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Spatiotemporal, morphological and source analysis of ultrafine particulates (PM_1) over Bengaluru, Karnataka, India

A. S. MANJUNATHA and K. E. GANESH*

Department of Physics, B.M.S College of Engineering, Affiliated to VTU-Belagavi,

**Bull Temple Road, Bengaluru – 560 019, India*

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***e mail : drkeg.phy@bmsce.ac.in**

सार – बेंगलुरु शहर के निम्नलिखित स्थानों: बसवनगुडी (BAS), डोम्लुर (DOM), होसुररोड (HOS) और डीसी हल्ली (DCH) परस्वदेशी रूप से निर्मित एयर सैंपलर का उपयोग करके 1 μm (PM_1) से कम वायुगति कीयव्यासकेकणिका पदार्थ का मापन और विश्लेषण किया गया है। अध्ययन अवधि के दौरान PM_1 द्रव्यमानसांद्रता 20.16 μg/m^3 से 68.64 μg/m^3 के बीच देखी गई। बसवनगुडी (BAS) में उच्चतम द्रव्यमान सांद्रता 68.64 μg/ m^3 देखी गई और डोम्लुर (DOM) में न्यूनतम द्रव्यमान सांद्रता 20.16 μg/m^3 देखी गई। सर्दी, गर्मी, मॉनसून और मॉनसूनोत्तर मौसम में बेंगलुरु के आसपास PM_1 की औसत द्रव्यमान सांद्रता क्रमशः 47.60μg/m^3, 40.24μg/m^3, 30.85 μg/m^3 और 38.76 μg/m^3 देखी गई। एकत्र किए गए कुछ नमूनों में बैसिलस जैसे सूक्ष्मजीव की उपस्थिति पाई गई है। मौलिक संरचना विश्लेषण से अधातुओं में कार्बन, ऑक्सीजन, नाइट्रोजन, सल्फर और धातुओं में जैसे सोडियम, एल्यूमीनियम, कैल्शियम और पोटेशियम की उपस्थिति का पता चला है।

ABSTRACT. Measurement and analysis of Particulate Matter of aerodynamic diameter less than 1 μm (PM_1) has been carried out using indigenously built air sampler at the following locations of Bengaluru city: Basavanagudi (BAS), Domlur (DOM), Hosur road (HOS) and DC Halli (DCH). The PM_1 mass concentrations were observed to vary from 20.16 μg/m^3 to 68.64 μg/m^3 during the study period. The highest mass concentration of 68.64 μg/m^3 was observed for the location BAS and the lowest mass concentration of 20.16 μg/m^3 was observed for the location DOM. The average mass concentration of PM_1 around Bengaluru for winter, summer, monsoon & post monsoon season is observed to be 47.60 μg/m^3, 40.24 μg/m^3, 30.85 μg/m^3 and 38.76 μg/m^3 respectively. Some of the collected samples showed the presence of microorganism such as bacillus. Elemental composition analysis showed the presence of non-metals Carbon, Oxygen, Nitrogen, Sulphur and traces of metals such as Sodium, Aluminium, Calcium and Potassium.

Key words – PM_1, Morphology, Elemental composition, Scanning Electron microscope, Anthropogenic activities, Ultrafine particles, Bengaluru, Air Sampler.

1. Introduction

Air pollution is caused due to very small liquid and solid particles suspended in the air which constitutes Particulate Matter (PM). Based on the size, PM is often divided into three main groups such as coarse fraction, fine fraction and ultrafine fraction. The coarse fraction contains the larger particles with size ranging from 2.5 μm to 10 μm ($PM_{2.5}$ - PM_{10}). The fine fraction contains the smaller particles with a size up to 2.5 μm ($PM_{2.5}$) and the particles with size smaller than 1 μm are called ultrafine particles as per the classification made by Junge (1963).

The atmospheric particulate matter originates mainly from traffic, industries (primary emission) or formed in the atmosphere through natural process from wear and tear of rock, volcanic activities, re-suspension of road dust (secondary emission) by transformation of gaseous emissions (gas to particle conversion) (Wilson *et al*., 2002). The size and chemical composition of PM_1 (particles with size 1μm) has a strong influence on human health (WHO/Europe), visibility, ecosystem (EPA) and cloud properties (Zhen Liu *et al*., 2020).

The PM_1 in atmosphere leads to the common lung and pulmonary diseases in human beings (Delfino *et al*.,

Fig. 1. PM_1 sampling locations in Bengaluru

2005) and such disease leads to alteration in morphology and functions of the epithelial cells (Ramgolam *et al*., 2009). Physical (size and morphology) and chemical (composition) characterization of atmospheric particles has received significant importance due to their effect on radiative and chemical properties. The detailed characterization of atmospheric particles provides useful information about their sources, atmospheric history, formation, reactivity, transport and removal of atmospheric chemical species (Lu *et al*., 2006; Adachi and Tainosho, 2004, Srimuruganandam *et al*., 2010). However, chemical composition of PM_1 plays very important role in chemical characteristics and its effect on ecology and environment (Marmur *et al*., 2006).

PM are strongly affected by meteorological parameters such as precipitation, mixing layer height, temperature, air mass origin and season (Jacob and Winner, 2009; Spindler *et al*., 2010). Weather change is supposed to have direct and indirect effects on urban PM which in fact depends on sampling season, air mass origin and temperature (Fransen *et al.*, 2012). The higher levels of PM concentration were observed during the winter months due to more frequent temperature inversions in winter combined with lack of precipitation (Aryal *et al.*, 2009).

Atmospheric PM originates from many sources and differed in terms of physical and chemical characteristics, effects on human health and the ecosystem, persistence in the atmosphere and the ability to react with each other (Pope and Dockery, 2006). Hence there arises a need to study on the variations of PM_1 in a mega city like Bengaluru. The present paper focuses on the study of concentrations, morphology and its elemental composition of collected PM_1 samples in Bengaluru at BAS, HOS, DOM and DCH locations based on the traffic density. Since there are very few studies have been carried out on PM_1 mass concentration over Bengaluru, the concentration of $PM_{2.5}$ is being compared with PM_1 mass concentration where ever required.

2. Materials and method

2.1. *Study area*

Bengaluru known as World's dynamic city and capital of Karnataka state of India is located between 77º24' E - 77° 28' E and 12° 46' N - 13° 11' N. It is situated at a height of about 920 meters above Mean Sea Level. It has a population of over ten million making it a megacity and the third most populous city and fifth most populous urban agglomeration in India. It is located in southern India on the Deccan Plateau. Because of the availability of resources, Bengaluru has become the prime location for every job aspirant. According to the latest vehicles statistics released from RTO, the total number of vehicles registered in 2016 is 61,12,897 and in the year 2017 it is 68,33,080 (transport.karnataka.gov.in). Hence, there is about 11.78% increase in total vehicles on Bengaluru roads whose contribution to the total particulate load in the atmosphere is significant which requires constant monitoring. Also, Bengaluru is one of the fastest growing cities in India and is also known as the *'Silicon Valley of India'* for heralding and spearheading the growth of Information Technology (IT) based industries in the country. With the advent and growth of the IT industry, as well as numerous industries in other sectors and the onset of economic liberalization since the early 1990s, Bengaluru has taken the lead in service-based industries

which have fueled the growth of the city both economically and spatially (Mahapatra *et al*., 2011). With this scenario, monitoring of air quality in and around Bengaluru becomes very important primarily in view of public health.

The summer season in Bengaluru starts from March to May with an average variation of temperature from 22 °C to 33 °C and the relative humidity from 40% to 68%. Monsoon season which starts from June to September with temperature from 18 °C to 30 °C and relative humidity from 70% to 80%. October to November is regarded as post monsoon season with a temperature of 19 °C to 28 °C and relative humidity from 88% to 97%. Winter season starts from December to February with temperature ranging from 16 °C to 28 °C and the relative humidity from 52% to 68% (https://www.karnataka.com/profile/karnataka-climate/).

The major contribution to air pollution in Bengaluru is vehicular traffic. Also, Bengaluru is having about 77,407 units of micro, small, medium and large-scale industries such as plastic, aluminium smelters, iron fabricators, ceramics and pharmaceutical companies along with construction activities (http://dcmsme.gov.in).

2.2. *Experimental Design*

Sampling of PM_1 was carried out on the terrace of a two-floor building at Basavangudi (BAS) (12.94° N and 77.56 °E), Hosur Road (HOS) (12.89° N and 77.64° E), Domlur (DOM) (12.95° N and 77.63° E) and DC Halli (DCH) (12.89° N and 77.62° E) over a period of one year. The locations are being marked in the map as shown in Fig. 1. The sample was collected on Poly Tetra Fluoro Ethylene (PTFE) filter paper with 47 mm diameter using indigenously made Envirotech APM577 PM_1 sampler. The air inlet section and impactor stages used in Envirotech APM577 PM_1 sampler is designed and developed by Indian Institute of Technology, Kanpur. The impactor system is designed to operate at an air flow rate of 10.0 LPM without any voltage fluctuation. The air inlet section has circular symmetry so that air entry is unaffected by wind direction, rain, insects etc. The inlet section immediately leads to impactor stage designed to trap particles size more than 1 µm with a filter paper of 27 mm. The fine particles of PM_1 are collected on the PTFE filter paper for a period of 24 h. The collected particles on filter paper was kept in filter storage for 24 h at a relative humidity of 35%.

Mass concentration was calculated gravimetrically by weighing the filter paper before and after sampling. Concentration of PM_1 in ambient air is determined by mass of particulates (grams) on the filter paper in collected air volume (m^3) for 24 h. Since the PM_1 is small in size, a repeated measurement of filter paper will provide the accurate mass concentration of the PM_1 in actual ambient air.

Typical calculation:

Initial dry gas meter reading (DGM) : 17.618 m^3

Final dry gas meter reading : 47.367m^3

Total Air Volume : (DGM Final reading - DGM Initial reading) = 23.749 m^3

Initial Filter paper weight = 0.15015g

Final Filter paper weight = 0.15347g

Dust of PM_1 collected = (Final wt.- Initial wt.) = 0.00332g = 3320µg

Concentration of PM_1 = (weight of PM_1 Dust/air sampling volume) = 3320/23.749 = 140 µg/ m^3

2.3. *SEM-EDAX*

Collected PM_1 samples were analyzed by Scanning Electron Microscope (SEM)-Energy Dispersive Analysis X-ray (EDAX). The SEM-EDAX analysis was carried out with the help of a computer-controlled field emission scanning electron microscope equipped with an energy dispersive X-ray system (EDAX). The filter papers were cut in 1 mm^2 from each sample. All the samples were mounted on plastic stubs for gold coating. A very thin film of gold (Au) was deposited on the surface of each sample using vacuum coating unit called Gold Sputter Coater to increase the electrical conductivity. The working conditions were set at an accelerating voltage of 5 kV, a beam current of 1 µA to 2 µA is passed. Images were taken at a magnification of X 2000, X 5000, X 10000 and X 20000.

2.4. *Micro-organism analysis*

The collected samples were used to study the presence of micro-organism using Lysogeny broth (LB)-Agar as a medium of growth. The LB-Agar powder of 37g contains 5g of peptone, 10g of peptone from casein, 10g of Sodium Chloride and 12g of Agar-Agar. The medium of LB-Agar was prepared using 8.14g pre mixed powder of LB- Agar and a 500ml of sterile water was added to make it 200ml of LB-agar medium. The gel was now placed for autoclave at 121°C under 30psi for 30min. High pressure used to prevent the gel mix from boiling over high temperature.

TABLE 1

Correlation statistics of meteorological parameters with PM1 mass concentration for the study period over Bengaluru

Parameter	Pearson's ratio	Adj. R-Square	Intercept	Slope	Standard error for intercept	Standard error in slope
RH%	-0.144	-0.041	83.362	-0.195	14.157	0.336
Temperature (°C)	-0.366	0.080	29.755	-0.095	2.554	0.061
Windspeed (km/hr)	-0.327	0.051	7.518	-0.051	1.564	0.037

3. Results and discussion

3.1. *Mass Concentration Analysis*

The PM_1 mass concentration has been measured for 24 h during the study period of July 2018 to July 2019 at four different locations of Bengaluru city as mentioned above. The mass concentration values found to vary from 21.27 $\mu g/m^3$ - 68.64 $\mu g/m^3$. The average mass concentration in winter, summer, monsoon and post monsoon seasons were observed to be 47.62 $\mu g/m^3$, 40.25 $\mu g/m^3$, 32.05 $\mu g/m^3$ and 38.76 $\mu g/m^3$ respectively. The lowest mass concentration of 20.16 $\mu g/m^3$was observed in the months of June 2019 which is monsoon season and highest mass concentration of 68.64 $\mu g/m^3$ was observed in December 2018 which is winter. The average 24 h mass concentrations of PM_1 in winter season that is in December month at BAS location is found to be higher than National Ambient Air Quality Standard limit of 60 $\mu g\ m^{-3}$ for $PM_{2.5}$. However, in January and February months mass concentration are found to be less than the standard limit. The lower PM_1 mass concentration observed in monsoon is due to washout of the particulates and highest concentration observed in winter is may be due to temperature inversion in ambient air.

Dependence of PM_1 mass concentration with temperature, RH and wind speed is shown in Fig. 2. The PM_1 mass concentration showed a negative correlation with temperature and wind speed, the extent of correlation is listed in Table 1. The negative correlation between mass concentration and temperature is because of ventilation of particulates outside the atmosphere due to breaking of aerosol layer with increase in temperature as a result of sunrise. Also, it has been observed that mass concentration with RH follows almost similar trend on some days and opposite trend on other days of sampling. Increase in mass concentration with RH indicates stacking up of particulates one above the other up to a certain threshold height which gives positive correlation. Once this growth exceeds a threshold limit then due to the effect of gravity particulate growth breaks. Hence this shows opposite trend between mass concentration and RH [Shaw *et al*. (1976)]. Shivakumar *et al.* (2022) have observed annual average value of 28 $\mu g/m^3$ for $PM_{2.5}$ concentration at Bengaluru for the year 2015. However, PM_1 mass concentration of 48.40 $\mu g/m^3$ for the year 2018 and 35.74 $\mu g/m^3$ for the year 2019 have been recorded for Bengaluru during the present study. Goyal *et al.* (2021), have observed that vehicular exhaust contributes about 57% in total particulate load at Bengaluru and was found to be the dominant source in residential area whose contribution increased up to 76% at road side location in Bengaluru City in South India.

3.2. *Morphological analysis of PM_1*

The PTFE filter paper used for the collection of PM_1 samples has been used for the morphological study with the help of Scanning Electron Microscope (SEM). SEM image gives specific source of PM_1 whether it is due to primary formation or secondary formation as suggested by Mirjana *et al*. (2006). Direct evidence of the composition and morphology of aerosol particles can be provided by single particle analysis as suggested by Geng *et al*., 2010; Ro *et al*., 2005; Utsunomiya *et al*., 2004. Particulates with different shapes such as isometric, platelets and fibres exist in the atmosphere and morphological properties often lead to the assumption of particle sphericity for most of the applications. An added complication is that particles with irregular morphology can collapse into a spherical shape upon humidification. As the particulates are smaller in size, they get into the alveolar duct and alveoli in lungs and damages the epithelial cells and morphology may induce significant pro-inflammatory responses in airway epithelial cells as observed by Huang *et al*. (2003). The morphology relates to chemical composition as well as toxicity if the compounds are organic as identified by Borgie *et al*., 2015; Kothai *et al*., 2009.

In the present study, we have also used EDAX technique to identify elemental composition. As suggested by Atar Singh *et al*., 2014, EDAX gives almost accurate elemental composition of PM_1. The analysis of particulate matter through SEM is the best tool as it gives the information about the shape of particulate matter. But, sometimes the identification of elemental composition may be difficult as two peaks resulting from two different elements may overlap obscuring each other and making identification difficult. However, there are methods to overcome this limitation. Any unambiguous peak assignment may be impossible in EDAX techniques. The detection limit of EDAX is typically about 0.2-0.5% as discussed in (Seifollah and Shokrollah, 2016).

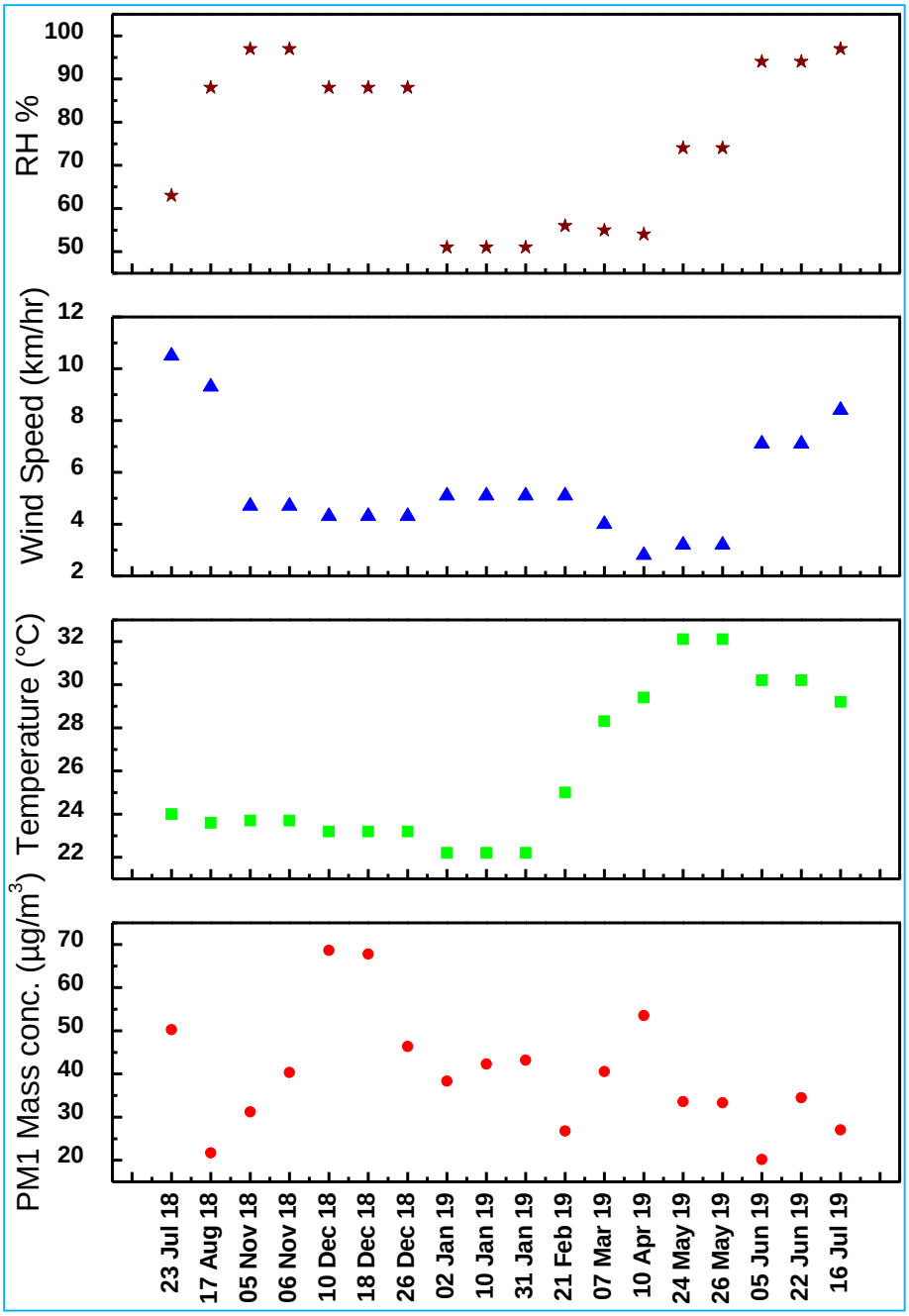
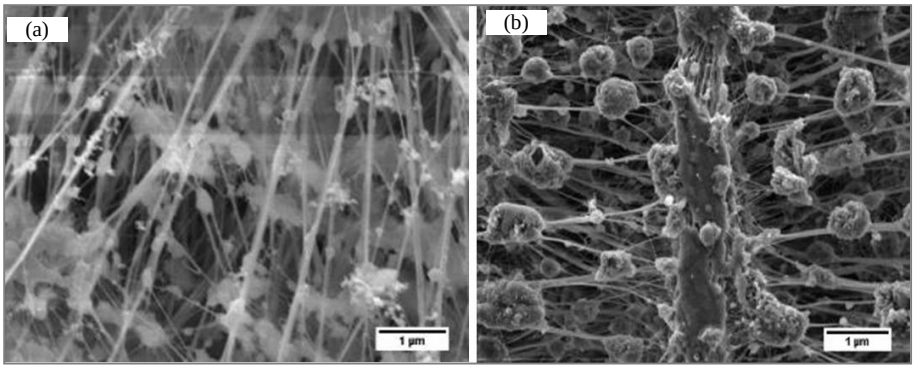


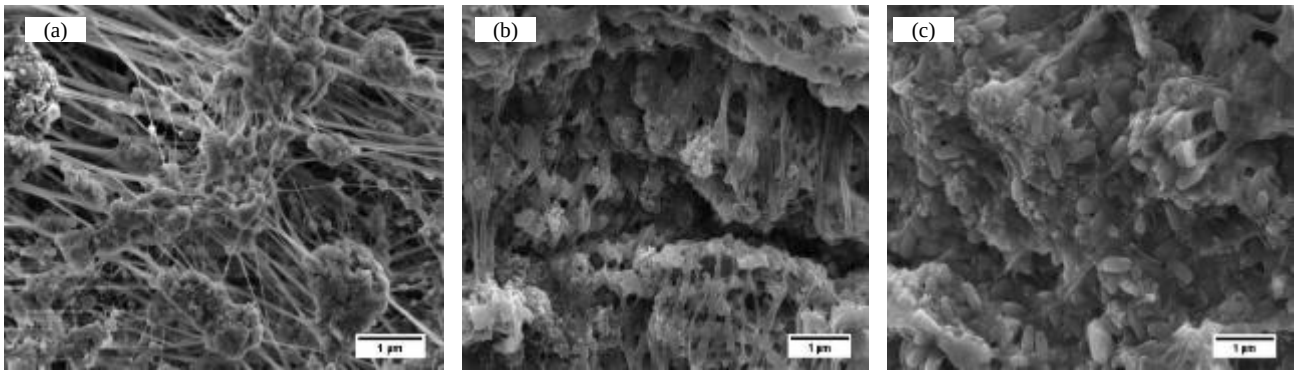
Fig. 2. Variation of PM_1 mass concentration with meteorological parameters

3.3. *Morphological analysis of PM_1 at BAS location*

A total of five samplings were carried out in BAS location during the study period along with SEM-EDAX analysis in July month. From Fig. 3(a) it is clear that the particulates are regular (spherical) and irregular in shape with smooth and rough surface area. Elemental composition in PM_1 is expressed in terms of weight % which indicates the relative concentration of the element in the sample. The elemental composition is found to be Carbon with 30.72 weight % and Oxygen with 1.21 weight % with traces of Phosphorus.



Figs. 3(a&b). SEM image of PM_1 at BAS in (a) July and (b) December month



Figs. 4(a-c). SEM image of PM_1 sample collected at BAS location in January month (a) without micro-organism studies and (b&c) micro-organism studies

The morphology of PM_1 was carried out in December month. As shown in Fig. 3(b) the particulates were found to have irregular shape with rough surface area and some of them were biological particles indicating the source of PM_1 from natural activities. The elemental composition was found to be Carbon with 46.81 weight %, Nitrogen with 17.88 weight%, Oxygen with 34.25 weight % with traces of Sulphur.

In the month of January two samplings were carried out. Morphological analysis of one sample showed particulates with irregular shape and rough surface area [Fig. 4(a)]. The elemental composition was found to be Carbon 50.93 weight %, Nitrogen 13.32 weight %, Oxygen 34.59 weight % with traces of Sulphur and Potassium.

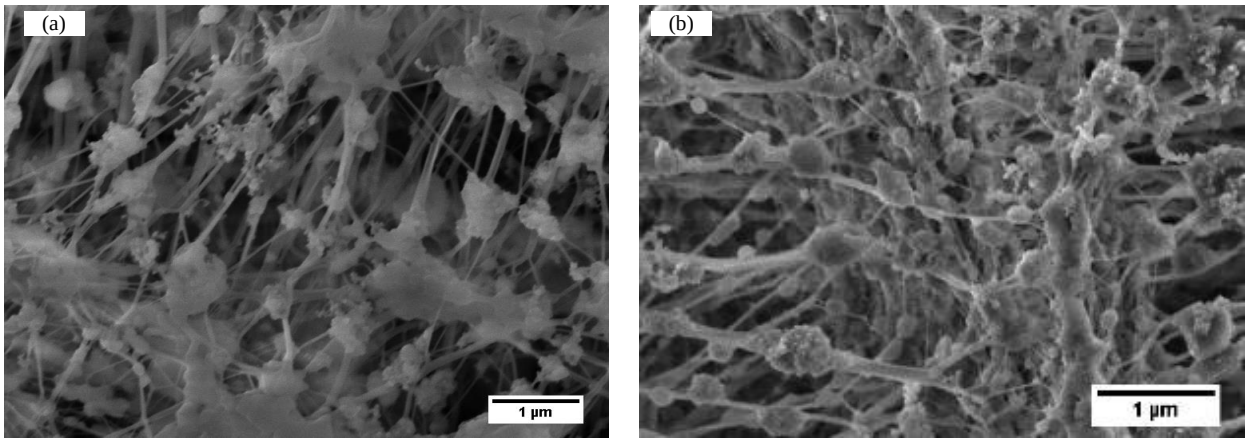
Other sample was used for microorganism analysis as the size of bacteria or virus varies from 100 nm to few micrometer as suggested by Ya-fen Wang *et al*., 2010. The sample filter paper was placed on LB-Agar solution in an autoclaved plate which acts like a growth medium for bacteria or virus. Same was stored in incubator overnight at a temperature of 37 °C and SEM of the same filter paper was carried out. The morphology of collected sample showed the presence of rod-shaped particles which confirms the presence of bacteria Bacillus [Fig. 4(b)] as observed in the work of Christine G *et al*., 2016. The elemental composition was found to be Carbon 37.30 weight %, Nitrogen 2.04 weight %, Oxygen 7.54 weight % and traces of Phosphorus and Sulphur.

The sampling carried out in the month of February was again used to study the presence of microorganism with SEM image technique. The SEM image of this sample [Fig. 4(c)] confirms the presence of microorganism with rod shaped morphology that is bacteria Bacillus. The elemental composition is found to be Carbon 44.29 weight %, Nitrogen 4.51 weight %, Oxygen 11.61 /weight %, Sodium 7.52 weight % with traces of Silicon, Phosphorus, Sulphur.

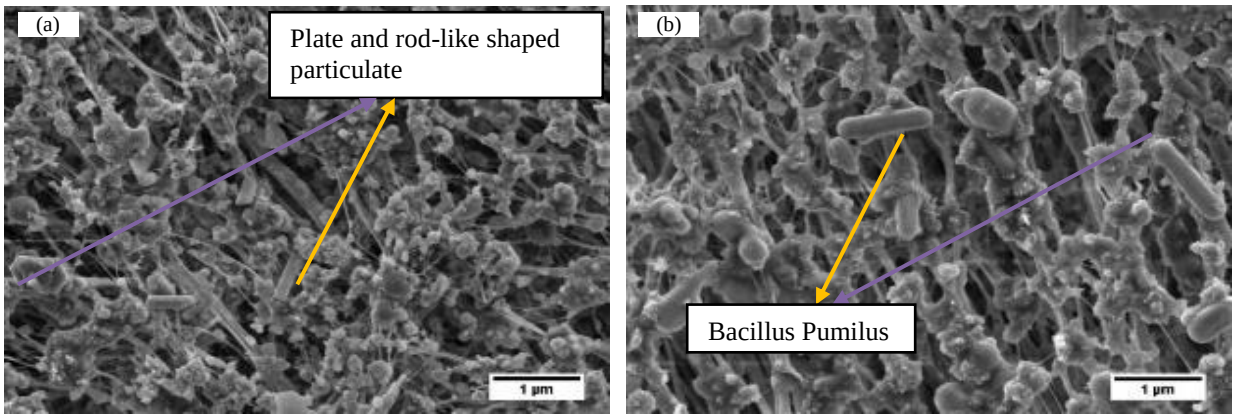
3.4. *Morphological analysis of PM_1 at HOS location*

A total of four samplings were carried out at HOS location during the study period and following are the observations:

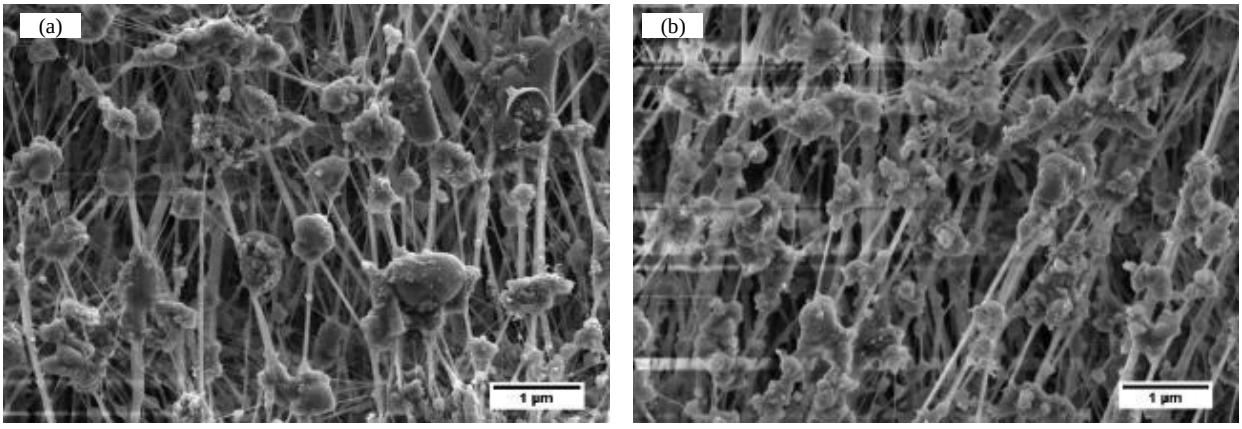
The SEM image morphology for the location HOS [Fig. 5(a)] shows the presence of spherical and irregular



Figs. 5(a&b). SEM image of PM_1 at HOS (a) in August month and (b) a day before Diwali



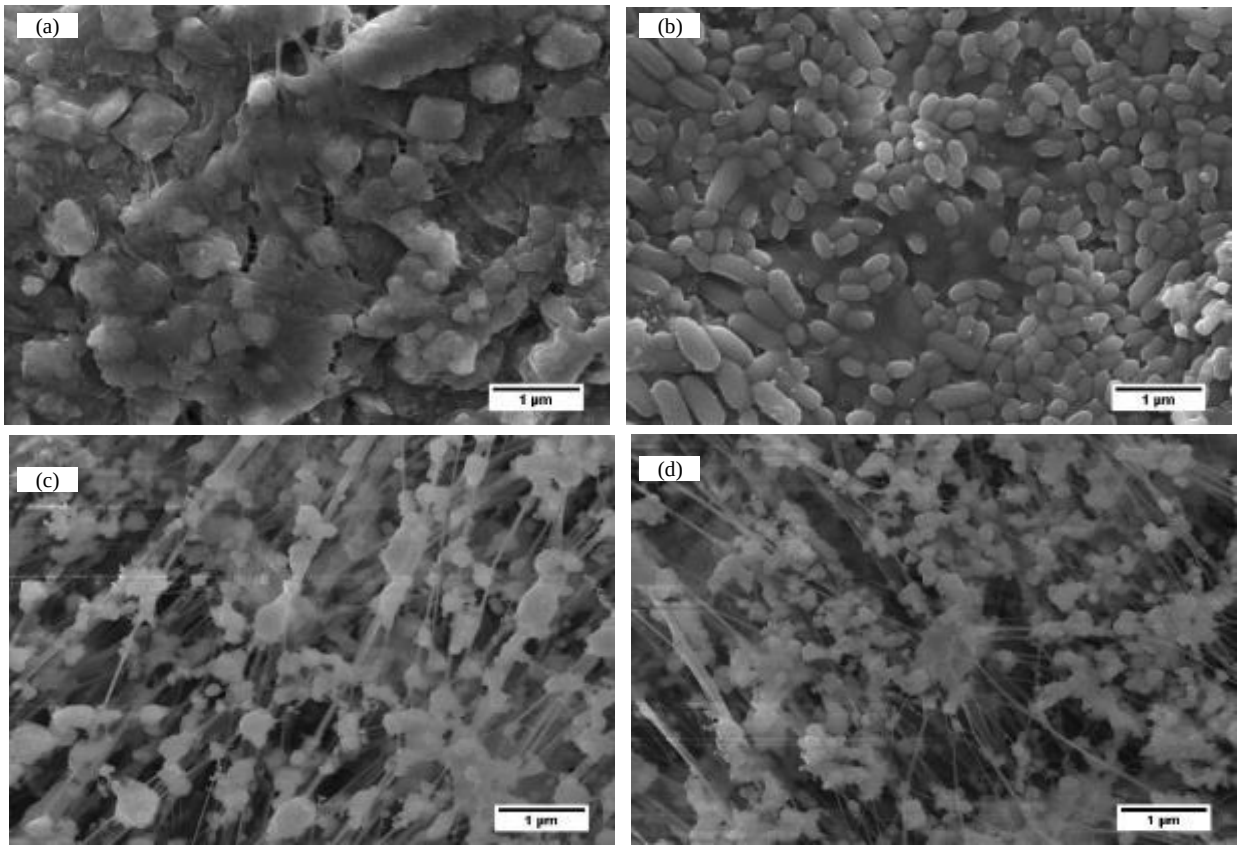
Figs. 6(a&b). SEM image on of PM_1 at (a) the day of Diwali and (b) HOS in December month



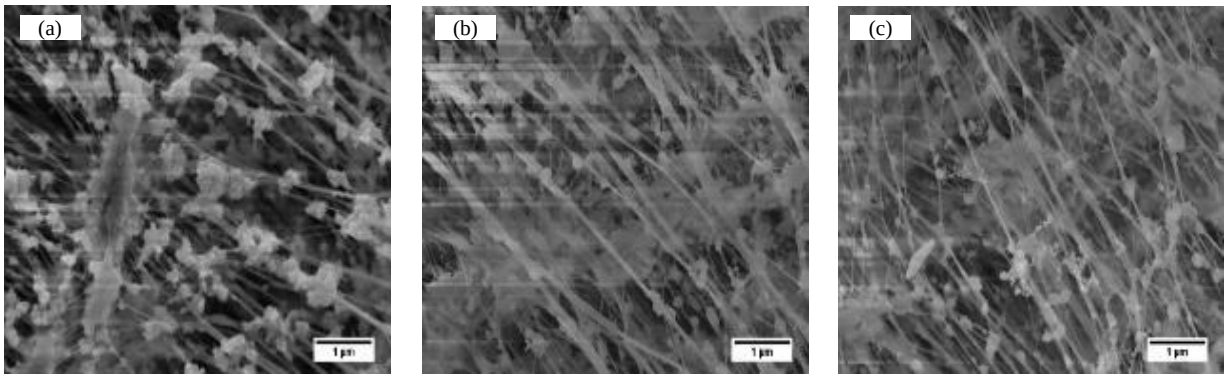
Figs. 7(a&b). SEM image of PM_1 sample collected at DOM (a) December and (b) January months

shaped particles with smooth and rough surface area. The elemental compositions are as follows Carbon, Oxygen with 29.89 weight % and 1.65 weight % respectively with traces of Phosphorus.

Particulates with different morphologies has been observed for the location HOS during Diwali festival (5-6 November, 2018). On 5th November, 2018, the particulates were spherical and irregular in shape with



Figs. 8(a-d). (a&b) SEM image of PM_1 sample collected at DOM in February, March with micro-organism studies and (c&d) April and May without micro-organism studies respectively



Figs. 9(a-c). SEM image PM_1 sample collected at (a) DOM June month and (b&c) DCH of June and July

smooth and rough surface area [Fig. 5(b)]. The elemental composition on previous day of Diwali was Carbon 58.64 weight %, Oxygen 28.77 weight %, Nitrogen 11.66 weight % and traces of sulphur. Whereas on 6th November, 2018, along with spherical and irregular shape, the particulates are observed to have plate like, rod like structures with smooth and rough surface area [Fig. 6(a)] with elemental composition of Carbon 50.30 weight %,

TABLE 2

Mass concentration and elemental composition of each sampling during study period over Bengaluru

Seasons	Month	Location	Source	PM_1Mass concentration ($\mu g\ m^{-3}$)	Elemental composition	Annual Average PM_1 Mass concentration ($\mu g\ m^{-3}$)
Monsoon 2018	**June**	**No data**				**48.40**
	July	**BAS**	**Primary and Secondary**	**50.87**	**C and O**	
	August	**HOS**	**Primary and Secondary**	**27.70**	**C, O and P**	
	September	**No data**				
Post-Monsoon 2018	October	No data				
	November (2 sampling)	HOS	Primary and Secondary	31.21 and 46.31	C, N, O, Al, S and K	
	December (3 sampling)	BAS, HOS and DOM	Secondary, Primary and Secondary	68.64, 67.77 and 46.36	C, N, O, S and P	
Winter 2019	**January (3 sampling)**	**DOM and BAS**	**Secondary, Secondary and Biological**	**38.35, 42.28 and 43.19**	**C, N, O, S, P, Na, Cl and K**	**35.74**
	February	**BAS**	**Biological**	**26.75**	**C, N, O, Si, P and S**	
Summer 2019	March	DOM	Biological	40.54	C, N and O	
	April	DOM	Biological	53.52	C, N, O, Si, P, S, Na, Cl and Ca	
	May (2 sampling)	DOM	Primary and Secondary	33.60 and 33.33	C, O and S	
Monsoon 2019	**June (2 sampling)**	**DOM and DCH**	**Primary and Secondary**	**20.12 and 34.48**	**C, N, O, Na and S**	
	July	**DCH**	**Primary and Secondary**	**27.02**	**C, O, Al and S**	
	August	**No data**				
	September	**No data**				

Oxygen 41.89 weight %, Nitrogen 5.44 weight % and traces of Aluminium, sulphur and potassium.

The morphology of collected samples at HOS location in December [Fig. 6(b)] shows spherical shaped particulates with smooth and rough surface area. Rod shaped particulates were found which may be Bacillus pumilus as observed in the study made by Flavien Pillet *et al*., 2006. The elemental composition was found to be Carbon 56.17 weight %, Nitrogen 12.09 weight %, Oxygen 30.92 weight % with traces of Potassium and Sulphur.

3.5. *Morphological analysis of PM_1 at DOM location*

Seven samplings were carried out in DOM location during the study period. Following are the observations:

The samplings were carried out in December and January months and on both days of sampling, the particulates were found to have irregular shape with rough surface area [Figs. 7(a&b)]. The elemental composition during these two samplings were Carbon 56.85 weight %, Nitrogen 15.31 weight %, Oxygen 26.98 weight % with

traces of Sulphur and Potassium and Carbon 52.36 weight %, Nitrogen 19.81 weight %, Oxygen 27 weight % with traces of Sulphur and Potassium respectively.

Two samplings made during the months of March and April were again used for the study of presence of microorganism. The SEM images of these samples [Figs. 8(a&b)] once again confirms the presence of microorganism bacteria Bacillus with rod shaped morphology along with some particles having cubical shape with smooth surface area which may be Sodium Chloride.

The elemental composition is found to be Carbon 36.63 weight %, Nitrogen 2.10 weight %, Oxygen 6.50 weight %, Sodium 5.32 weight % and Chlorine 3.89 weight % and Carbon 47.31 weight %, Oxygen 25.05 weight %, Nitrogen 10.32 weight %, Sodium 3.12 weight % and traces of Silicon, Phosphorus, Sulphur, Chlorine and Calcium respectively.

The morphology of sampling collected in the month of May showed the presence of particulates in ambient air with spherical & irregular shape having rough and smooth surface area [Fig. 8(c)]. The elemental composition was found to be Carbon 31.31 weight %, Oxygen 2.62 weight % with traces of Sulphur.

The morphology of sampling made during the months of May and June shows that the particulates are regular and irregular in shape with smooth and rough surface area [Figs. 8(d) - 9(a)] and elemental composition is found to be Carbon 29.37 weight %, Oxygen 2.68 weight % with traces of Sulphur and Carbon 33.91 weight %, Oxygen 3.63 weight % and traces of Nitrogen, Sodium and Sulphur respectively.

3.6. *Morphological analysis of PM_1 at DCH location*

A total of two samples were carried out in the study period for this location and following are the observation:

The morphology of sampling carried out in the month of June and July shows that the particulates are regular and irregular in shape with smooth and rough surface area [Figs. 9(b&c)]. The elemental composition is found to be Carbon 29.61 weight %, Oxygen 1.06 weight % and traces of Aluminium and Sulphur and Carbon 29.33 weight %, Oxygen 1.50 weight % with traces of Sulphur.

The morphology of particulate matter during the study period is found to be spherical in shape with smooth surface area which shows that the source of PM_1 in ambient air is mainly from anthropogenic activities such as vehicular traffic, industrial activities, bio mass burning. The spherical nature of PM_1 indicates that the source is from vehicular emission and industrial activities with carbon dioxide as the major pollutant (Table 2). However, particulates having irregular shape with rough surface area identify the source of PM_1 as due to dust particles and resuspension of road dust. The EDAX analysis made for all the samples observed a following standard deviation in the elemental composition of Carbon, Nitrogen and Oxygen is 10.77 weight %, 12.02 weight % and 12.77 weight % respectively.

4. Conclusions

The PM_1 mass concentration has been carried out at four different locations of Bengaluru city Basavangudi (BAS), Hosur road (HOS), Domlur (DOM) and DC Halli (DCH). The highest mass concentration of PM_1 was observed to be 68.64 $\mu g/m^3$ at BAS and lower value of 20.16 $\mu g/m^3$ at DOM. Meteorological parameters such as temperature, wind speed and relative humidity contributes significantly to the variation of PM_1 mass concentration values. SEM-EDAX analysis for understanding the morphology and elemental composition of PM_1 shows that particulate matter has both irregular and regular shape with smooth and rough surface area. This indicates that source of PM_1 is from both anthropogenic and natural activities. The micro-organism studies of few samples show the presence of bacteria such as Bacillus and Bacillus pumilus which may have effect on human health leading to food poisoning, anthrax etc. EDAX analysis shows the presence of non-metals as well as metals and most abundant non-metal elements were Carbon, Oxygen, Nitrogen, Sulphur and Potassium. The traces of observed metals are Sodium and Calcium. These non-metals and metals may have direct or indirect effect on human health as the presence of higher weight % of Carbon and Oxygen in ambient air may lead to lungs disorder. However, for a clear understanding of the dynamics of particulate matter a greater number of samplings to be done with different spatio-temporal scenarios which will be taken care in the upcoming studies.

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