{2.5}$  containing  $\text{OD}_{0.44}$  (0.44  $\mu\text{m}$ ),  $\text{OD}_{0.88}$  (0.88  $\mu\text{m}$ ),  $\text{OD}_{1.77}$  (1.77  $\mu\text{m}$ ) and  $\text{OD}_{2.6}$  (2.6  $\mu\text{m}$ ) and another size group of cumulative  $\text{OD}_{2.5}$  (0.44  $\mu\text{m}$  - 2.6  $\mu\text{m}$ ),  $\text{OD}_5$  (3.5  $\mu\text{m}$  - 5.3  $\mu\text{m}$ ) and  $\text{OD}_{>5}$  (>5.3  $\mu\text{m}$ ). Image Analysis System (Leica DMR, Germany) was used at a magnification of 1000X for determination of particle size distributions for various categories of sampling locations. The digital micro images of particle size distributions were also obtained. Scanning Electron Microscope (JSM-35 CF) was used for determination of the morphology of the airborne particles. The determination of the concentration of toxic and major elements was performed using Atomic Absorption Spectrophotometer (Shimadzu AA 680 G). The Standard Reference Material 1643b from U.S. National Bureau of Standards was simultaneously used for evaluation of the analytical accuracy of elements.

On the basis of the results obtained under the study, it was observed that the color of aerosol samples provided a fair indication regarding the likely source of soot in particulate matter as it gradually changed from the background gray to the brown and ultimately to the black color at various locations (covering 84 sampling sites) depending upon the intensity of traffic related activities thus establishing that vehicular emissions were the major source of soot at breathing level in ambient air of Shillong. It appears that soot particles coagulate fast in highly humid conditions such as in Shillong and settles down. It was evident from the gray color of samples at across locations of all three traffic intersections. The vertical movements of soot particles could be observed up to the monitored height of 17 meters as the sample

color changed from the black at breathing level to dark gray at the highest monitored location. This implied that fine soot particles go up to higher levels but the identification of the maximum heights could not be possible due to limitations of the availability of the sampling locations above 17 meters of height.

The TSP concentrations at CB locations were found to be low and within the prescribed Indian NAAQS while at MP, MU, HP and HU locations, it were found to be quite high ranging from “high” to “critical” levels. It showed a gradual decrease at across locations in north and south of traffic intersections. The TSP concentrations at the farthest points in across directions of traffic intersections (approximately 900 meters distance from highway) were comparable to TSP levels of CB locations. The TSP concentration at IN locations was “moderate” and the drop in concentrations was quite substantial compared to the H locations. At both the IE locations, TSP concentration was found to be “critical”. Substantial gradual decrease was recorded in TSP levels at A locations with increasing heights from ground levels up to the height of 17 meters. This indicated that vertical diffusion of TSP was quite dismal. On the basis of the mean TSP concentrations, the Shillong city was mapped into “low”, “moderate”, “high” and “critical” zones (Fig. 1). The map provides a fair indication about areas where the people are exposed to the elevated TSP levels in the city. From the least square linear regression plots and calculation of Pearson correlation coefficients a fair relationship between TSP concentrations and traffic density was established. The diesel vehicles were linked with higher levels of TSP at steep road gradients of MU and HU on the basis of correlation analysis. Meteorological variables exhibited rather weak interrelations



**Fig. 1 Map of Shillong showing various zones based on TSP concentrations**

with TSP. Ambient temperatures showed negative correlations indicating its inverse behaviour with TSP.

No soot concentration was detected at CB locations but it was found comparatively high at steep gradient locations of MU and HU perhaps due to high acceleration engine conditions of the vehicles. Soot concentrations also showed a gradual decrease at across locations both in north and south at traffic intersections. The farthest points at across directions of two intersections did not show soot concentrations. The concentrations of soot were quite significant at IN locations, which could pose serious health risks. Soot concentrations followed a lognormal distribution with TSP. The high and significant ( $p < 0.05$ ) correlations between soot and TSP were noted at traffic activity areas. Strong positive correlations between soot and traffic density of diesel driven vehicles at steep road gradient locations of MU and HU indicated higher soot emissions. However, the negative correlations with total traffic density in certain cases implied that factors like engine conditions and road gradient were also equally important for the build up of soot concentrations at breathing level of the atmosphere.

High OD concentrations were detected at the locations surrounded by thick pine vegetation. This fact may be attributed to the presence of oils (possibly terpenes) in pine trees, dispersion of which get accentuated in the atmosphere due to wind. Detection of low TSP and soot contents in samples containing high OD concentrations appears to be due to removal of these concomitants perhaps by adsorption. Higher ambient temperature and wind speed increase OD concentrations as evinced from their positive correlations.

The concentrations of fine solid particles of  $PM_{0.44}$  and  $PM_{0.88}$  showed significant increase at various traffic activity related locations and were highest at certain traffic intersections in comparison with CB locations. The concentration of  $PM_{1.77}$  also showed increase at traffic activity related locations and it was more at plain locations of MP and HU than at uphill locations of MU and HU, which is indicative of the probable source as resuspended dust due to vehicular motions. The concentrations of  $PM_{0.44}$ ,  $PM_{0.88}$  and  $PM_{1.77}$  showed decrease from H locations to IN locations. The decrease was gradual from  $PM_{0.44}$  to  $PM_{1.77}$ . Invariably, the concentration of cumulative  $PM_{2.5}$  also showed significant increase at traffic activity related locations and had been highest at certain traffic intersections. In general, the concentration of  $PM_5$  and  $PM_{10}$  exhibited decrease at traffic activity related locations in comparison with CB locations, however it was found to be highest at certain traffic intersections.  $PM_{>10}$  showed less variations and it was somewhat similar to the concentrations at CB locations. This decrease might be attributed to the dilution effect due to sudden increase in fine particles at these locations. The concentration of  $PM_5$ ,  $PM_{10}$  and  $PM_{>10}$  showed increase at IN locations. The observation might be attributed to the fact that indoors were not subjected to abrupt changes in particulate concentrations in comparison to highways resulting in such differences.

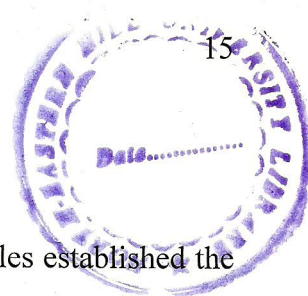
Examination of temporal variations in PM concentration of various size groups revealed significant variations among various sampling locations. It meant that the build up of various size groups of particulates at a particular location was more site-specific and it not only depended on its topographical situation but also

on the factors like traffic density and prevailing meteorological conditions. While the higher build up of  $PM_{0.44}$  and  $PM_{0.88}$  at traffic activity related locations could be directly linked to vehicular emissions, the build up of  $PM_{1.77}$  and  $PM_{2.6}$  could be linked to coagulation of fine particles accentuated by generally high humid conditions in Shillong. The difference in concentrations of  $PM_{0.44}$  and  $PM_{0.88}$  at moderate traffic density locations of MP and MU was more than the HP and HU locations suggesting further the site-specific nature of locations but as the vehicular emissions became higher, this factor turned out to be weak thus reducing the gaps in concentrations of particles of these size groups. The traffic intersection locations while registering increase in concentrations of  $PM_{0.44}$  and  $PM_{0.88}$  and showing random decrease in concentrations at across locations did not depict pattern of gradual decrease that again suggested the site-specific nature of the locations and influence of meteorological factors. The comparatively less concentrations of  $PM_{0.44}$ ,  $PM_{0.88}$ ,  $PM_{1.77}$  and  $PM_{2.6}$  at IN locations were indicative of the fact that penetration of fine particles in close vicinity of highways was not that pronounced. This might be attributed to the fact that the samplings were performed during the winters when people generally keep the indoor close for keeping their houses warm. The significant variations in concentration of  $PM_{0.44}$  and  $PM_{0.88}$  at IE sites also signified the site-specific nature as vehicular emissions influenced one of the locations. The vertical movement of  $PM_{0.44}$  and  $PM_{0.88}$  up to the height of 17 meters could be established. This became significant because of the situation of high number of residential buildings along the highways within the city confines. The concentrations of  $PM_5$ ,  $PM_{10}$  and  $PM_{>10}$  were influenced more by the natural

factors (mostly for  $PM_5$  as pollens, spores and other biogenic materials belong to this size group) than the anthropogenic activities. The fact that concentration of these particulates became higher at across locations of traffic intersections strengthened the assumption.

The least square linear regression line plots drawn between solid particle concentrations and traffic density and Pearson correlation coefficients further established that the higher build up of  $PM_{0.44}$  and  $PM_{0.88}$  at MP, MU, HP and HU locations was due to vehicular exhaust emissions. It also showed that heavy vehicles were the highest contributor of  $PM_{0.44}$  and  $PM_{0.88}$  build up at MP, MU, HP and HU locations followed by light vehicles and two wheelers. Linear regression plots established the source of  $PM_{1.77}$ ,  $PM_{2.6}$ ,  $PM_5$ ,  $PM_{10}$  and  $PM_{>10}$  other than vehicular emissions. While the build up of  $PM_{1.77}$  and  $PM_{2.6}$  could be linked to coagulation of fine particles and resuspension of dust, the  $PM_5$ ,  $PM_{10}$  and  $PM_{>10}$  could be linked fairly to natural sources.

Source apportionment of PM using PCA indicated that vehicular emissions and resuspended dust were the two influencing factors at plain locations that accounted for 83% and 73% for PM build up at MP and HP locations respectively. The vehicular emissions, resuspended dust and gas-particle conversion and coagulation were the three influencing factors at uphill locations accounting for 89% and 84% for PM build up at MU and HU locations, respectively. The 5-Factor Receptor Model was found to be quite suitable as it accounted for almost 100% of PM build up in Shillong.



The correlation analysis of PM with meteorological variables established the site-specific nature of the locations as the sudden rise in particle concentrations was influenced by factors like coagulation. In general, the relationships between PM concentrations and meteorological variables were not very strong. The relationships of PM concentrations and ambient temperature were highly varying for fine particles but the positive relationships with  $PM_{>10}$  suggested that temperature assists in keeping these particles airborne for considerable period of time. Humidity also had varying relationships with PM but inverse relationships with fine particles had obviously demonstrated that high humidity reduces the concentration of particles belonging to this size group by way of facilitating coagulation. The rise in fine particle concentrations at across locations of traffic intersections appeared to be due to high wind speeds. High wind speeds also appeared to assist the build up of coarse particles concentrations at all the locations. The wind direction assisted the build up of fine particle concentrations at most of the locations. It was due to frequent direction changes, which helped in horizontal mixing of the PM.

The insignificant standard deviations between solid particle size distributions data obtained with IAS and optical microscope established that latter could be used for particle size determination with comparable precision and accuracy. IAS had also been found to be very useful in obtaining additional information like particle's length, breadth, area, perimeter and roundness, which could be used for further understanding of particle's physical properties. The digital images were quite useful in identification of the source of airborne particles.

Scanning electron microscopy provided useful information about individual particle's morphology and textural structure. It also provided the information regarding the particle's possible composition according to its shape and texture and helped in identifying the source. The prevalence of crustal and biogenic particles at CB locations and crustal particles with embedded small particles, porous and fluffy soot particles, conglomerates with concentric circular structure of discontinuous fringes and inter planer spacing at traffic activity related locations could be explicitly observed under SEM. The morphology of particulates from diesel and petrol vehicular exhausts revealed that these particles were fluffy in nature in case of diesel vehicles and compact in case of petrol vehicles. The behaviour of these particles after inhalation appears to be of great interest due to their morphological structures and high prevalence at breathing level atmosphere of Shillong.

The  $OD_{0.88}$  and  $OD_{1.77}$  were the most prevailing and dominant size of OD among all the size groups implying that fine OD attains these sizes fast by coagulation process and remain airborne for comparatively longer period of time. Barring a few locations, the concentration of  $OD_{0.88}$  and  $OD_{1.77}$  was high at CB locations establishing further the source as biogenic in origin. The release of terpenes by pine trees is a well-known phenomenon. It was not unlikely that the build up of  $OD_{0.88}$  and  $OD_{1.77}$  concentrations at CB locations was due to abundance of pine trees and other vegetation. Almost all OD belonged to the size group of cumulative  $OD_{2.5}$  and thus were liable to be inhaled and lodged deep into the human respiratory system. The insignificant concentration of  $OD_5$  and  $OD_{>5}$  implied that OD did not remain airborne for longer period of time and get scavenged from the

atmosphere perhaps through embedding of solid particles and then settling due to gravity because of their heavier mass.

Similar to the observations made for PM, examination of temporal variations in OD concentrations of various sizes revealed significant variations among the sampling locations signifying substantial difference in OD concentrations. It means that the build up of OD of various size groups at a particular location was more site-specific and it not only depended on its topographical situation but also on the factors like vegetation cover, up to some extent the traffic density and prevailing meteorological conditions. While the higher build up of the concentration of OD<sub>0.44</sub> at traffic activity related locations could be directly linked to the vehicular emissions, the build up of OD<sub>0.88</sub> and OD<sub>1.77</sub> could be associated with coagulation of fine OD released from pine trees/vegetation. High concentration of OD<sub>0.88</sub> and OD<sub>1.77</sub> at traffic activity related locations could be linked with vehicular emissions with a bias towards these size groups at uphill locations of MU and HU. In general, the concentrations of OD<sub>0.88</sub> and OD<sub>1.77</sub> increased at across locations of traffic intersections. The observance of decrease/increase in concentration of these OD at across locations of traffic intersections was also indicative of site-specific nature of the locations as per the type and thickness of vegetation cover and influence of meteorological factors. The comparatively higher concentrations of OD<sub>0.88</sub> in indoor environment of the house pointed at least the three likely sources/phenomena viz. i) comparatively less dispersion ii) house hold activities and iii) wooden furniture, floor, ceilings etc. The slight variations in concentrations of OD<sub>0.44</sub> and OD<sub>0.88</sub> at one industrial site were due to its proximity to a pine forest. The OD<sub>0.44</sub> released at

ground level got coagulated to  $OD_{0.88}$  and moved vertically with further simultaneous coagulation leading to formation of  $OD_{1.77}$ . Any further increase in its size led to scavenging of OD in the atmosphere.

The correlation analysis obtained between OD concentrations and traffic density further established that the build up of  $OD_{0.44}$  at traffic activity related locations was due to vehicular exhaust emissions. Interestingly, correlation analysis showed that this build up was more due to heavy vehicles followed by light vehicles and two wheelers. Heavy vehicles were the highest contributors of  $OD_{0.88}$  build up at MU and HU locations indicating the bias of these vehicles to emit OD of this size group at steep gradient conditions. The correlations of  $OD_{1.77}$ ,  $OD_{2.6}$ ,  $OD_5$  and  $OD_{>5}$  with traffic density was random and not that significant.

The concentrations of Pb had shown significant increase at traffic activity related locations and were found to be more at uphill locations of MU and HU than at plain locations of MP and HP. Gradual drop in Pb concentrations at across locations of traffic intersections and decrease in concentrations at higher elevations (A locations) indicated vehicular emissions as the prime Pb source. High concentrations of Pb at IN locations are of great concern due to high number of residential buildings situated on the highways in Shillong. The highly 'critical' Pb concentrations at MP, MU, HP and HU locations were also of serious concern. The high concentrations of Ni, Cu, Cd, Cr, Zn, Mn and Co invariably pose high health risks. High concentrations of Zn and Co should have been due to natural rock composition or the weathering of galvanized sheets and, as such, attributed to natural occurrence.

Enrichment factor analysis of elements showed that Cd and Pb were the most enriched elements in Shillong followed by Cu, Zn and Co. Ni and Mn were slightly enriched elements while Cr, K, Mg and Na were not enriched. The use of one general natural-crust composition as reference in calculating the enrichment factors showed weakness of the model. If available, the continental crust composition of the corresponding city should be used in calculating enrichment factors to avoid such indistinctness.

The correlation analysis of elements established that positive association of Pb with Cd and K at CB locations was indicative of their common transport mechanism. The strong correlations of Ni with Cu, Cr, Zn, Co, Mg and Na suggested that part of these elements in ambient air was due to the rock crust composition. The association of elements at traffic related locations changed completely with vehicular emission related elements like Pb, Cu, Cr and Mn and soil and resuspended dust associated elements like Fe, K, Mg, Na showing strong correlations.

The 5-Factor Receptor Model for source apportionment of elements using PCA had been found to be quite suitable as it accounted for almost 84-89% of airborne elemental build up in Shillong. The model also indicated that the vehicular emissions, resuspended dust and weathering of building materials were amongst the most important factors for elements in TSP at breathing level in Shillong.

It may be concluded that this study has provided essential information about air quality in terms of TSP, soot, solid particles and oil-drop size distributions and elemental compositions at breathing level in Shillong. It is anticipated that the

outcome of the present work will assist in formulation of action plans for curbing the problem of prevailing air pollution and in planning future developmental programmes of Shillong. It is also believed that the outcome of the study will assist in evolvement of "National Standards" for soot. It may also provide a valuable insight for an appropriate decision on whether to adopt mass based or number based standards for  $PM_{2.5}$  and  $PM_{10}$  in our country.

The present study has also offered an exhaustive model to characterize breathing level ambient air quality in urban habitat. Hence, such studies may be extended to other cities in the north-eastern region and in the country as a whole. The study was performed at the time when unleaded petrol and Euro-I and Euro-II compliant vehicles were not introduced in Shillong, and as such, future works on these aspects could be helpful in understanding the impact of the introduction of the same. A significant proportion of the people reside along the highways and major roads of Shillong and, as such, are invariably exposed to elevated concentrations of TSP, soot,  $PM_{2.5}$ , Pb and other trace elements of toxic nature. The simultaneous health surveys would reveal the nature of medical problems and associated morbidity and mortality rates. The information will be useful in assessment of the actual quantum of the pollution problems and will assist in taking requisite control measures.

It is expected that this work will provide further understanding for the urban atmospheric pollution problems and will go a long way in adoption of apposite air pollution control strategies in order to protect people from its serious health hazards.

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