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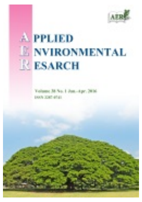

Comparison of Direct-reading and Gravimetric Methods of Particle Measurement in a Science Building, Silpakorn University

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Abstract

This study aimed to develop relationships between particulate matter (PM) concentrations obtained from a direct-reading instrument to those from a gravimetric method. TSI DustTrak II Aerosol Monitors (Model 8530), a direct-reading instrument for PM_{10} and $PM_{2.5}$ measurement, together with personal air pumps connected to a Sensidyne cyclone and a SKC Personal Environmental Monitor (PEM) for gravimetric PM_{10} and $PM_{2.5}$ measurements respectively were deployed in the Faculty of Science building, Silpakorn University, Nakhon Pathom, Thailand. Comparison of the results from each instrument indicated that PM_{10} and $PM_{2.5}$ concentrations obtained from the TSI DustTrak were higher. The linear relationship from ordinary least squares (OLS) regression between PM_{10} data determined by TSI DustTrak (x) and Sensidyne cyclone ($\hat{y}$) was significant (R^2=0.92) and could be represented as $\hat{y} = 0.272x$. For $PM_{2.5}$, the relationship between concentrations determined by TSI DustTrak (x) and SKC PEM ($\hat{y}$) was also significant (R^2=0.92) and represented by $\hat{y} = 4.848\sqrt{x}$. Validation of both equations was undertaken by comparing predicted values from these relationships against the actual concentrations found by gravimetric analysis, with R^2=1.0 and 0.92 for PM_{10} and $PM_{2.5}$, respectively. It is suggested that these site-specific OLS regression equations can provide fast and convenient estimation of concentrations derived by gravimetric analysis from direct-reading TSI DustTrak monitor data.

Keywords: Particle monitoring; Gravimetric method; Direct-reading monitor; OLS linear regression; TSI DustTrak 8530

Introduction

Particulates, especially fine particles, are a major air pollution problem, causing adverse effects on human health. Respirable dust (particulate matter with aerodynamic diameter of 4 µm or less; PM_4) can enter respiratory

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system and accumulate in the lungs whereas particles with aerodynamic diameter of 2.5 μm or less ($PM_{2.5}$) affect both respiratory and coronary systems. Exposure to PM2.5 increases mortality rates and hospital admissions among the population [1–3].

In order to determine the concentrations of those respirable particles, the gravimetric method has been legally adopted as the reference analysis method, e.g., Federal Reference Method (FRM) [4], NIOSH Method 0500 [5]. However, gravimetric methods have disadvantages. For example, similar conditions are required during pre- and post-filter weighing but this is difficult to control, the analytical procedure is time consuming, and the results needs further calculation.

At present, various techniques such as light scattering and beta attenuation can be employed by direct-reading instruments for particle monitoring. In the former, a laser diode emits light that is scattered by PM in a constant air stream. The amount of light scattered is determined by a detector and subsequently converted to a relative mass concentration by specific software provided by the manufacturer.

Although light scattering techniques have not been certified by agencies such as the US EPA, NIOSH and OSHA as a reference method, they are recommended for indoor air quality monitoring for indoor air quality guidelines/ standards in certain areas such as Hong Kong [6].

In this study, the TSI DustTrak monitor, utilizing a light scattering technique, was employed as the direct-reading instrument. It is one of the most popular direct-reading instruments and widely used for indoor air quality monitoring [7–10]. Its measurement range is from 0.001 to 400 mg m^{-3} for particle sizes between approximately 0.1 and 10 μm with a resolution of 0.001 mg m^{-3} or ± 0.1% of the reading, whichever is greater. A limitation of TSI DustTrak operation is the detection of PM with diameters less than 0.1 μm. For PM with diameter less than 0.25 μm for example, the amount of light scattered is proportional to PM size to the sixth power. As a result, the PM size distribution as well as particulate shape and density could affect the measurement [11–12]. Furthermore, other factors that may affect TSI DustTrak measurement are time, environment and location of the sampling [12–13]. A previous study on PM_{10} sampling by TSI DustTrak Model 8520 in comparison with a dichotomous sampler (gravimetric method) at the same site but in different seasons, has shown that the relationships between PM_{10} levels determined by these two methods were different, depending upon the season [14].

Advantages of TSI DustTrak measurement are that the instrument is portable, easy to use, and provides fast and continuous results. In circumstances when a fast result is needed, the direct-reading instrument would be useful. Although measurement by direct-reading instrumentation is not as widely recognized as the reference standard analysis compared to gravimetric methods, a number of studies have been performed to investigate their relationship. The intention of the current investigation was to use such a relationship to estimate gravimetric PM concentrations from DustTrak direct readings.

Comparisons of PM concentrations obtained from direct-reading instruments such TSI DustTrak and those from gravimetric methods have indicated that PM concentrations from the former were typically higher than those from gravimetric analyses [11, 13, 15–16]. Wang et al. reported that the TSI DustTrak reading was higher than that from gravimetric analysis by 4.76 times. This factor (4.76) was then used as the correction factor to estimate PM concentrations from gravimetric analysis [13]. However, the relationship of PM concentrations obtained from these two methods (direct-reading vs gravimetric method, e.g., TSI DustTrak 8520 vs Minivol [15], TSI DustTrak 8530 vs cyclone [16]) were not as statistically significant ($R^2<$

0.79) compared with the relationship obtained from two direct-reading instruments (R^2>0.93). For example, the comparisons of TSI DustTrak 8520 vs E-BAM [11] and TSI DustTrak 8530 vs SHARP Monitor Model 5030 [17] revealed high correlations with R^2 of 0.99 and 0.93, respectively.

As mentioned earlier, TSI DustTrak measurements have been observed to vary with the environment and location of sampling site. Hence, the relationship of the concentrations obtained from direct-reading vs gravimetric likely depend upon sampling site as well. Previous studies have been conducted in many locations such as a study undertaken in a truck cabin by using TSI DustTrak and the gravimetric instrument PQ200 (a US EPA Federal Reference Method designated sampler) to measure $PM_{2.5}$ concentrations. It was reported that the DustTrak provided concentrations twice as high [18]. In another study measuring PM_{10} concentrations in livestock houses (pig and poultry), TSI DustTrak results underestimated those from gravimetric analysis (cyclone equipped samplers) in both pig and poultry houses. This underestimation is perhaps owing to different refractive index, particle shape, density, size, and size distribution of livestock associated particles as compared to the Arizona Road Dust used for TSI DustTrak's annual factory calibration [19]. In an indoor academic environment such a room located in the Edinburgh University Medical School, a significant linear relationship was found for PM_{10} data from a TSI DustTrak monitor and the gravimetric instrument (PQ100/Graseby Andersen (US EPA approved device) but the direct-reading monitor's results were higher when PM_{10} concentrations exceeded 10 µg m^{-3} [20].

In fact, air pollution problems in university buildings are similar to those found in other public buildings that involve many different activities, multiple offices and occupants. The use of TSI DustTrak monitors to determine PM concentrations in a building could provide a fast response if results can be calibrated against those from gravimetric methods. In this study, a building in the Faculty of Science, Silpakorn University was chosen as the sampling site. There are quite a number of classrooms, chemical/biological laboratories and offices in the building. As a result, any elevated levels of PM would impact many students and these spaces. Apart from internally generated PM, since Nakhon Pathom is in an agricultural area, open burning occurs quite often with a consequent smoke hazard affecting the entire area including the university vicinity.

In summary then this study aimed to determine whether any significant relationship existed between PM concentrations obtained from a TSI DustTrak II Aerosol Monitor 8530 and those from a gravimetric method in a science building, Silpakorn University.

Materials and methods

1) Sampling instrument and analysis

Indoor air samples were collected for PM_{10} and $PM_{2.5}$ analyses using two different sampling methods. The desktop TSI DustTrak II Aerosol Monitor 8530, (TSI Inc., Shoreview, MN, USA), employed a light scattering laser photometer with a wavelength of 655 nm for measurement. It detects scattered light (diffracted, reflected and refracted) at angles of up to 90 degrees to the laser beam. Particle-laden air is drawn continuously through the cut-size inlet designed for PM_{10} or $PM_{2.5}$ collection. The sampling rate was set at 3.0 L min^{-1}. The instrument automatically recorded data at 1-min intervals for 24 h. Subsequently, data were downloaded through the instrument's software and averaged to obtain mean 24-h concentrations.

For PM_{10} determination by a gravimetric method, a personal cyclone device (10 mm Dorr-Oliver Cyclone, Sensidyne, Clearwater, FL, USA) was connected to a GilAir 5 personal air pump (Sensidyne, Clearwater, FL, USA) operating with flow rate of 1.7 L min^{-1} and 24-h sampling time [21]. The cyclone uses centrifugal force to separate PM_{10} in the air stream. The centrifugal force causes particles with diameter greater than 10µm to bounce off the cyclone wall and fall down into a hopper below while the smaller ones (PM_{10}) are collected on a filter. For $PM_{2.5}$ measurement, a SKC Personal Environmental Monitor (PEM) was connected to a GilAir 5 personal air pump operating with a flow rate of 2.0 L min^{-1} and 24-h sampling time as recommended in the EPA IP-10A Method [22]. The SKC PEM is based on an impactor plate trapping particle with an aerodynamic diameter greater than 2.5 µm, leaving PM with diameter less than 2.5 µm to be deposited on a downstream filter. Both PM_{10} and $PM_{2.5}$ methods used glass fiber filters (GC-50 37 mm diameter, pore size 0.5µm (ADVANTEC MFS Inc., Pleasanton, CA, USA)) for particle sampling. Filters were equilibrated before and after sampling.

A seven-digit Mettler Toledo Model XP2U microbalance (Mettler-Toledo, Greifensee, Switzerland) with 0.1 µg readability was used for weighing the filter before and after sampling. The temperature in the isolated weighing room was kept at 25°C. The microbalance was turned on and conditioned for 4 to 6 h prior to use. The increased weight of the filter after sampling divided by air volume determined PM mass concentrations [21]. Three replicated measurements agreeing to within less than 0.01% of filter weight were reported.

The results from gravimetric analysis were then compared to those from DustTrak direct reading. Throughout the sampling period, temperature and humidity were measured by a Xiaomi Mijia sensor (Xiaomi Communications, Beijing, China).

The results showed that room temperature was 28±2°C (26–31°C) and 24-h relative humidity was 78±5% (71–84%). The relative humidity through the sampling period was rather constant. As a result, if relative humidity had any effect on TSI DustTrak readings, it would affect these readings equally throughout the sampling period.

2) Sampling time and location

Four air sampling instruments were set up in the lobby of the 5th floor of Science building 4, Silpakorn University, Nakhon Pathom, Thailand. Each instrument was located 2 m apart and its air inlet was at 1.5 m above ground. During the sampling period (September 2018 to April 2019), two sampling deployments were undertaken. From September to December 2018, two TSI DustTraks and two GilAir 5 personal air pumps connected to Sensidyne Cyclones were used to collect PM_{10} samples. Then, during January to April 2019 two DustTraks and two GilAir personal air pumps connected to SKC PEMs were employed for $PM_{2.5}$ collection.

It was noted that during the sampling period, probable external sources of elevated PM concentrations from open-burning in the Nakhon Pathom area were determined from remote sensing hotspot counting as reported monthly on the Thai Royal Forest Department's website [23].

3) QA/QC procedures

Before each sampling, TSI DustTraks were zeroed by employing the zero filter apparatus provided by the manufacturer and was annually calibrated with standard ISO 12103-1, for QA/QC. Flow calibration was performed prior to each sampling. Its impactors were calibrated with a MiniVol (Airmetrics, Inc., Springfield, OR, USA) and a FH 62 C14 continuous ambient monitor (Thermo Andersen, Smyrna, GA, USA). Prior to each sampling, the impactor was cleaned and pre-oiled. GilAir 5 personal air pumps were calibrated before and after each sampling. The flow rates were averaged to obtain the actual flow rate throughout the sampling.

Both TSI DustTrak and GilAir 5 personal air pumps employed a Model 4046/4146 TSI Primary Calibrator (TSI Incorporated, Shoreview, MN, USA) for flow calibration. The Internal filter of TSI DustTrak was replaced every 350 working hours or when the instrument alarm went off. A laboratory filter blank was used for laboratory contamination checking and an unsampled filter for checking the stability of the microbalance. Filters were passed through a U-ionizer for charge removal prior to weighing. Duplicate samplers were used to evaluate the reproducibility of TSI DustTrak and gravimetric measurements.

4) Statistical analyses

4.1) Pearson's correlation

The Pearson's correlation coefficient (*r*) is a measure of linear association between two variables *x* and *y*. In this study, PM determinations were conducted by two TSI DustTrak monitors and two different sampler configurations for gravimetric analysis. There may be some differences in the results. Therefore, the Pearson's correlation was employed to detect the association between the concentrations within the sampler type.

4.2) The paired sample *t*-test

Paired sample *t*-tests were conducted to test differences between PM concentrations obtained from the gravimetric analysis and direct-reading instrument at the significance level of 0.05. If any mean difference was found, it indicated a systematic bias between these two analysis methods. The magnitude of systematic bias is represented by the absolute value of the mean difference measured by the two methods.

4.3) Regression analysis

Regression analysis was used to determine the correlation between PM concentration readings from TSI DustTrak monitors and those obtained from the gravimetric method. When the scatter plots of PM concentrations from TSI DustTrak vs gravimetric method were linear, a simple linear regression was applied. If the scatter plots between those concentrations were non-linear or variances of error terms were not constant, transformation of the values were considered to give a best fit regression equation.

For fitted models, the regression equation and the coefficient of determination (R^2) are determined. A value of R^2 close to 1 implies that most of the variability in the dependent variable (in this case is the PM concentrations obtained from the gravimetric method) is explained by the regression model [24].

Significantly different regression slope indicates proportional bias of PM concentrations between samplers [25]. Proportional bias is a bias that depends on concentration. In addition, regression intercepts significantly different from zero reflect systematic bias of PM concentrations between samplers. When the intercept parameter is discarded, the adjustment of the least-squares regression equation is refitted again. This means that the regression line passes though the origin [26].

4.4) Precision of the regression equation

The root-mean-square error (RMSE) from the best fit regression equation is used to describe the relative agreement of the two sampling methods. The closer the RMSE to zero, the more precise the regression analysis is.

However, RMSE by itself does not indicate whether the estimation is acceptable. Hence, the scatter index (SI) is derived to determine this. SI is calculated by dividing the RMSE by the mean of the observation (i.e. the mean concentration of PM measured by the gravimetric method). If SI is less than one, the regression equation is acceptable [17].

4.5) Model validation

The model or regression equations were validated using two methods. (1) The regression equation was validated by substitution of the x-value of PM concentrations measured by the TSI DustTrak monitor, to obtain predicted values. The predicted values were then regressed with the actual concentrations found by gravimetric analysis. If the slope was equal to 1 or close to 1, it means that the regression equation obtained from the study was valid. (2) PM concentrations from TSI DustTrak monitors were plotted against PM concentrations from the gravimetric method. In accordance with US EPA criteria for test validation, a factor of 2 was employed denoted by a lower dotted line representing x=2y and an upper dotted line representing y=2x. If the data points fall within the dotted lines, the model is regarded as validated [27].

Results and discussion

1) 24-h mean and standard deviation of PM_{10} and $PM_{2.5}$

The 24-h PM_{10} samples were collected by TSI DustTrak monitors and a gravimetric method for 8 months covering both weekdays and weekends (September 2018 to April 2019). The mean, standard deviation and range of 24-h PM_{10} concentrations obtained with the direct-reading monitor were 98.3±52.8 (33.0–229.5) $\mu g\ m^{-3}$ and from the gravimetric method 28.5± 13.7 (8.0–55.4) $\mu g\ m^{-3}$. Mean, standard deviation and range of 24-h $PM_{2.5}$ concentrations obtained from TSI DustTrak monitors were 142.9±84.1 (35.5–371.5) $\mu g\ m^{-3}$ and 54.2±27.1 (14.0–118.8) $\mu g\ m^{-3}$ from gravimetric analysis. It was obvious that PM concentrations from TSI DustTrak readings were approximately 3.5 times higher for PM_{10} and about 2.6 times for $PM_{2.5}$ ($p= 0.000$). This could because of the higher sensitivity of the TSI DustTrak monitor enabling detection of a wider range of aerosol types (smoke, dust, fumes, mist etc.). Results were consistent with those of Huang conducted in a university building in Taiwan [28].

Comparing the gravimetric PM concentrations found in this study to those reported in previous work, our concentrations are much higher. For example, Yanosky et al. [25] reported 24-h indoor $PM_{2.5}$ concentrations to be 5.0–20.4 $\mu g\ m^{-3}$ in the Environmental Health Science Building in the University of Georgia campus in Athens, Georgia, USA. Compared to a study carried out in a classroom in Lisbon where the gravimetric PM_{10} concentration was 65.4 $\mu g\ m^{-3}$, concentrations in this study were 1.5 times higher. [29].

As mentioned earlier, it was noticed that the higher PM concentrations in this study might be influenced by various open-burning sources during the sampling period. In order to investigate this effect, the annual report of active fire hotspot counting in the Nakhon Pathom area based on satellite imagery was obtained from the Royal Forest Department's website [23]. It was found that the occurrence of increased PM concentrations was consistent with increasing numbers of hotspots. During the PM_{10} sampling period, the hotspot counts were higher than normal (5–21 counts vs <2 counts) but lower than those counts during the $PM_{2.5}$ collection period (21–114 counts) [23]. This may be a factor as to why the concentrations of $PM_{2.5}$ were higher than PM_{10} and could also indicate that PM concentrations varied depending upon external activity and time of the sampling.

However, mean concentrations of PM_{10} and $PM_{2.5}$ obtained from this study could not be compared with indoor air quality standards and guidelines established by international and national organizations [30] because these standards are relevant for 8-h exposures, but the results of this study were based on 24-h average concentrations.

2) Correlation of the concentrations within the same sampler type

The Pearson's correlation coefficients between duplicate concentrations from the same sampler type were all positive (Table 1). The paired sample t-tests showed that the duplicate concentrations within sampler type were not significantly different ($p>0.05$). Although the significance of the comparison between PM_{10} concentrations obtained from cyclone 1 and cyclone 2 was lower (p=0.60 than the other comparisons (p>0.75), the result was still in the acceptable range as discussed below in section 3.4. However, the results of the correlation between duplicate direct-reading measurements for both PM_{10} and $PM_{2.5}$ (r>0.98) were better than those found with the gravimetric analysis (r<0.83). This suggested higher precision of the direct-reading method as compared to the gravimetric method.

Since the correlation of PM concentrations obtained from the same sampling type was not different, the concentrations from the same sampling type were averaged and used for further linear regression analysis.

3) The ordinary least squares (OLS) linear regression analysis

Concentration data of both PM_{10} and $PM_{2.5}$ were normally distributed and evaluation of the concentration differences between TSI Dust-Trak reading and gravimetric analysis methods using the paired sample t-test showed a significant difference (p=0.00). The OLS regression analysis between the concentrations from gravimetric analysis and TSI DustTrak readings were as follows;

For PM_{10}, the concentrations from gravimetric analysis correlated well with the TSI DustTrak readings and the relationship was represented by the OLS regression equation as

$$\hat{y} = 0.272x \qquad \text{(Eq. 1)}$$

$$R^2=0.92,\ r=0.96,\ \text{RMSE}=9.0\ \mu\text{g m}^{-3},\ \text{SI}=0.32$$

where $\hat{y}$ represents predicted PM_{10} concentrations from the gravimetric method and x represents PM_{10} concentrations from TSI DustTrak monitors (Figure 1). The RMSE was 9.0 µg m^{-3} and SI was 0.32 which implied that the precision of the equation was acceptable since the SI was less than one.

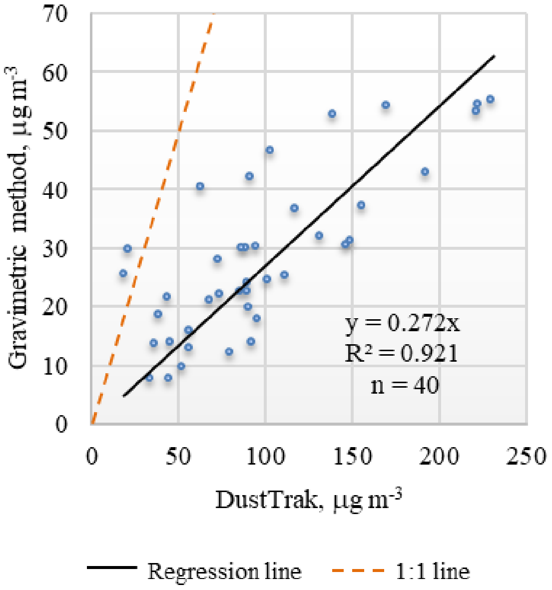

Figure 1 OLS regression for PM_{10} data.

Table 1 Comparison of PM concentrations within the same sampler type

Instrument	n	Mean±SD, µg m^{-3}	Range (Median), µg m^{-3}	Sig. (2-tailed) p-value	*r*
PM_{10}					
TSI DustTrak no.1	40	99.6±55.5	35.0–252.0 (90.5)	0.82	0.99
TSI DustTrak no.2	40	97.0±50.4	31.0–222.0 (87.5)		
Cyclone no.1	40	27.6±14.2	8.0–54.7 (27.8)	0.59	0.60
Cyclone no. 2	40	29.4±16.4	6.4–71.0 (27.1)		
$PM_{2.5}$					
TSI DustTrak no.1	39	147.2±88.1	36.0–386.0 (118.0)	0.75	0.98
TSI DustTrak no.2	39	141.1±82.6	35.0–357.0 (119.0)		
SKC PEM no.1	40	55.1±28.8	11.5–106.5 (50.1)	0.77	0.83
SKC PEM no.2	40	53.3±28.0	9.2–132.8 (48.6)		

For $PM_{2.5}$, the linear relationship between concentrations from gravimetric analysis and TSI DustTrak was not highly correlated ($r=0.768$ and $R^2=0.590$) (Table 2). Therefore, several models were investigated to establish a relationship. The best fit of the OLS models in Table 2 was the relationship between the concentration obtained from gravimetric method with the square root of TSI DustTrak concentration (or √x [TSI DustTrak]). The relationship was expressed as

$$\hat{y} = 4.848\sqrt{x} \qquad \text{(Eq. 2)}$$

$$R^2=0.92,\ r=0.96,\ \text{RMSE}=17.5\ \mu g\ m^{-3},\ \text{SI}=0.32$$

where $\hat{y}$ expresses predicted $PM_{2.5}$ concentrations from the gravimetric method and x expresses $PM_{2.5}$ concentrations from TSI DustTrak monitors (Figure 2). The precision of the equation was acceptable since the SI was 0.32.

In general, the relationship between the concentrations from direct-reading measurement (light scattering) and gravimetric analysis is linear. However, comparison of the coefficient of determination (R^2) from OLS regression equations in Table 2 showed that R^2 in the equation using the square root of x (√x [TSI DustTrak]) was greater than that simply using x in the correlation. Furthermore, the variances of random errors in the equation obtained from x [TSI DustTrak] were not constant. Data distribution was far from the regression line as concentration from the TSI DustTrak increased.

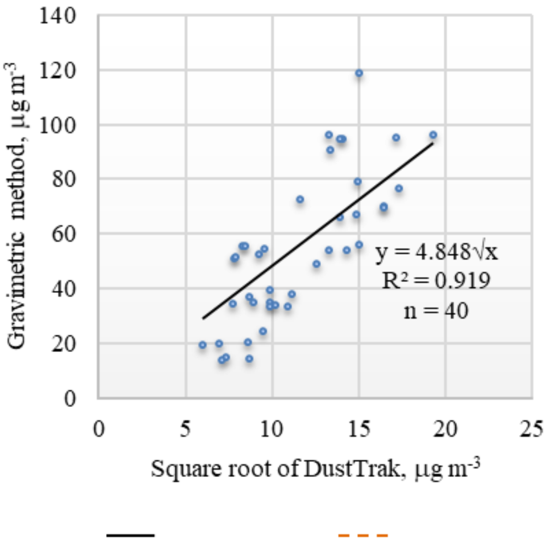

Figure 2 OLS regression for $PM_{2.5}$ data.

Overall, for both PM_{10} and $PM_{2.5}$, $R^2=0.92$ implied that PM concentrations for gravimetric analysis could be explained by the regression model [14] and 92% of the gravimetric measurement could be explained by the TSI DustTrak measurement. The correlation coefficient (r) of the equation was 0.96, implying that concentrations from TSI DustTrak measurement and concentrations by gravimetric analysis were highly correlated. The SI=0.32 implied that the precision of the relationships was acceptable [17].

Table 2 The relationship between $PM_{2.5}$ concentrations from gravimetric method and TSI DustTrak with various transformations

Transformation	Relationship*	r	R^2	RMSE, $\mu g\ m^{-3}$	SI
None	$\hat{y} = 0.248x+18.847$	0.77	0.59	17.6	0.32
Forced zero intercept	$\hat{y} = 0.346x$	0.95	0.90	19.8	0.37
Square root	$\hat{y} = 6.186\sqrt{x}+16.682$	0.79	0.62	17.0	0.31
Square root and forced zero intercept	$\hat{y} = 4.848\sqrt{x}$	0.96	0.92	17.5	0.32

Remark: *Note that $\hat{y}$= $PM_{2.5}$ concentration from the gravimetric method and x=$PM_{2.5}$ concentration from TSI DustTrak

4) Model validation

The validity of the regression model was evaluated by investigating the relationship between the predicted concentrations and actual concentrations found by gravimetric analysis and also testing the validation of the model according to US EPA criteria [27].

For PM_{10}, the regression Eq. 1 was used together with concentrations measured by TSI DustTrak (x-value) to obtain the predicted concentration for gravimetric analysis. The predicted values from the calculation were then plotted against the actual concentrations found by grvimetric analysis. The correlation between the predicted concentrations and actual concentrations demonstrated a linear relationship with the slope of the equation close to one (Figure 3). This implied that the regression Eq. 1 could reliably relate PM_{10} concentrations from TSI DustTrak measurement to gravimetric concentrations.

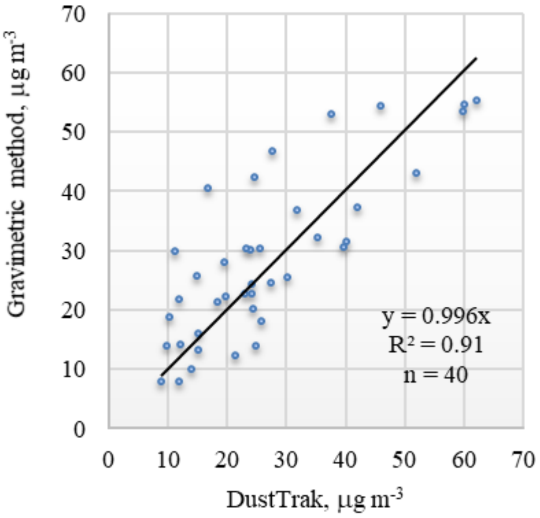

Figure 3 OLS regression equation testing for PM_{10}.

PM_{10} concentrations obtained from TSI DustTrak readings were then plotted against PM10 concentrations obtained from the gravimetric method (Figure 4) with dotted lines denoting over- or under-prediction by a factor of 2. It was obvious that only 2 data points out of a total of 40 data points (5% of data) did not fall within the dotted lines. This indicated that about 5% of gravimetric analyses might be underestimated if the model (or Eq. 1) was used to predict the result.

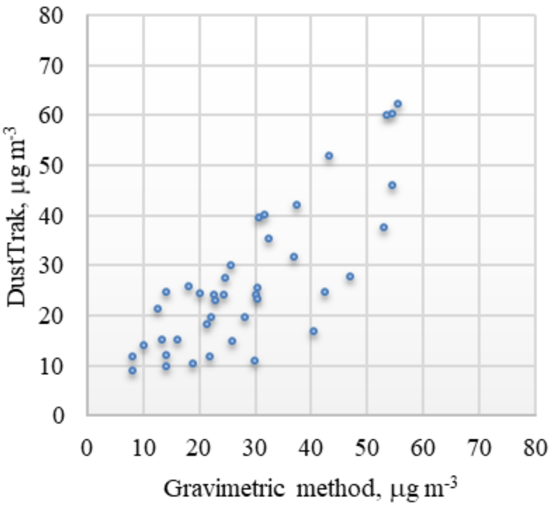

Figure 4 Plot to establish validity of the PM_{10} model.

Analogously for $PM_{2.5}$, Eq. 2 was validated by substitution of the square root of x-values, the concentrations measured by TSI DustTrak, to get the predicted values for gravimetric analysis. The correlation between the predicted concentrations and actual concentrations showed a linear relationship (R^2=0.92) with the slope of the equation close to one (Figure 5). This implied that regression Eq. 2 could be used to estimate $PM_{2.5}$ concentrations derived by gravimetric analysis from TSI DustTrak measurements.

Validation of $PM_{2.5}$ data was also undertaken by plotting the square root of $PM_{2.5}$ concentrations readings from TSI DustTrak against $PM_{2.5}$ concentrations obtained from the gravimetric method (Figure 6). Again, over- and under-prediction by a factor of 2 was denoted by dotted lines. It was observed that 3 data points of 40 data points (7.5% of data) were above the upper limit. This indicated that about 7.5% of gravimetric analyses might be over-estimated if the model (or Eq. 2) was used to predict the result.

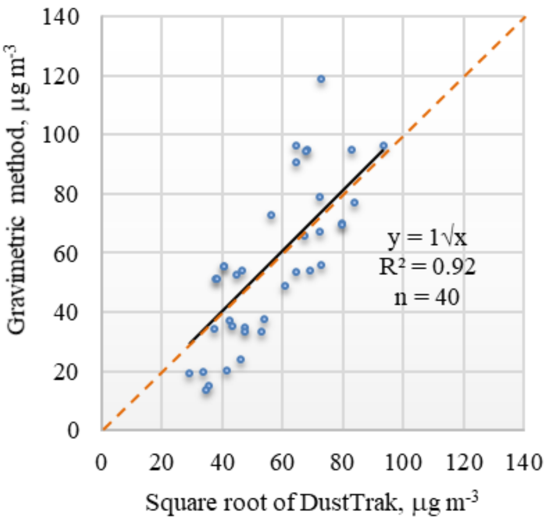

Figure 5 OLS regression equation testing for $PM_{2.5}$.

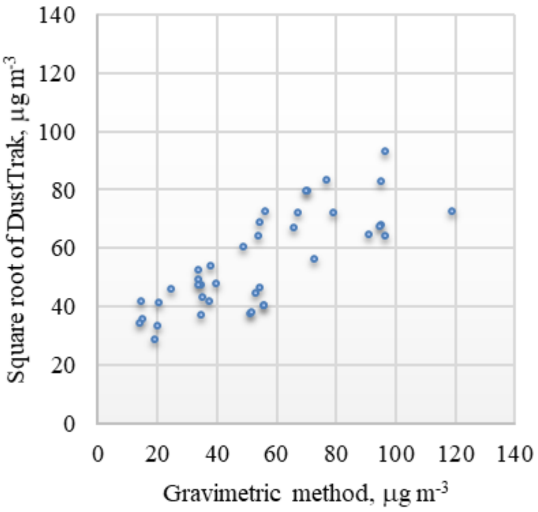

Figure 6 Plot to establish validity of the $PM_{2.5}$ model.

It should also note that QA/QC for both laboratory procedures and instrument usage employed in this study may increase the precision and accuracy of the results and provide the better, more significant relationships when compared to those reported earlier. Furthermore, the validity of both OLS regression equations was tested and the results shown in Figure 3 and Figure 5 confirmed that the OLS regression Eq. 1 and 2 could be used to predict PM concentrations from gravimetric analysis by TSI DustTrak measurements. These equations are simple, easy to use and provide a rapid result to estimate the gravimetric analysis concentration.

However, the equations obtained from this study can only be used for this sampling site. The slope factor might change depending upon the location of the sampling, and this needs further study.

Conclusion

The relationship of PM_{10} and $PM_{2.5}$ concentrations from direct-reading instrument and those from gravimetric analysis were significantly related at R^2=0.92. The validity of the equations obtained from the relationships were also investigated and confirmed that PM concentrations from TSI DustTrak measurements could be used to estimate the concentrations determined by gravimetric analysis. The simple equations derived from these relationships would provide faster results by enabling estimation of gravimetric analysis concentration data from TSI DustTrak direct readings.

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