Measuring and monitoring construction dust using mobile phone cameras

Dust is a generic term used to describe fine particles that are suspended in the atmosphere. Sources of dust emitted directly into the air are due to vegetation, burning of biomass, industrial and construction of activities, wind-blown, etc. Dust can be defined in practical terms as any particle from a few nanometres (nm) to a few micrometres (μm) in diameter that can become suspended in the atmosphere. According to the British Standard code (BS 6069-2)[1] dust is defined as a solid particulate matter (PM) 1–75 μm in diameter. Dust can be formed due to particles which are emitted directly and secondary particles which are formed by chemical processes in atmosphere. Particle size is an important factor influencing the dispersion and transport of dust in the atmosphere and its effects on human health. Particles less than 10 μm in diameter (known as PM_{10}) are often inhalable, while particles less than 2.5 μm are considered respirable (known as $PM_{2.5}$). Particle size less than 10 μm can cause health hazards, whereas those greater than 10 μm are associated with public perception and nuisance[2]. PM10 is of more concern to human health as the particles can enter the lungs, causing breathing and respiratory problems, with long-term health effects. These particles also carry adhered carcinogenic compounds into the lungs[3].

Construction dust consists of direct particulate matter which is emitted due to construction work on ground, and poses a great problem for health and environment. In India, there is a regulation that dust concentration during construction must be less than 2.5 mg/m^3 (Central Pollution Control Board (CPCB)). However, dust measuring, monitoring and counter measures have not been properly implemented so far because dust measurements are expensive. In India, the construction industry is the second largest employer next to agriculture; it employs around 10 million people. The annual turnover of the construction industry is more than 6% of the national GDP. It is one of the most vulnerable segments in terms of safety and health-related incidents in comparison with the other sectors. Several research and engineering techniques have been developed to provide dust-monitoring measures at construction sites. Recently, in construction sites in Japan, digital camera-based methods for measuring dust were introduced. Further, these methods are improved by introducing innovative techniques using mobile phone cameras, because the performance of these cameras has improved significantly. Shinji[4] initially developed an innovative, handy and quick dust-monitoring method using a mobile phone camera to measure the dust concentration at a construction site. This new method is more economical, easy to perform and also has a high correlation with digital dust indicator (DDI).

The objective of this study is to investigate the implementation of mobile phone camera-based dust-measuring technique to plan and execute the dust-management system at a construction site. The developed methodology is implemented for monitoring at Central College metro station in Bangalore. This method is quite useful to the workers at the construction site to take precautions based on the level of dust concentration. The mobile monitoring system was calibrated and validated against the traditional DDI method to assure statistical validity. The result of this measurement was also displayed on a colour panel at the construction site so that workers could take required precautions accordingly.

Where particulate matter is considered to be the main ambient air pollutant, two dust fractions are commonly used in monitoring programmes, PM_{10} and $PM_{2.5}$. The PM_{10} includes particles with an aerodynamic diameter up to 10 μm and $PM_{2.5}$ represents particles with an aerodynamic diameter up to 2.5 μm. Aerodynamic diameter is defined as the diameter of a hypothetical sphere of density 1 g/cm^3 having the same terminal velocity in calm air as the particle in question, regardless of its geometric size, shape and true density[5].

Dust can be divided into four categories: generated dust, total suspended dust, nuisance dust and fugitive dust nuisance[2]. The scope of this study is measuring and monitoring of construction dust which is mainly due to generation at construction sites. To evaluate the impact of dust on human health due to exposure to dust or to investigate the effectiveness of dust control measures, one must have a method for the evaluation of dustiness. Many methods have been used in the literature to measure the dustiness at construction sites – particle mass-based methods or particle count method, particle light scattering methods and particle light absorption methods, mobility measurements and chemical components and precursor gases equipment. Particle count method was developed based on air as it enters and exits the filter. Filter efficiency is the ratio of particles trapped by the filter to the total number of particles found in the air upstream of the filter. Mass concentration method is the simplest among the dust-measuring methods to determine the total weight of dust collected in a given volume of air. In gravimetric method air passes through the instrument at a desirable rate of 2.5 l/min under the action of a diaphragm pump. The major advantage of modern light scattering instruments is that the addition of electronic circuitry permits a combination of immediate readout and integration over any chosen time-interval. Hence, they can be employed for both short-term and long-term sampling.

In recent years, because of the performance improvement of mobile phone cameras, they were used to measure the concentration of dust at various constructions sites[4]. This method is easy to handle and inexpensive in long run. The flash photograph taken by the camera is used for the internal processing to quantify the dust density. With the help of artificial neural network (ANN) techniques, the flash photographs can be processed and the most probable dust density can be estimated. For this entire internal processing in the mobile phone, Shinji[4] developed the dust concentration measuring program on a HTC desire Android OS 2.2 version and this was installed in the hand phone. Figure 1 represents the dust measuring mechanism using the mobile phone camera. ANN has been adopted in this study to measure the dust concentration. A neural network consists of a number of inter-connected processing units, commonly referred to as neurons or neurodes. Each of these neurodes receives input signal from other neurodes to which it is connected and each of these connections has numerical weights associated with it. These weights describe the nature and strength of the influence of the network and are adjusted iteratively until the error is reduced within tolerable limit. The validity of dust concentration measured by this method is compared with the traditional dust concentration measures such as DDI.

Bangalore city, the capital Karnataka, occupies an important position not only in the state but also in the country. It is considered as one of the major industrial, commercial and educational centres in southern India. Urbanization in India is more rapid around national capital and state headquarters. Bangalore is no exception to this case. It has the dubious distinction of being the fastest growing metropolis in the country. Similarly, vehicular population has been increasing tremendously, leading to traffic congestion and uncertainties in travel time. To mitigate these problems, mass transit for Bangalore had been started under the Bangalore Metro Rail Corporation Ltd (BMRC). Figure 2 shows the route map of east–west corridor of Bangalore Metro rail alignment phase 1. The red colour alignment shows the underground corridor and the blue alignment shows the elevated corridor.

For the present study, Vishveshwaraya station (Figure 2), also called the Central College station (8.78 km), in the east–west corridor of Bangalore Metro Project phase-I has been considered. In this study four locations were identified to measure dust concentration (Figure 3).

The methodology for dust measuring and monitoring at Central College station is shown in Figure 4. The entire procedure is as follows: taking flash photographs at the identified locations in the study area, calculation of dust concentration, development of database in the server provided by the Indian Institute of Science (IISc), Bangalore, and data analysis and information to the site workers through colour panel.

The traditional digital dust measuring instrument, SIBATA modelled Digital Dust Indicator LD-3K2 model equipped with a laser that measures relative concentration of respirable particles through the intensity of scattered light was used. Prior to monitoring each day, background and span checks were conducted to remove filled air in the detector, and compare the measured value of the light

Figure 1. Dust measuring system using mobile phone camera.

Figure 2. East–west corridor route map of Bangalore Metro.

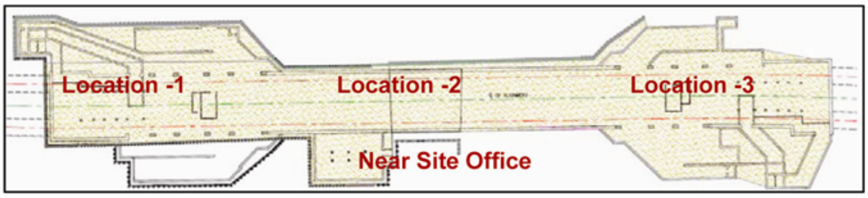

Figure 3. Dust-monitoring at Vishveshwaraya metro station.

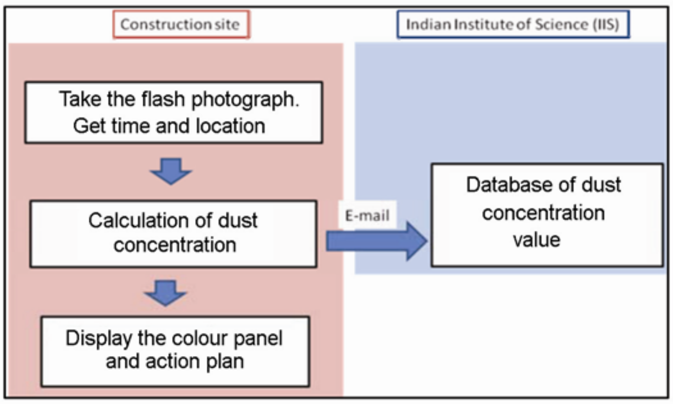

Figure 4. Methodology for dust monitoring in the study area.

scattering plate. The relative concentration of Suspended Particulate Matter (SPM) with size less than 10 μm in diameter was measured every minute, and expressed as counts per minute (CPM). Dust measuring system developed by mobile camera needs calibration before collection of real data. For this, the photographs taken in Dust Box were synchronized with DDI and correlation analysis was carried out after calibration and validation of dust monitoring system (DMS) values.

Correlation analysis was carried out between dust concentration measured by mobile phone camera and that measured by DDI to know the degree of correlation among values obtained by both these techniques. For this, 108 samples were collected simultaneously using both techniques. The sample collection of dust concentration data is spread over various time-periods such as morning, afternoon and evening hours at four different locations of the study area represented (Figure 5). From Figure 5, it can be observed that highly positive correlation ($r = 0.94$) exists between the dust concentrations measured by both the techniques.

Further, regression analysis was carried out to understand the relation between the dust concentrations measured by these methods. The estimated regression model coefficients for the collected sample are presented in Table 1. The sign of the estimated coefficients of the variable is positive; this indicates that the dust concentration measured by the mobile phone camera showed a positive contribution to DDI value. Based on *t*-statistics (greater than 1.95), it can be concluded that there is significant relation among these values. The estimated R^2 values were very high (0.88), which indicates that the uncertainty explained (88%) by these values is very high. Also, observed *F* value is high (799.284) and significance of *P* value is less than 0.005. This emphasizes that the dust concentration measured using the mobile phone camera is significant. Further these values are validated on statistical grounds using standard *t*-test and *F*-test.

The dust concentration data obtained using mobile phone camera were validated against the DDI dust concentration values. Mainly these values are statistically validated by considering Student's *t*-test for significance of difference between the means of observed DDI values and DMS values. *F*-test is also considered for validating the significant difference in variance of observed dust values obtained by both instruments.

The *t*-statistic value is estimated using eq. (1) to assess the statistical validity of mean between the dust measured by mobile phone (DMS) and DDI.

$$t = \frac{x_a - x_m}{\sqrt{\frac{s_a}{N_a} + \frac{s_m}{N_m}}}, \qquad (1)$$

where x_a and x_m are the mean values of dust concentration measured by mobile phone camera and DDI respectively, s_a and s_m are the values of variance of DMS and DDI dust concentration measured respectively, and N_a and N_m are the sample size of DMS and DDI values respectively. It can be observed from Table 2 that the *t*-value obtained by eq. (1) is less than the *t*-critical value for 5% level of significance, which is obtained from the standard *t*-table. This emphasizes that the dust values measured by mobile phone values have no significant difference with dust measured values by DDI.

After validation, DMS is used in the present cut and cover metro construction site. The developed DMS was difficult to use directly under sunshine, to overcome this difficulty, a dust-monitoring chassis box was developed to measure dust concentration. The box is kept open to collect the dust concentration before taking the measurement. Then the box is closed and the flash photograph taken in the dark box.

For the present study, data were collected in three locations (Figure 3). A total of 48 days dust data have been measured in September, October and November 2011. Dust was measured during four different time periods on each day, i.e. at 9.00 a.m., 11.00 a.m., 2.00 p.m. and 5.00 p.m. and four dust samples were collected each time. The average concentration for each time-period was estimated for each sample for each location. This was considered in the analysis and decision-making for an action plan. The sample size collected for various locations is presented in Table 3.

The dust concentration data measured at all the three locations were analysed and summary of statistical parameters such as mean, median, kurtosis, skewness for all the locations were estimated (Table 3). This statistical information of dust concentration is useful to know about the central tendency and variability of dust concentration at the measured locations of the study area during work. Table 3 shows that the mean of dust concentration at location 3 is marginally higher than that in the other locations. The standard deviation for this location is also higher (1.78 mg/m^3). The kurtosis value provides a measure of the 'peakedness' of dust concentration. Location 1 has a higher kurtosis value indicating high peak values and less variability than the other locations. It can be observed from the results that the width of the particle size distribution of location 3 is more than those at locations 1 and 2. Dust collected over the entire sampling interval was low, but when dust concentration was expressed in terms of drilling time,

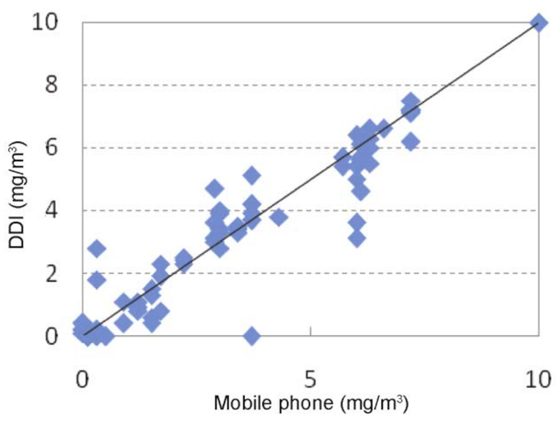

Figure 5. Correlation of dust concentration using mobile phone camera and digital dust indicator (DDI).

Table 1. Coefficients estimated by linear regression analysis

	Coefficients	Standard error	*t* Stat	*P* value
Intercept	0.118	0.148	0.797	0.427
DMS (mg/m^3)	0.945	0.033	28.272	0.000

Table 2. Statistical summary of validation results of measuring dust

Dust values measured by mobile phone camera		Dust measured by digital dust indicator		Student's *t*-test	
Average	Variance	Average	Variance	*t*-value	*t*-critical
3.370	8.418	3.304	8.530	0.168	1.990

Table 3. Statistical summary of the dust concentration measured in the study area

Statistical parameter	Location 1 (sample size 120)	Location 2 (sample size 83)	Location 3 (sample size 118)	Combined (sample size 321)
Mean	1.84	1.91	2.05	1.97
Median	1.33	1.36	1.56	1.36
Standard deviation	1.63	1.62	1.78	1.75
Kurtosis	7.83	7.08	5.55	5.60
Skewness	2.14	2.09	2.03	2.01
90th percentile of dust concentration	3.40	4.0	4.20	4.20

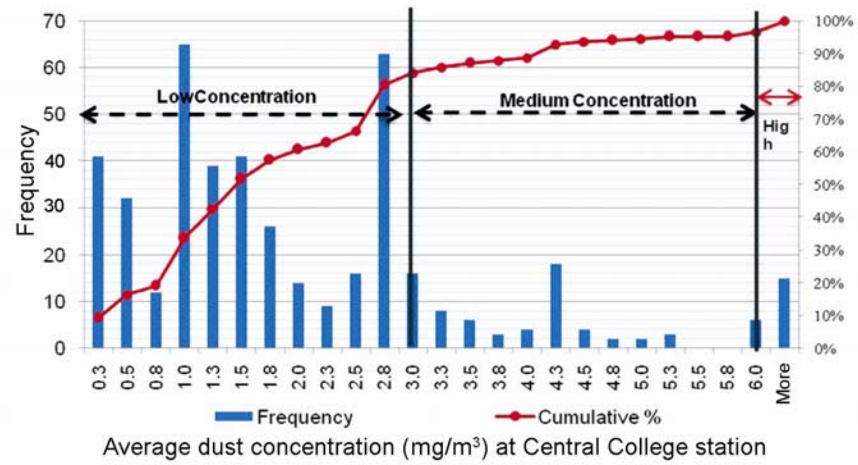

Figure 6. Combined average particle size distribution of samples collected at locations 1–3.

dust exposure increased. Further to discuss this scenario additional and repeated measure of dust concentration is necessary. Based on the observations, it is therefore recommended that the workers should wear filtered dust mask during drilling at the locations.

The probability of particle size distribution of dust concentration of the combined data is presented in Figure 6. It can be observed that all the distributions are skewed to the right. From the cumulative distribution it was observed that the median value (at 50%) is almost the same in all the locations and is about 1.4 mg/m^3, except at location 3 where it is about 1.60 mg/m^3. The 90th percentile of dust concentration levels has crossed the lower safety limit which is 3.0 mg/m^3. That is out of 20 measured samples two samples cross the lower concentration level in all the three locations. Therefore, from the observed results it is strongly suggested that the workers should use at least a simple dust mask while working at any location.

In this study a method has been introduced to measure dust concentration using a mobile phone camera. The method is dynamic and a good alternative to traditional methods such as DDI. This innovative technique has been calibrated and validated before implementation in the study area. For this, the traditional DDI data were considered. From the results of calibration it has been identified that high positive correlation ($r = 0.940$) exists between the dust concentrations measured by DDI and mobile phone camera. Further, the data were validated statistically by using *t*-test. The results show that there is 5% level of significance in the dust concentration measured using mobile phone camera.

Further this method was implemented at the construction site of Central College station, Bangalore Metro and a total of 445 samples were collected from four different locations in the study area. It was observed from particle size distribution of dust concentration that the median value is almost the same in all the measured locations at Central College metro station (1.5 mg/m^3). The 90th percentile of dust concentration levels crossed lower safety limit of 3.0 mg/m^3, i.e. out of 20 measured samples, two samples crossed the lower concentration level in all the measured locations. Based on the observed results, it is strongly suggested that simple dust masks need to be used as a preventive measure in construction work. If the concentration level crosses the upper safety limit of 6.0 mg/m^3, simple mask protection might not help reduce exposure sufficiently. The combined use of dust masks with filters can reduce exposures to acceptable levels.

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Eastern Ghats' biodiversity reserves with unexplored lichen wealth

The Eastern Ghats (EG) is a discontinuous range of mountain situated along eastern coast of India (Figure 1). It stretches from Mahanadi Basin in the north to Nilgiri Hills in the south, covering a distance of 1700 km and spreading over an area of 75,000 sq. km. The average elevation of the mountain range is about 600 m and the highest peak is Shevaroy Hills that reaches up to a height of 1700 m. EG supports a rich array of tropical forests including pockets of moist deciduous, evergreen and semi-evergreen forests. About 2600 angiosperms, gymnosperms, pteridophytes and 160 cultivated plants are known from EG[1], which also includes over 530 tree species, 1800 medicinal and 450 endemic plants[2]. The biodiversity richness in the region can be illustrated with an example from six hill complexes of the southern EG wherein 143 lianas and 272 tree species are reported[3,4]. The EG is home to several unique taxa such as *Shorea roxburghii* G. Don (*S. talura* Roxb.), *S. tumbaggaia* Roxb., *Pterocarpus santalinus* L. f. (red sanders), *Cycas beddomei* Dyer and some wild varieties of rice (*Oryza granulata* Nees & Arn., *O. sativa* Thw. and *O. malampuzhaensis* Krish. & Chand.)[5,6]. EG is also a region for discoveries of taxonomic novelties; for example *Corallodiscus* Batalin, a new generic record of plant and *Phallus indusiatus* Vent. & Pers., a new generic record under fungus are reported from Odisha[7,8]; *Clarkeinda trachodes* (Berk.) Singer, a rare tropical Asian monotypic mushroom was recorded from Tamil Nadu (TN)[9]. Apart from plants, Rao and Krishna[10] recently discovered two species of spider and one each species of scorpion and mantis from the Nallamala Hills.

EG contributes significantly to both species richness and endemicity of the Indian region. However, the forests of EG are relatively under-studied and have received less attention for conservation compared to the relatively better-known Western Ghats[3,11]. Ultimately EG is left with insufficient data for several groups of organisms. This is one of the reasons that phytogeographers were forced to merge EG with the Deccan Plateau and call it the Deccan peninsular biogeographic zone[12]. The data deficiency is prominent in the case of cryptogams, especially lichens. Singh and Sinha[13]

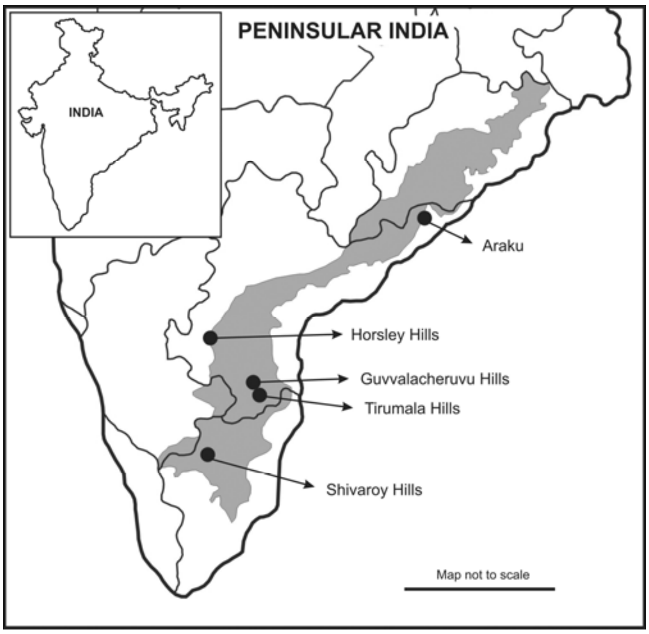

Figure 1. Schematic presentation of Eastern Ghats and some important localities surveyed for lichen collection in the present study.