Spatiotemporal and Source Analysis of Ultrafine Particulates (PM1) over Bengaluru, Karnataka, India

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Research

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Abstract

Measurement and analysis of Particulate Matter (PM_1) of aerodynamic diameter less than 1μm (PM_1) has been carried out using indigenously built air sampler APM 577 from IIT-K for the period July 2018 - July 2019. Bengaluru being one of the megacities of India requires constant follow up of air quality. Following locations of Bengaluru city have been selected for the study: Basavanagudi (BAS), Domlur (DOM), Hosur road (HOS) and DC Halli (DCH). The mass concentrations of collected PM_1 samples have been observed to vary from 20.16 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 seasonal average mass concentration of PM_1 around Bengaluru for winter, summer, monsoon & post monsoon season during the entire study period is observed to be 47.60, 40.24, 30.85 and 38.76 μg m^{-3} respectively. 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 μg m^{-3} for $PM_{2.5}$ however in January and February months mass concentration is found to be less than the standard limit. The Scanning Electron Microscope-Energy Dispersive Analysis X-ray techniques were used to understand the morphology and elemental composition of PM_1. Scanning electron microscope images confirms the presence of particulates both from anthropogenic (primary) and natural (secondary) activities. Also, some of the collected samples showed the presence of microorganisms and biological particles such as Bacillus. Elemental composition analysis showed the presence of non-metals such as Carbon, Oxygen, Nitrogen, Sulphur and traces of metals such as Sodium, Aluminium, Calcium and Potassium. A detailed study along with the possible conclusion is the subject matter of this paper.

Introduction

Air pollution is caused due to very small liquid and solid particles suspended in the air which constitutes Particulate Matter (PM). Based on 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 to 10 μm ($PM_{2.5}$-PM_{10}). The fine fraction contains smaller particles with size up to 2.5 μm ($PM_{2.5}$) and the particles having size smaller than 0.1 μm are called ultrafine particles.

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) as suggested by Wilson et al. [1]. The size and chemical composition of PM_1 has a strong influence on human health, visibility, ecosystem and cloud physics.

The PM_1 in atmosphere leads to the common lung and pulmonary diseases in human beings as stated in Delfino et al. [2] and such disease leads to alteration in morphology and functions of the epithelial cells as observed in the work of Ramgolam et al. [3]. Physical (size and morphology) and chemical

(composition) characterization of atmospheric particles has received significant importance due to their effect on radiative and chemical properties. A detailed characterization of atmospheric particles provides useful information about their sources, atmospheric history, formation, reactivity, transport and removal of atmospheric chemical species as stated in Lu et al. and Adachi and Tainosho [4, 5]. Also, composition of PM_1 plays a very important role in chemical characteristics and its effect on ecology and environment as stated in Marmur et al. [6]. The surface area is predominating in particles of size less than 2.5 μm whereas mass is predominating in coarse particles.

PM are strongly affected by meteorological parameters such as precipitation, mixing layer height, temperature, air mass origin and season as mentioned in Jacob and Winner [7] and Spindler et al. [8]. 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 as suggested by Fransen et al. [9]. The higher levels of PM concentration were during the winter months due to more frequent temperature inversions in winter combined with lack of precipitation as stated in Aryal et al. [10].

Atmospheric PM is 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 as observed in the work of Pope and Dockery [11]. Bengaluru Being one of the mega cities of India requires thorough monitoring of air quality. An attempt has been made in this study by covering as much locations as possible to bring out the concentrations, morphology and elemental composition of collected PM_1 samples across Bengaluru.

Methods And Material

2.1 *STUDY AREA*

Bengaluru is known as one of the World's dynamic Indian city and capital of Karnataka state, IT capital of India which is located between 77º24'E-77°28'E and 12°46'N-13°11'N. It is situated at a height of about 920 m above 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 the job seekers. According to latest vehicles statistics released from RTO, the total number of vehicles registered in 2016 is 61,12,897 whereas in the year 2017 it is 68,33,080 (www.transport.karnataka.gov.in) [12]. Hence there is about 11.78% increase in total vehicles on Bengaluru roads in just one year which in turn adds on to the total particulate load of the atmosphere.

The summer season in Bengaluru is from April to June with temperature between 22 to 33 °C and the Relative Humidity (RH) varies from 40 to 68%. During monsoon season which starts from June to September, the temperature varies from 18 to 30 °C and RH varies from 70 to 80%. Post monsoon season which starts from October to November, records temperature from 19 to 28 °C and RH from 88 to 97%.

Winter season starts from December to February, with temperature between 16 to 28 °C and the RH from 52 to 68%.

The major contribution to air pollution in Bengaluru is due to the following: vehicular traffic, 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 everyday construction activities (http://dcmsme.gov.in) [13].

The meteorological parameters such as atmospheric temperature, wind speed, wind direction and relative humidity plays a vital role in changing the concentration of particulate matter in the atmosphere. The average temperature, wind speed and relative humidity over Bengaluru during study period July 2018 to July 2019 is shown in Table 1.

2.2 *EXPERIMENTAL PROTOCOL*

Sampling to determine mass concentration and source analysis of PM_1 was carried out on the terrace of a two floor building in Bengaluru at different locations such as Basavanagudi (BAS) (12.94º N and 77.56º E), Hosur Road (HOS) (12.89º N and 77.64º E), Domlur (DOM) (12.95º N and 77.63º E) and DC Halli (DCH) (12.89º N and 77.62º E) over a period of one year as shown in Fig.1. These locations are selected for the study as they are having high vehicular traffic with large number of residential houses as identified by Karnataka State Pollution Control Board [14]. The maximum sampling frequency was thrice in a month except during monsoon and pre monsoon season.

We have used portable APM-577M sampler, indigenously built by Envirotech and Indian Institute of Technology – Kanpur to measure PM_1 concentration. The PM was collected on a PolyTetraFluoroEthylene-PTFE filter paper with diameter 47 mm. The PM_1 sampler operates without any voltage fluctuation. With the help of a critical orifice, the air flow rate was maintained at 10 L min^{-1}. 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 with a filter paper of 27 mm designed to trap particles having size more than 1 µm. The fine particles of PM_1 are collected on the PTFE filter paper for a period of 24 h. The collected PM_1 on filter paper was incubated for 24 h with 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 (µg) 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 has been carried out so that accurate mass concentration of the PM_1 in actual ambient air can be determined.

Typical calculation:

Initial air volume = 11.0464 m^3

Final air volume = 24.8068 m^3

Total air volume = (Final air volume-Initial air volume) = 13.7604 m^3

Initial mass of filter paper = 0.1414 g

Final mass of filter paper after 24 h= 0.1421 g

Mass of PM_1 collected on filter paper = (Initial mass of filter paper- Final mass of filter paper after 24 h) = 0.0007 g

See formula 1 in the supplementary files.

2.3 *SEM-EDAX*

PM_1 samples were analysed by Scanning Electron Microscope (SEM)-Energy Dispersive Analysis X-ray (EDAX) TESCAN-VEGA3 at BMS College of Engineering, Research and Development facility centre. The SEM-EDAX analysis was carried out with the help of computer-controlled field emission SEM equipped with an EDAX for all the samples to avoid uncertainty in determining the elemental composition. The filter papers were cut in 1 mm^2 from each sample and 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 samples were placed in the SEM-EDAX chamber. Working conditions were set at an accelerating voltage of 5 kV and a beam current of 1 pA to 2 μA is passed. Images were taken at a magnification of X2000, X5000, X10000 and X20000. Six samples were analysed at a time.

2.4 *MICRO-ORGANISM ANALYSIS*

The collected samples of PM_1 were used to study the presence of microorganism using Lysogeny broth (LB)- Agar procured by Sigma- Aldrich which acts as a growth medium. The LB-Agar powder of 37 g contains 5 g of peptone,10 g of peptone from casein, 10 g of Sodium Chloride and 12 g of Agar-Agar. The medium of LB-Agar was prepared using 8.14 g pre mixed powder of LB-Agar and a 500 mL of sterile water was added to make it 200 mL of LB-agar medium. The gel was now placed for autoclave at 12 °C under 30 psi for 30 min. High pressure was used to prevent the gel mix from boiling over high temperature.

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 earlier. A total of 18 samplings were made during the study period. In general, it is observed that the mass concentration values were found to vary from 21.27- 68.64 μg m^{-3}. The average mass concentration in winter, summer, monsoon and post monsoon seasons were observed to be 47.62, 40.25, 32.05 and 38.76 μg m^{-3} respectively. The lowest mass concentration of 20.16 μg m^{-3} was recorded in the month of June 2019 which is monsoon season and highest mass concentration of 68.64 μg m^{-3} was recorded in December 2018 which is winter at BAS location. The highest value 68.64 μg m^{-3} of PM_1 mass concentration observed during winter season was consequently higher than $PM_{2.5}$ National Ambient Air Quality Standard (NAAQS) 24 h standard limit of 60 μg m^{-3} (data.gov.in) [15]. The observed PM_1 mass concentration is being compared with $PM_{2.5}$ NAAQS 24 h standard limit since PM_1 limit value has not been legislated as referred by E Koulouri et al. [16].

Washout of atmospheric particles due to rain during monsoon season might be the reason for observed lower mass concentration. Highest mass concentration observed in winter may be due to the temperature inversion in ambient air. It is to be noted that the mass concentration values are having dependency on environment sampling location.

The dependence of PM_1 mass concentration with temperature, Relative Humidity (RH) and wind speed is shown in Fig. 2. The mass concentration with temperature, wind speed and RH showed a negative correlation, the extent of correlation is listed in Table 1a. 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 Fig. 2a. 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 results in positive correlation. Once the particle growth exceeds a threshold limit then due to gravity settling all the particles settles down resulting in negative correlation Fig. 2a between mass concentration and RH as studied by GE Shaw et al. [17].

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. [18]. Direct evidence of the composition and morphology of aerosol particles can be provided by single particle analysis as suggested by Geng et al. Ro et al. Utsunomiya et al. [19-21]. 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. [22]. The morphology relates to chemical composition as well as toxicity if the compounds are organic as identified by Borgie et al. [23].

In the present study, we have also used EDAX technique to identify elemental composition. As suggested by Atar Singh et al. [24] EDAX gives almost accurate elemental composition of PM_1. But, sometimes 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. The detection limit of EDAX is typically about 0.2-0.5% as discussed in Seifollah and Shokrollah [25].

3.2.1 *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. 3a 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.

The morphology of PM_1 was carried out in December month. As shown in Fig. 3b 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. 4a. 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 micrometre sizes as suggested by Ya-fen Wang et al. [26]. 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. 4b as observed in the work of Christine G et al. [27]. 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. 4c 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.

3.2.2 *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. 5a shows the presence of spherical and irregular 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 smooth and rough surface area Fig.5b. 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. 6a with elemental composition of Carbon 50.30 weight%, 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. 6b 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. [28]. 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.

3.2.3 *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 Fig. 7a -7b. 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 Fig. 8a - 8b once again confirms the presence of microorganism with rod shaped morphology that is bacteria Bacillus 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. 8c. 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 Fig. 8d-9a 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.

3.2.4 *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 Fig. 9b-9c. 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. 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.

Conclusion

The PM_1 mass concentration analysis for four different locations of Bengaluru city showed the highest mass concentration 68.64 μg m^{-3} at BAS location and lower value of 20.16 μg m^{-3} at DOM location. A significant contribution from meteorological parameters such as temperature, wind speed and relative humidity has been observed in the variation of PM_1 mass concentration values across Bengaluru city. SEM-EDAX analysis for understanding the morphology and elemental composition of PM_1 shows that particulate matter has both irregular and spherical shape with smooth and rough surface area indicating

that the source of PM_1 is from both anthropogenic (primary) and natural activities (seconadry). The micro-organism studies of few samples showed 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 showed the presence of non-metals and most abundant non-metal elements were Carbon, Oxygen, Nitrogen, Sulphur. The traces of metals observed are Sodium, Aluminium, Calcium and Potassium. 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. With the available time and resources this work has been carried out. However, for a clear understanding of the dynamics of particulate matter more number of samplings to be done with different spatio-temporal scenarios.

Declarations

Availability of data and material

The data is available is included in the article as supplementary material

Competing interests

The authors declare that they have no competing interests

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Authors' contributions

Author and co-author have read and approved the final manuscript.

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Tables

Table 1. meteorological data over Bengaluru during the study period.

Month	Temperature °C	Wind Speed km h^{-1}	Relative Humidity %
July	24.2	10.5	63
Aug	23.6	9.3	88
Nov	23.7	4.7	97
Dec	23.2	4.3	88
Jan	22.2	5.1	51
Feb	25.0	5.1	56
Mar	28.3	4.0	55
Apr	29.4	2.8	54
May	32.1	3.2	74
June	30.3	7.1	94
July	29.5	8.4	97

Table 1a. correlation statistics of RH, temperature and windspeed with mass concentration

	Pearson's r	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	-0.366	0.080	29.755	-0.095	2.554	0.061
Windspeed	-0.327	0.051	7.518	-0.051	1.564	0.037

Table 2. shows the mass concentration and elemental composition of each sampling during July 2018 – July 2019

Month	Location	Source	Mass concentration µg m^{-3}	Elemental composition
July	BAS	Primary and Secondary	50.87	C and O
August	HOS	Primary and Secondary	27.70	C, O and P
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
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
February	BAS	Biological	26.75	C, N, O, Si, P and S
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
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

Figures

Figure 1

PM1 sampling locations in Bengaluru

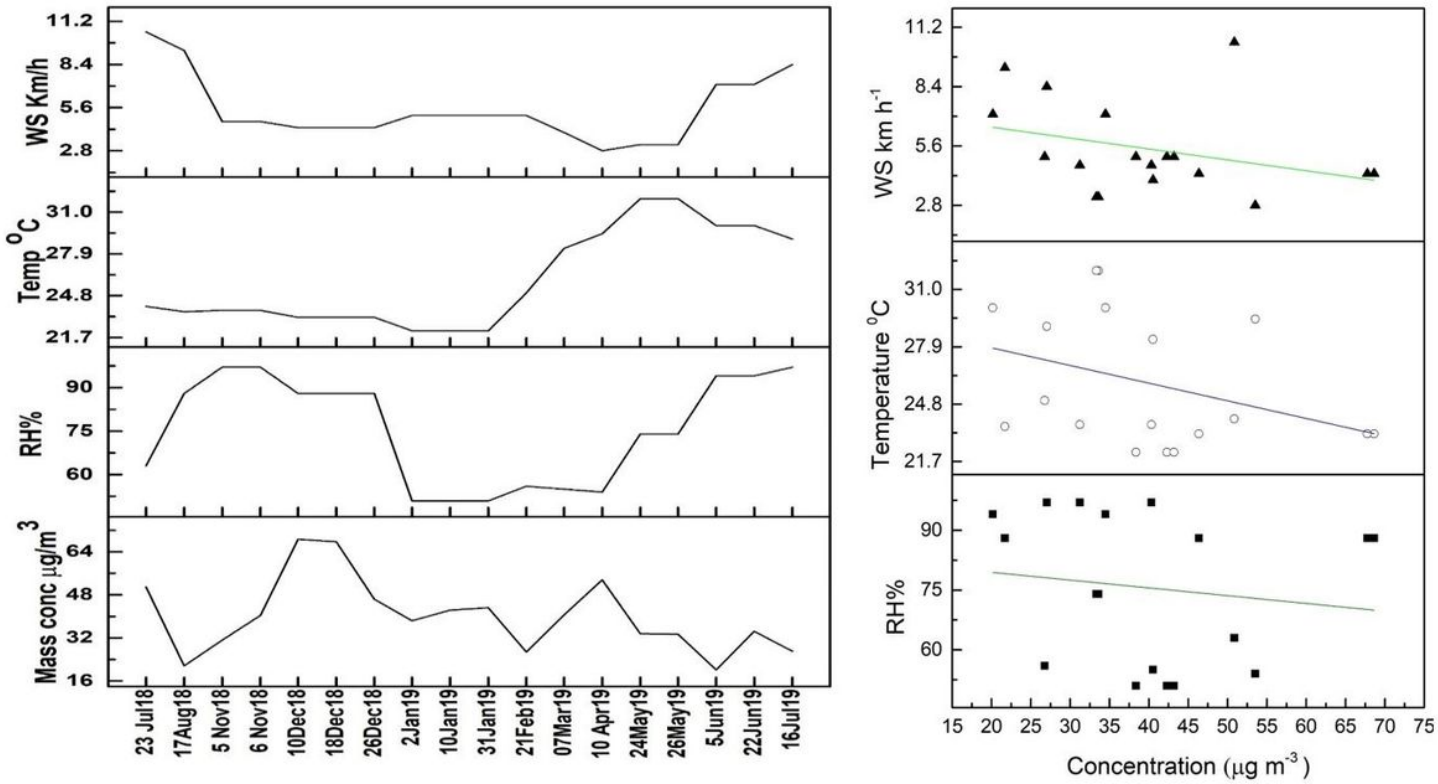

Figure 2

Mass concentration and meteorological parameters during sampling dates. Correlation of meteorological parameters with PM1 Mass concentration

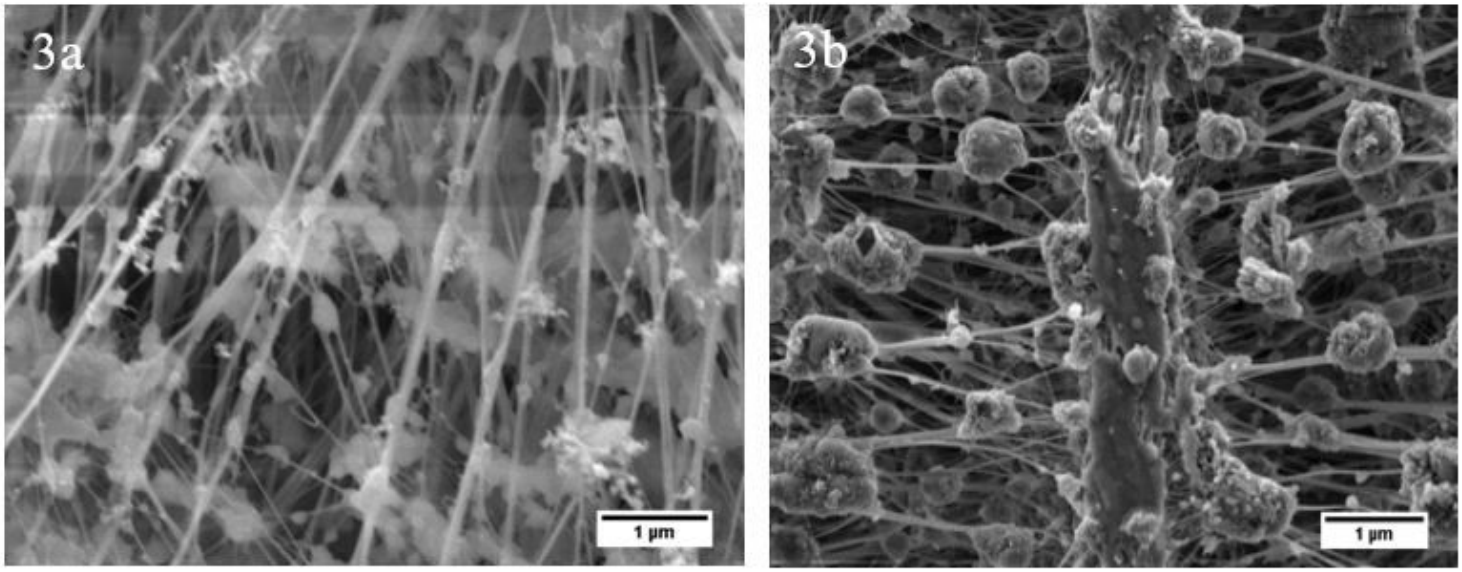

Figure 3

SEM image of PM1 at BAS in July month. SEM image of PM1 at BAS in December month

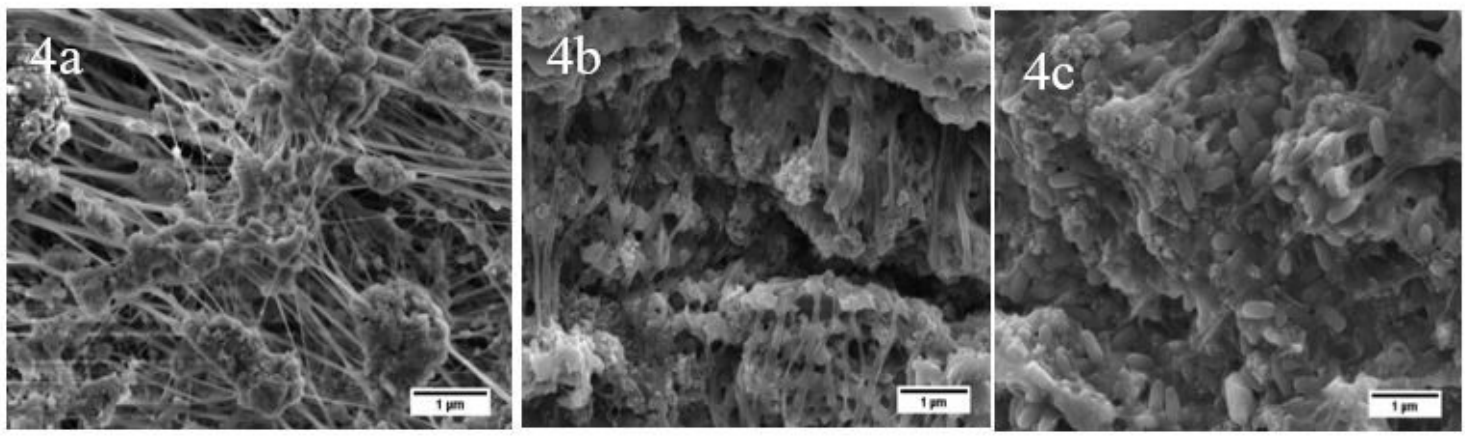

Figure 4

4a SEM image of PM1 sample collected at BAS location in January month without micro-organism studies Fig. 4b-4c SEM image of PM1 sample collected at BAS in January month and micro-organism studies

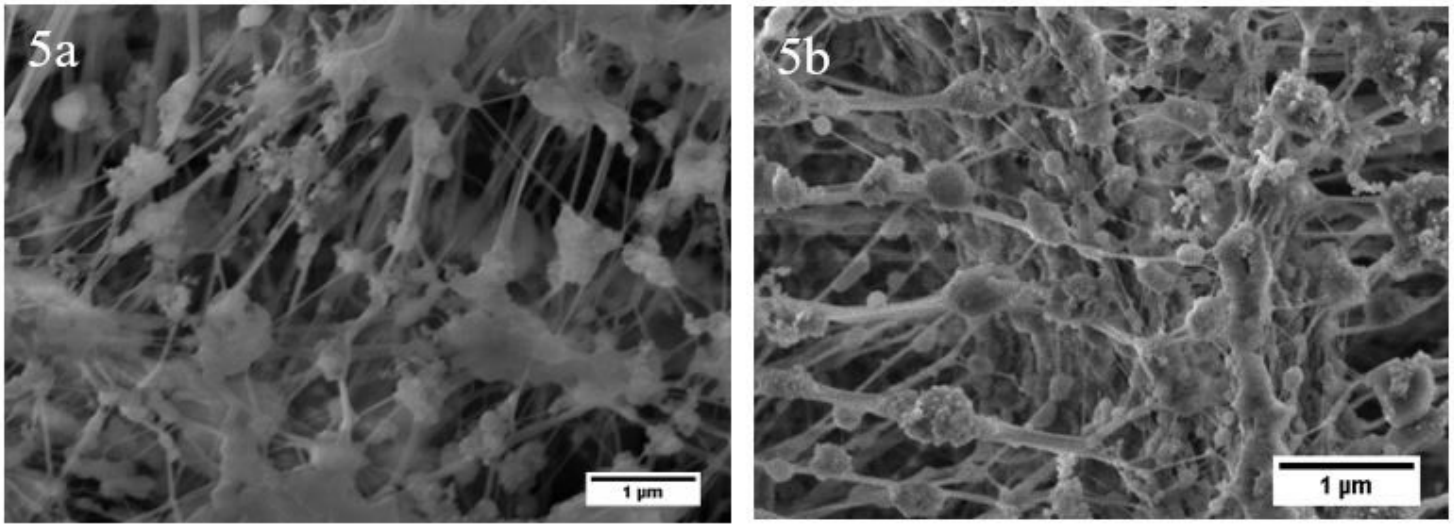

Figure 5

SEM image of PM1at HOS in August month. 5b SEM image of PM1 at HOS a day before Diwali

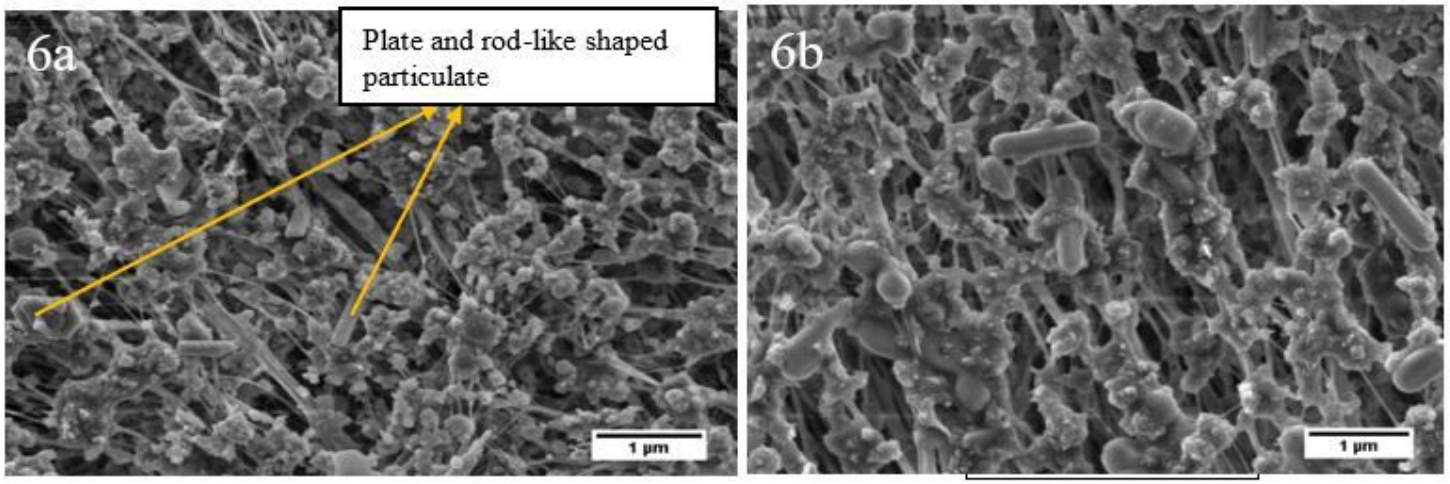

Figure 6

SEM image on of PM1 at the day of Diwali . 6b SEM image of PM1 at HOS in December month

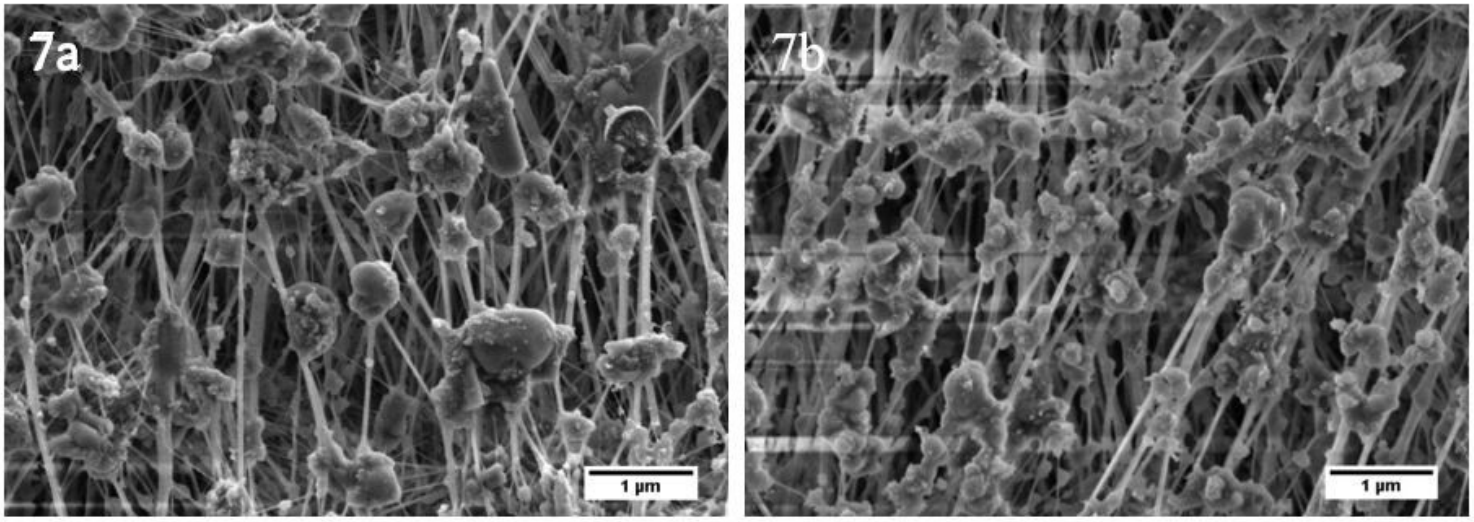

Figure 7

SEM image of PM1 sample collected at DOM . SEM image of PM1 sample collected at DOM

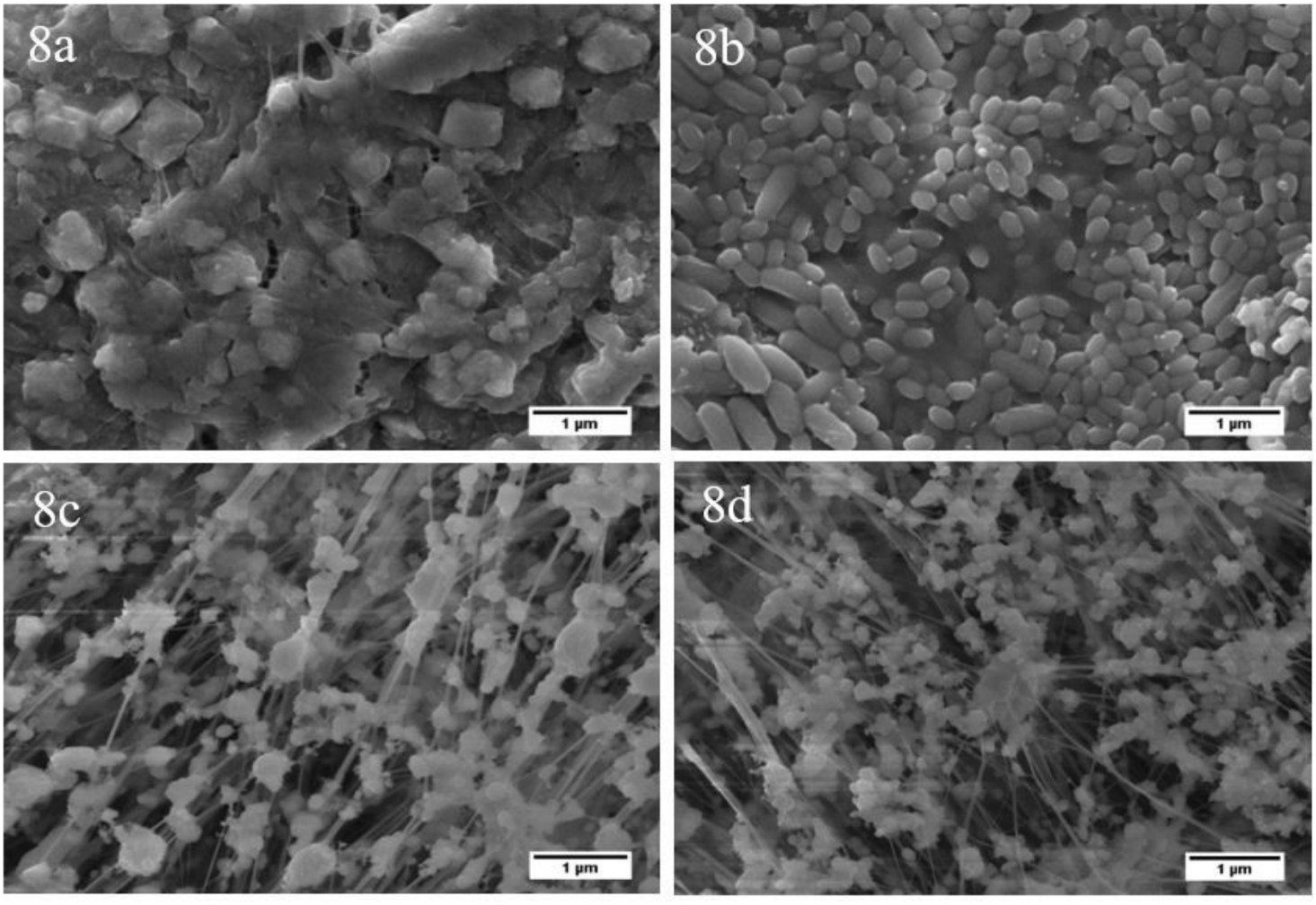

Figure 8

SEM image of PM1 sample collected at DOM in February, March with micro-organism studies. Fig. 8c-8d SEM image of PM1 sample collected at DOM in April and May without micro-organism studies respectively.

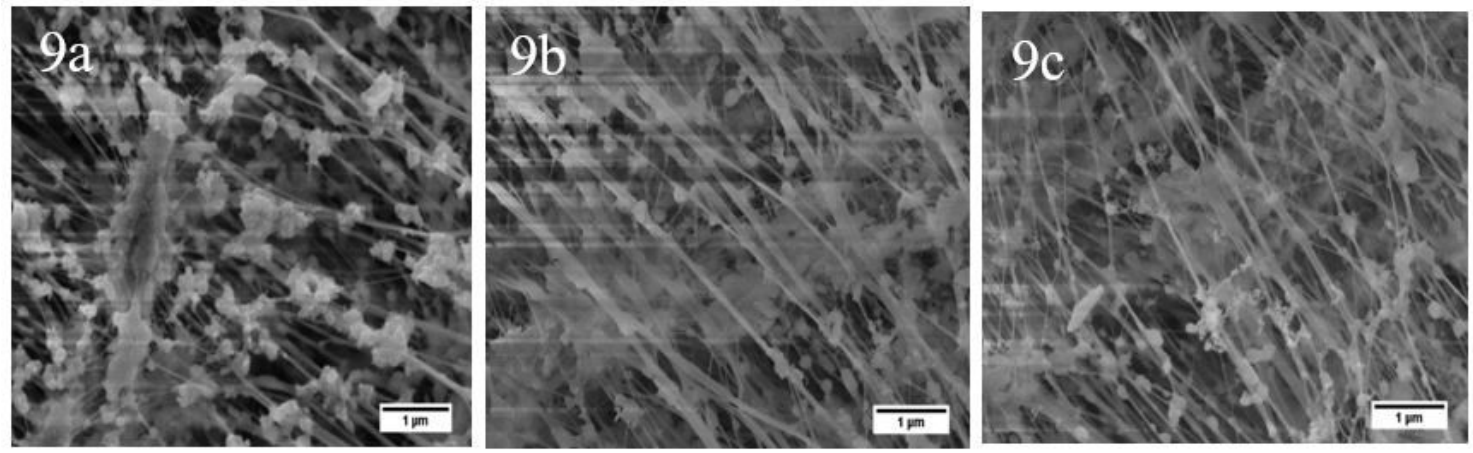

Figure 9

SEM image PM1 sample collected at DOM June month and Fig. 9b-9c SEM image PM1 sample collected at DCH of June and July.

Supplementary Files

This is a list of supplementary files associated with this preprint. Click to download.

- PM1datasheet1.xlsx