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Comparison of Particulate Matter (PM_{10}) Monitoring Using Beta Attenuation Monitor (BAM) and Simple Instrument

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ABSTRACT

This research focused on comparing PM_{10} mass concentration record generated by two co-located particulate monitors, Beta Attenuation Monitor (BAM) and Direct Reading Monitor (DRM), operating outdoors at Perai, Penang. DRM record were adjusted to predict BAM with a correction factor *k* derived from co-located BAM and DRM at a research site to make data comparable in real terms. Predicted BAM records were obtained using quantile regression which is Method A (5 groups of percentile). The *k* was successfully identified for five (5) groups of percentile for Method A and monitoring record were treated using two techniques and named as Record 1 and Record 2. The best *k* was selected for each group of percentile. In Perai, R^2 value is higher (0.9170) for Record 1. Conversely, Record 2 shows lower R^2 value, which is 0.8324. A simple monitor now can be used to produce reliable direct reading real time particulate matter measurement.

Keywords: *Quantile regression, Direct reading monitor, correction factor (k)*

1. INTRODUCTION

Dimitriou and Christidou (2007) mentions one of the main problems faced around the world is air pollution that harms the health of wildlife that would cause the loss of biodiversity or adversely affect the function of the environment as a system. Sherman and Matson (2003) defined air pollution as the presence of undesirable levels of physical or chemical impurities on the air. Air pollution becomes an increasing source of environmental degradation in the developing nations of East Asia (Alles, 2009). Many organization such as the World Health Organization (WHO, 1999) recognized particulate matter (PM), nitrogen dioxide (NO^2), carbon monoxide (CO), lead (Pb), ozone(O^3) and sulfur dioxide (SO^2), as classical pollutants presenting a hazard to sensitive populations. PM_{10} particles are very small to be inhaled and accumulate in the respiratory system (Colls, 1997).

In recent years, increasing number of monitoring system for particulate matter (PM) are available and are wide ranging in type, cost, flexibility and accuracy. According to Kingham et al. (2006), accurate and reliable monitoring of PM aerosol in the respirable size fraction (<10 µm aerodynamic diameter PM_{10}) is legislative requirement of local authorities in many developed world countries. One of the essential prerequisites for monitoring requirements is the availability of a cost effective monitoring system that has been demonstrated to be reliable and accurate in its application to stationary source emissions. Chung et al. (2001), pointed about traditional monitoring networks (continuous aerosol mass monitor, integrating nephelometer, tapered element oscillating microbalance) for airborne particulate matter. QUARG (1996) pointed that the of monitoring (gravimetric and direct reading method) are designed to determine the concentration of particle in the different sizes (PM_{10} and $PM_{2.5}$). In Malaysia, PM_{10} monitoring was conducted by Alam Sekitar Malaysia Sdn. Bhd. (ASMA). Md Yusof et al. (2010) lists two instruments used for monitoring of PM_{10} that are high volume sampler (HVS) and beta attenuation monitor (BAM). BAM is the standard instrument used by Department of Environment (DoE) to measure particulate matter in 52 monitoring station in Malaysia. This 52 monitoring station are not enough to cover or represent every polluted areas in Malaysia. However, develop new monitoring stations is beneficial to the country, but it will be costly and need good maintenances. Additionally, air quality at the rural areas also cannot be monitored. Therefore, a new alternative instrument such as Direct Reading Monitors (DRM) will enable air pollutants to be monitored more comprehensively. Even though DoE has set up their monitoring station, the number of monitoring stations is limited. With the use of simple instruments and cost effective, the air quality in areas without monitoring stations can be monitored and assessed.

A small number of past research have compared the tapered element oscillating microbalance (TEOM) and a series of manual gravimetric methods (Allen et al., 1997; Ayers, 2004; Cyrys et al., 2001; Hauck et al., 2004; Williams et al., 2000) but fewer have compared other commercial monitors (Baldauf et al., 2001; Chung et al., 2001; Heal et al., 2000; Monn, 2001; Salter and Parsons, 1999). There are many researcher comparing the gravimetric methods and mass concentration results of the BAM. Several papers show that results differ between those methods (Arends et al., 2000; Watanabe et al., 2000; Salminen and Karlsson, 2003).

DRM were developed as early warning instruments for use in industrial, where a leak or an accident could release a high concentration of a known chemical into the ambient atmosphere (Aitken et al., 2004). Unlike air sampling devices, which are used to collect samples for subsequent analysis in a laboratory, direct reading instruments provide information at the time of sampling, enabling rapid decision making (Kim et al., 2004). The DRM can also be configured for start or stop times, recording periods, averaging time and other parameters (MetOne Instrument, 2002). The BAM instrument is widely used for continuous monitoring of suspended particulate matter (SPM) in Japan and worldwide (Mizuno and Kaneyasu, 1994; Watanabe et al., 2000) Relationship of beta ray attenuation to particles mass were used to measured the mass concentration of atmospheric aerosols (Chueinta and Hopke, 2001; Arends et al., 2000; Salminen and Karlsson, 2003; Chang and Tsai, 2003; Hauck et al., 2004). Cheng et al. (2008) compared PM_{10} and $PM_{2.5}$ mass concentrations inside trains and on underground station platforms in Taipei using a TSI Dust Trak monitor (TSI Model 8520). Cheng, (2008) reported, the TSI Dust Trak monitor was calibrated with the Met One E-BAM sampler within the underground station. Experimental results suggested that the TSI Dust Trak overestimated PM_{10} and $PM_{2.5}$ levels by about 2.0 and 2.2 times, respectively, compared with the Met One E-BAM sampler.

2. EXPERIMENTAL METHOD

2.1 Sampling Site

The stations are located in an industrial area (Perai). Perai is an administrative town in Seberang Perai and located on the south side of the Perai River. Sampling for Perai was performed at the Air Quality Monitoring Station (CAQMS) at Sekolah Kebangsaan Taman Inderawasih as shown in Figure 1.

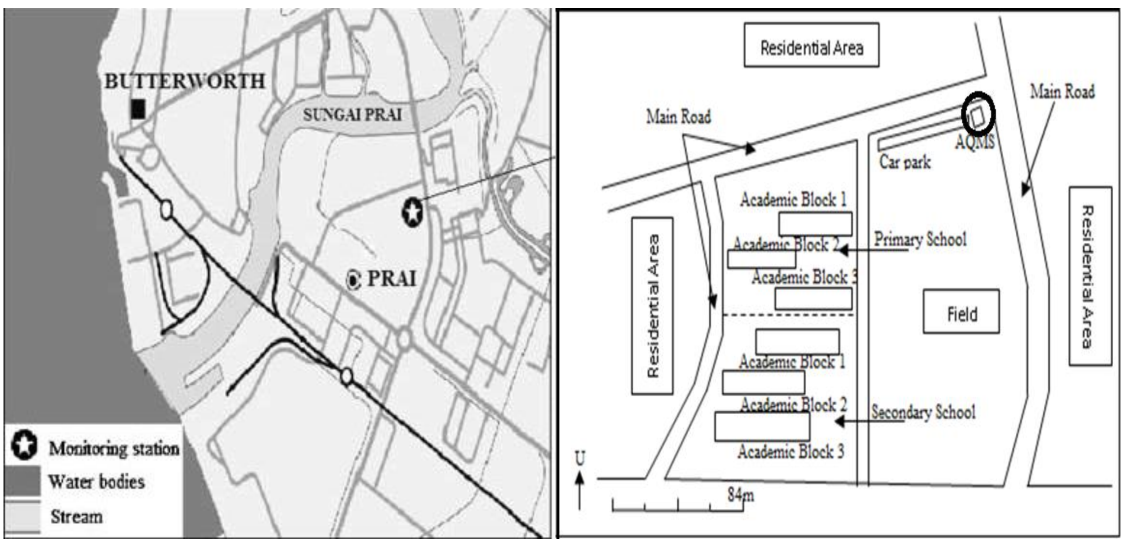


Fig. 1. Perai monitoring station

Perai site has a permanent air quality monitoring station. The site has high density industrial and medium density of residential dwellings with the most of air pollutants sourced from industrial zone. Perai is predominantly affected by local industrial emissions and also affected by traffic from near major road. Table 1 shows the site geographical information.

Table 1 Site geographical information

Station	Categories	Coordinate
Perai, Penang (Sekolah Kebangsaan Taman Inderawasih)	Industrial	5°23’51.12” N 100°24’14.41” E

2.2 Setting and Sitting of Instruments

Industrial area is an area where industrial sources make an important contribution to the total pollution. DRM and BAM instrument were run co-locatedly at the same place in order to compare PM_{10} concentration recorded by both instruments. The DRM needs to be placed in an open area, away from any obstruction, such as trees and buildings, which could introduce some separation and cause highly variable concentration. The height of instrument shall normally be higher than the height of observer for security reasons (QUARG, 1996). Therefore, the DRM instrument was set up on top of the cabin where the BAM is operated. Monitoring campaign was conducted from 16 to 29 July 2011 (14 days). In this work, DRM and BAM were placed co-locatedly to evaluate their comparability and calculate the correction factors (*k*).

2.3 Regression Analysis

2.3.1 Pre-processing Data

The data used in this study is hourly PM_{10} concentration levels (in micrograms per cubic meter) monitored in Perai. Missing data was replaced via mean top bottom method (Yahaya et al., 2005). The hourly average PM_{10} concentrations were calculated from data collection at every 1 minute. The total observations for Sekolah Kebangsaan Taman Inderawasih were 384 hours. The average of the daily concentration was calculated to plot the time series to investigate the trend of PM_{10} concentration at Perai.

PM_{10} concentration record was treated using two techniques and was renamed as Record 1 and Record 2. Record 1 is the data that has been cleaned by removing the first 2 days (48 hours) monitoring record and the PM_{10} concentration less than 10 µg/m³. Otherwise, Record 2 is the data that only removed out the first 2 days monitoring record. The reason for removing out the first 2 days monitoring record is the DRM takes some time to stabilize.

2.3.2 Quantile Regression

Quantile regression was used to determine the relationship between the DRM and BAM with the slope of the regression. In order to get better regression, DRM records were divided into 5 groups of percentile. Regression analysis involved one independent variable and another one dependent variable, plotted as a scatter plot. The scatter plot used to examine the relationship between these two variables. In this study, regression line was forced to zero (through origin) because PM_{10} concentrations cannot be less than zero.

Quantile is one of the numerical characteristics of random quantities used in mathematical statistics. This method classifies data into a certain number of categories with an equal number of units in each category. The Least Absolute Deviation method (LAD) or L_1 method is a widely known alternative to the classical least squares or L_2 method for statistical analysis of linear regression models. Instead of minimizing the sum of squared errors, it minimizes the sum of absolute values of errors (Cheng et al., 2008). The *k* for each group was obtained using EViews 6 software based on the formula in equation 1 and 2.

$$\text{LAD} = \text{Min} \sum \left| \left(y_i - \hat{y}_i \right) \right| \quad (1)$$

Where,

LAD = Least Absolute Deviation

y_i = BAM (Observed)

$\hat{y}_i$ = DRM (Observed)

$$BAM_{pred} = \beta_{\bullet} + \beta_1 x \quad (2)$$

Where,

$\beta_{\bullet}$ = constant value

β_1 = *k* value

x = DRM (observed)

DRM records were divided into five groups of concentrations record based on percentile of concentrations as shown in Table 2. In order to see the micro changes for *k* values, each group in five groups of were divided into another seven groups of percentiles (25, 50, 75, 90, 95, 98, and 99).

3. RESULT AND DISCUSSION

3.1 Time Series Plot of PM_{10} Concentration

The hourly average PM_{10} concentrations data were calculated from data recorded at every 1 minute. The time series plots for BAM and DRM for Record 1 and Record 2 are presented in Figure 2 and Figure 3. PM_{10} concentration recorded between both instruments was different. This is due to different detection method between both instruments (DRM used laser and BAM used beta ray) and respond time (DRM was set to record PM_{10} every 1 minute, while BAM records hourly PM_{10}). Therefore, the correction factor (*k*) is needed to get the better record when using DRM and BAM. PM_{10} concentration in Perai is slightly higher even in shorter monitoring duration due to significant constant industrial sources in Perai that deteriorate air quality level in this area. Figure 2 (Record 1) is the data that has been cleaned by removing the first 2 days (48 hours) monitoring record and the PM_{10} concentration less than 10 µg/m³. Otherwise, Figure 3 (Record 2) is the data that only removed out the first 2 days monitoring record.

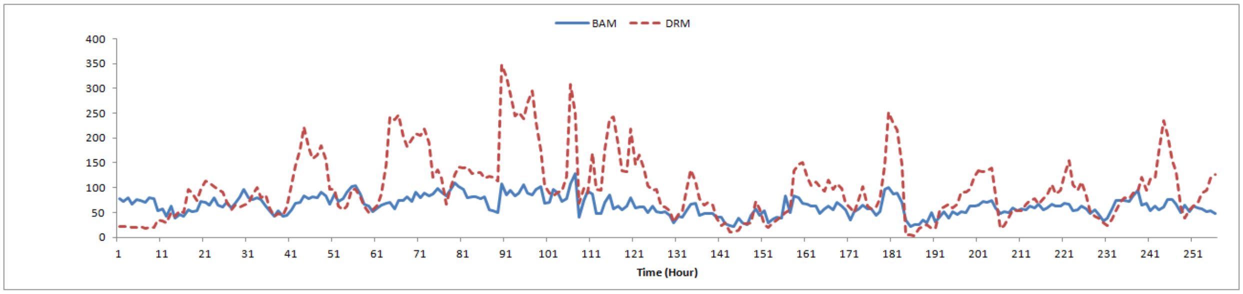


Fig. 2 Times series of Record 1 hourly average PM_{10} for Perai using BAM and DRM

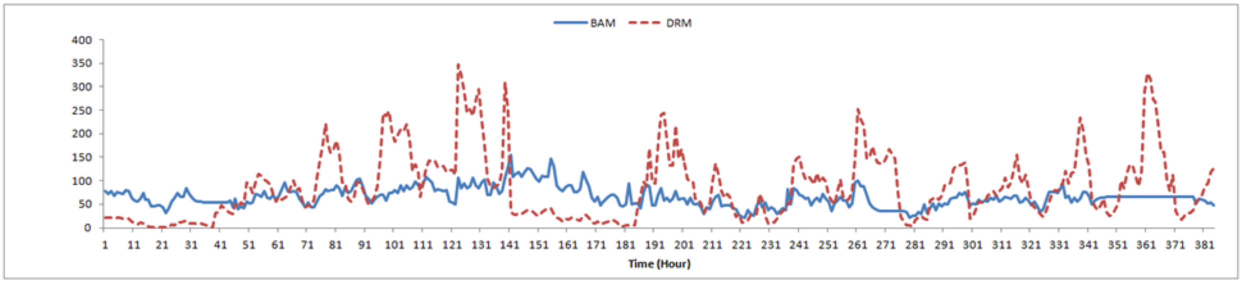


Fig. 3 Times series of Record 2 hourly average PM_{10} for Perai using BAM and DRM

3.2 Correction Factors (k), and Linear Model for 5 Groups of Percentiles (Method A)

Table 2 and 3 show the range of PM_{10} concentration recorded based on groups of percentile, the correction factor (*k*) and linear model for Perai (Method A). Data were divided into 5 groups for both Records (Record 1 and Record 2). The *k* was obtained using quantile regression. The *k* for each groups of percentile is the best *k* from 7 groups of quantile (25, 50, 75, 90, 95, 98, and 99). From 7 groups of quantile, one *k* was selected based on performance indicator. At the end, 5 best *k* for each group of percentiles were obtained. The linear model can be used to predict the value of predicted BAM. Equation for (0, 20] percentile only has *k* and without constant because assumption were made that the regression line should started at zero (origin).

Predicted BAM obtained by using the linear model in Table 2 and 3 were used to plot predicted BAM versus BAM observed as shown in Figure 4 and 5. The plot display that predicted BAM and BAM observed was well correlated. Most of the data in Figure 4 are distributed in the range of 95% confidence interval which means that prediction is good. In addition to that, R^2 value displayed in the plot is also high.

Table 2 Groups of percentile, correction factor (*k*) and linear model for Perai using Record 1

Record 1			
Percentile	**PM_{10} concentration recorded using DRM, *x* (µg/m³)**	**Correction factor (*k*)**	**Linear model**
(0, 20]	$x < 50$	1.2782	$BAM_{pred} = 1.2782x$
(20, 40]	$50 \le x < 73$	0.4355	$BAM_{pred} = 26.675 + 0.4355x$
(40, 60]	$73 \le x < 99$	1.1583	$BAM_{pred} = -14.2664 + 1.1583x$
(60, 80]	$99 \le x < 143$	0.5506	$BAM_{pred} = 23.8540 + 0.5506x$
(80,100]	$x \ge 143$	0.2967	$BAM_{pred} = 53.9649 + 0.2967x$

Table 3 Groups of percentile, correction factor (*k*) and linear model for Perai using Record

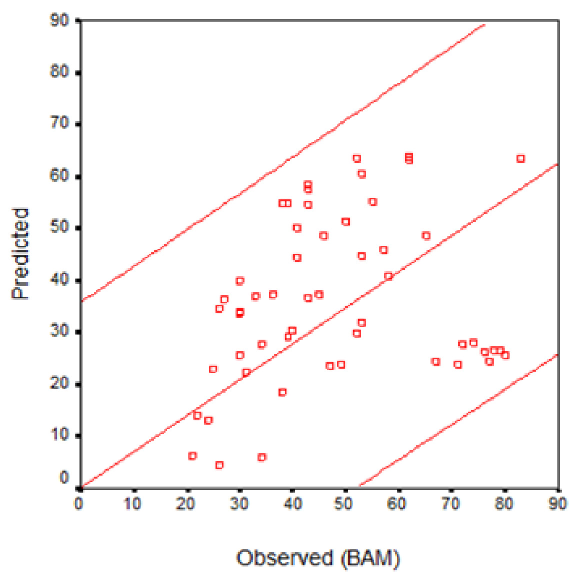
Record 1			
Percentile	**PM_{10} concentration recorded using DRM, *x* (µg/m³)**	**Correction factor (*k*)**	**Linear model**
(0, 20]	$x < 50$	1.2782	$BAM_{pred} = 1.2782x$
(20, 40]	$50 \leq x < 73$	0.4355	$BAM_{pred} = 26.675 + 0.4355x$
(40, 60]	$73 \leq x < 99$	1.1583	$BAM_{pred} = -14.2664 + 1.1583x$
(60, 80]	$99 \leq x < 143$	0.5506	$BAM_{pred} = 23.8540 + 0.5506x$
(80,100]	$x \geq 143$	0.2967	$BAM_{pred} = 53.9649 + 0.2967x$

Table 3 Groups of percentile, correction factor (*k*) and linear model for Perai using Record

Record 2			
Percentile	**PM_{10} concentration recorded using DRM, *x* (µg/m³)**	**Correction factor (*k*)**	**Linear model**
(0, 20]	$x < 21$	1.2781	$BAM_{pred} = 1.2781x$
(20, 40]	$21 \leq x < 53$	0.3361	$BAM_{pred} = 33.3680 + 0.3361x$
(40, 60]	$53 \leq x < 91$	0.6093	$BAM_{pred} = 46.3680 + 0.6093x$
(60, 80]	$91 \leq x < 135$	0.0373	$BAM_{pred} = 60.9172 + 0.0373x$
(80,100]	$x \geq 135$	0.1473	$BAM_{pred} = 46.8190 + 0.1473x$

In Figure 4, only R^2 plot for [0, 20] percentile was below 0.9 (0.7994) meanwhile the rest were above 0.9. The highest R^2 is 0.9730 at (80, 100] percentile shows the best predicted is at (80, 100] percentile and might be affected by the total numbers of data, which is at (80, 100] percentile the data is less compared to (0, 20] percentile and others.

Meanwhile, Figure 5 shows that at (0, 20] and (20, 40] percentile the R^2 are 0.8073 and 0.8104 respectively. The other three groups of percentiles show above 0.9 which is the highest are 0.9606 for (60, 80] percentile.



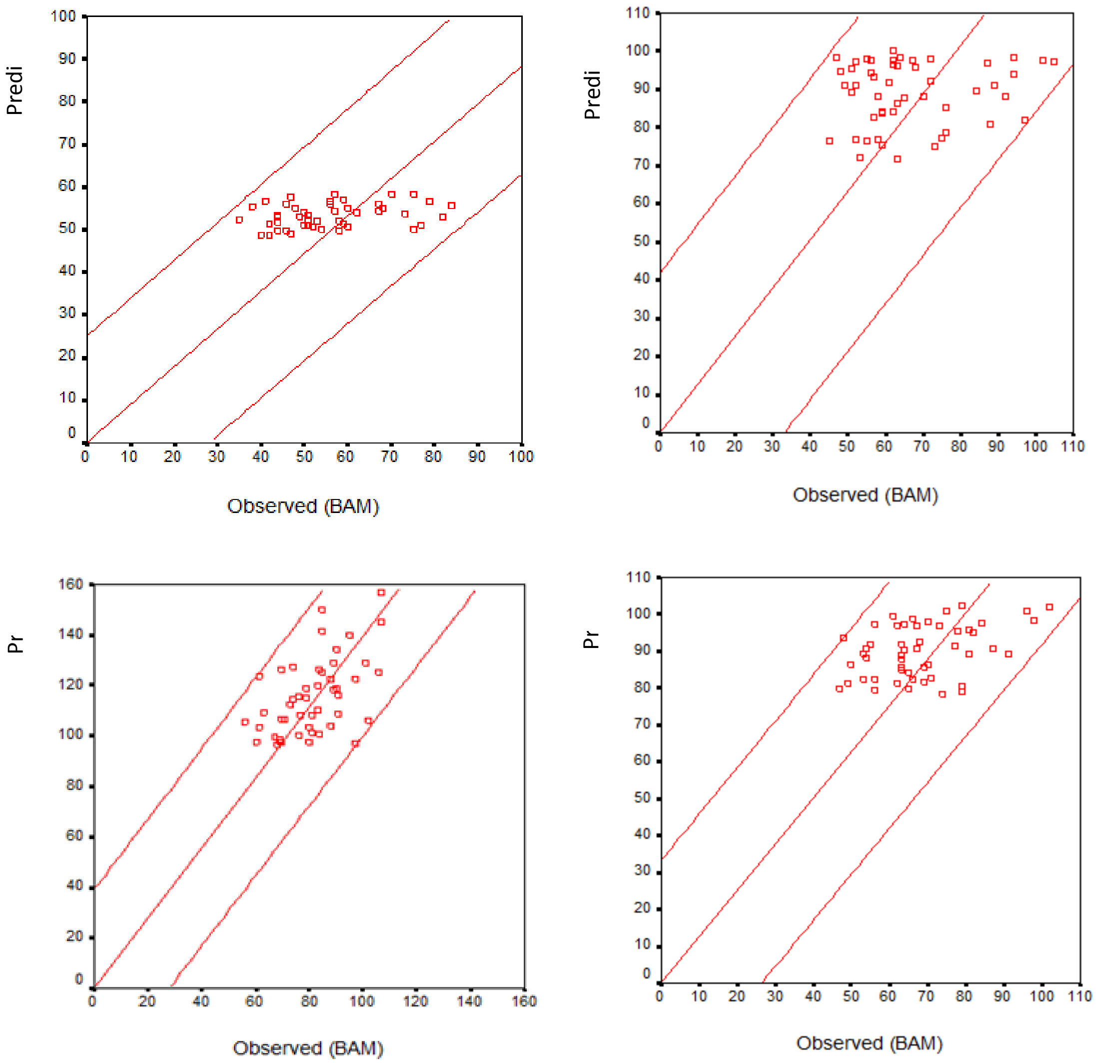
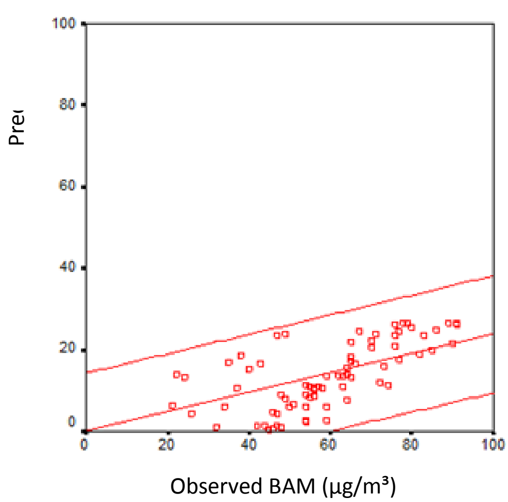


Fig. 4 Observed and predicted PM_{10} concentration for Perai (Record 1).
(A and B is 95% confidence interval)



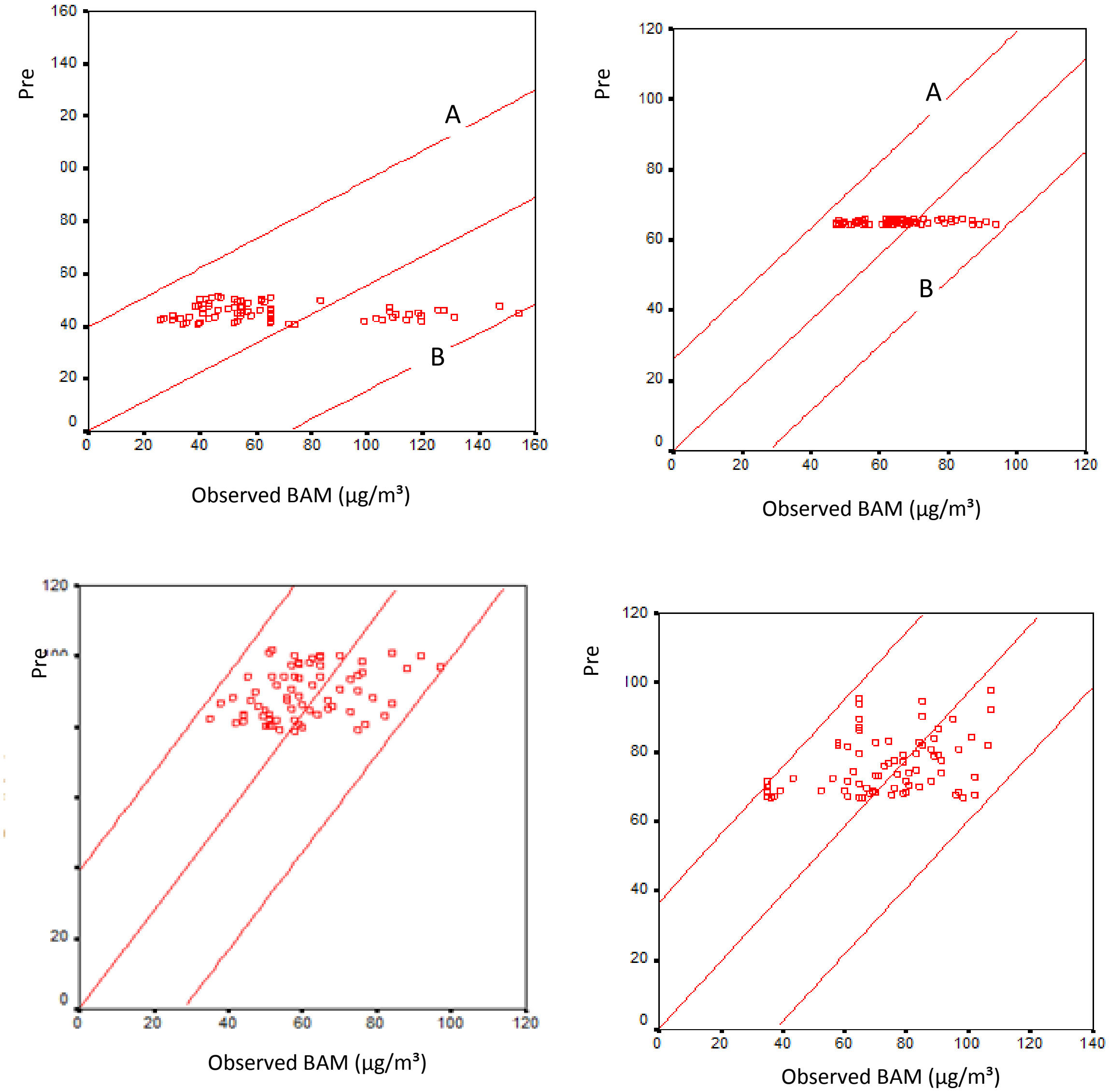


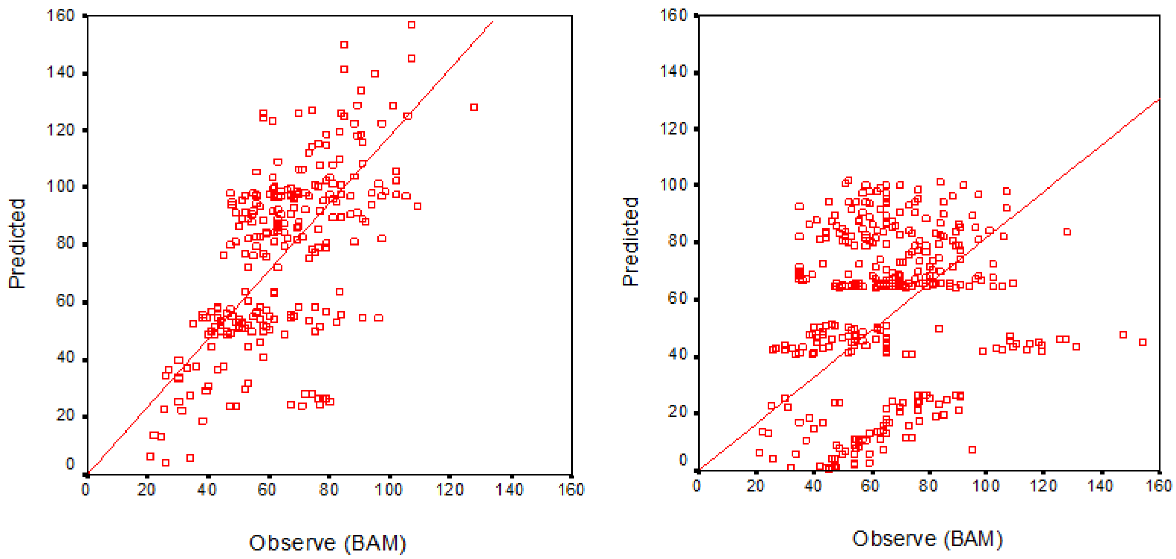
Fig. 5 Observed and predicted PM_{10} concentration for Perai (Record 2)
(A and B is 95% confidence interval)

3.3 Comparing Results between Record 1 and Record 2

Figure 6 displays overall plot using all *k* for Record 1 and Record 2. The plots show the predicted BAM were well correlated even though all five groups of percentile were used.

Better R^2 value, (0.9170) was obtained for Record 1 compared to Record 2 where the R^2 value is only 0.7810. The plot shows that Record 1 provides better regression because of the influence of data treatment technique. Record 1 omits all values less than 10µg/m³.

When the monitoring records were divided into five groups with uniform range, the number of monitoring record for each group is almost equivalent. Therefore, each group of percentile in Method A gives a good regression for predicted BAM and observed BAM.



a – Record 1 (R^2= 0.9170)
b – Record 2 (R^2= 0.7810)
Fig. 6 Observed and predicted PM_{10} concentration (µg/m³) for Perai

4. CONCLUSION

The concentration of PM_{10} monitored using DRM and BAM are slightly different due to different in detection method between both instruments (DRM used laser and BAM used beta ray) and different in respond time (DRM was set to record PM_{10} concentration every 1 minutes, while BAM record hourly PM_{10}). The relationship between both instruments was related with the slope coefficient of the regression *k*. The regression line was forced to zero (through origin) because there are no negative PM_{10} concentrations. The monitoring records used in the analysis were treated using two techniques and named as Record 1 and Record 2. Every group (5 groups) was analyzed in other seven groups of percentile (25, 50, 75, 90, 95, 98, and 99). R^2 values for Record 1 is 0.9170 and 0.7810 for Record 2

This research shows that simple instrument like DRM are useful as an alternative instrument for monitoring of PM_{10} concentration at new areas and selected points because the DRM is a portable machine and its cost is cheap as compared to BAM. So, the local authority can monitored the air quality efficiently and the monitoring record can be used for other research work or monitoring. It was found that the concentration recorded using DRM was lower compared to BAM.

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