Morphology and Elemental Component of $PM_{2.5}$ at a School Located Near Industrial Area in Malaysia

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Abstract Fine particles are recognized as one of the main air pollutants that could give negative effects on human health and air quality status. Increase in amount of industrial activities and vehicle could enhance the number of possible sources of $PM_{2.5}$. This may increase the concentration of $PM_{2.5}$ for both ambient and inside the building including school. Morphological properties and elemental composition are two components that role significantly in determination of potential sources of particulate matter. Thus, in this research, physical characteristic and elemental component for indoor and outdoor $PM_{2.5}$ was determined by using Field Emission Scanning Electron Microscopy coupled with energy dispersive X-ray (FESEM-EDX). Results show that there is significant ($p < 0.05$) relationship between indoor and outdoor $PM_{2.5}$ concentrations at this selected school with correlation coefficients, r = 0.376. For the morphology and elemental composition analysis, it shows that there are similar shapes of indoor and ambient $PM_{2.5}$ which irregular shaped and transition metal particles. For the elemental components, range for indoor elements of $PM_{2.5}$ is O > Si > Ca > C > Na > Mg > Al > Cl and for outdoor $PM_{2.5}$, the range is O > Si > Na > Ca > Ba > Al > Mg > K > Cl. Therefore, effect of outdoor towards indoor $PM_{2.5}$ had been significantly identified in this school classroom.

Keywords Fine particles · Indoor and ambient air · Physical characteristic · Chemical composition

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1 Introduction

Particulate matter with a diameter less than 2.5 μm ($PM_{2.5}$) could give effects on environment i.e. radiation balance, cloud formation, daily activity such as visibility deficiency and lead to negative effect on human health and living organism [11, 4, 20]. $PM_{2.5}$ which directly emitted from combustion process becomes a concern among researchers due to its toxicological and physiological conditions which had been identified could give adverse effects on human health [16]. Size of particles, morphology, composition and mixing phase of $PM_{2.5}$ at certain monitoring and sampling area could be affected by local sources emission of $PM_{2.5}$, ambient atmospheric reaction (the formation of particles), and transportation of $PM_{2.5}$. The emissions from industrial activity for instance burning activities could increase number of fly ash particles and vehicles emission become major contributor towards carbon types soot particles. Besides, types of vehicles could give effect on physical and chemical characteristics of particles [19]. Morphology properties of particles are very important in order to identify agglomeration and particle formation that effects on interaction with other bodies [19, 21, 24]. In addition, morphology of atmospheric particles could give effect on radiative and chemical properties [1, 7]. Morphological analysis of particulate matter could help recognize possible emission sources based on percentage of elemental composition consist in particulate matter. There are fourteen elements that normally consistently found inside particulate matter which are O, C, N, Si, Ca, Fe, Al, Al, Cl, K, Mg, S, Na, Ti, Zn [6, 13, 15, 18]. Distribution of weight percentage of these elements could be utilized to classify the possible sources for example large amount of carbon caused by carbonaceous materials that emitted from vehicles, diesel generators, and emissions from industrial activities [18] and biomass burning [6]. Therefore, the objective of this study is to determine the concentrations of $PM_{2.5}$, and the morphological and elemental composition for indoor and ambient conditions of a school located nearby industrial area in Perak, Malaysia.

2 Material and Methodology

2.1 Location of Sampling Site

Monitoring and sampling activities of this study were conducted at a school (School A) in Perak. The selected school was located less than 1 km (<1 km) from industrial sources in Simpang, Perak with coordinate 4° 53′ 49.98″ N, 100° 40′ 50.98″ E. The classroom in this school utilized mix-mode ventilation systems which is combination of natural and mechanical aids i.e. fans. In addition, the classroom was built-up with louvre windows and two doors as opening system. Primary school children (Standard 1) occupied this classroom. Figure 1 shows the location of potential source in the red circle which was a calcium carbide and lime manufacturing plant located approximately 0.8 km away from the school at Simpang, Perak.

2.2 Monitoring and Sampling of $PM_{2.5}$ Samples at School

Concentration of fine particles, meteorological parameters (temperature, relative humidity and wind speed) for indoor and outdoor were measured hourly average throughout teaching and learning session (7:00 a.m.–13:45 p.m.) for two days in the school. For sampling and monitoring of outdoor $PM_{2.5}$, a portable Environmental Beta Attenuation Monitor (E-BAM) had been utilized with flow rate 16.7 L/min (Met One Instrument Inc., Oregon) and for indoor $PM_{2.5}$, an optical direct reading monitor with flow rate 2 L/min (E-Sampler) (Met One Instrument Inc., Oregon) was used. In consideration of difference on flow rate of these instruments, k-factor value was predetermined using regression analysis and value

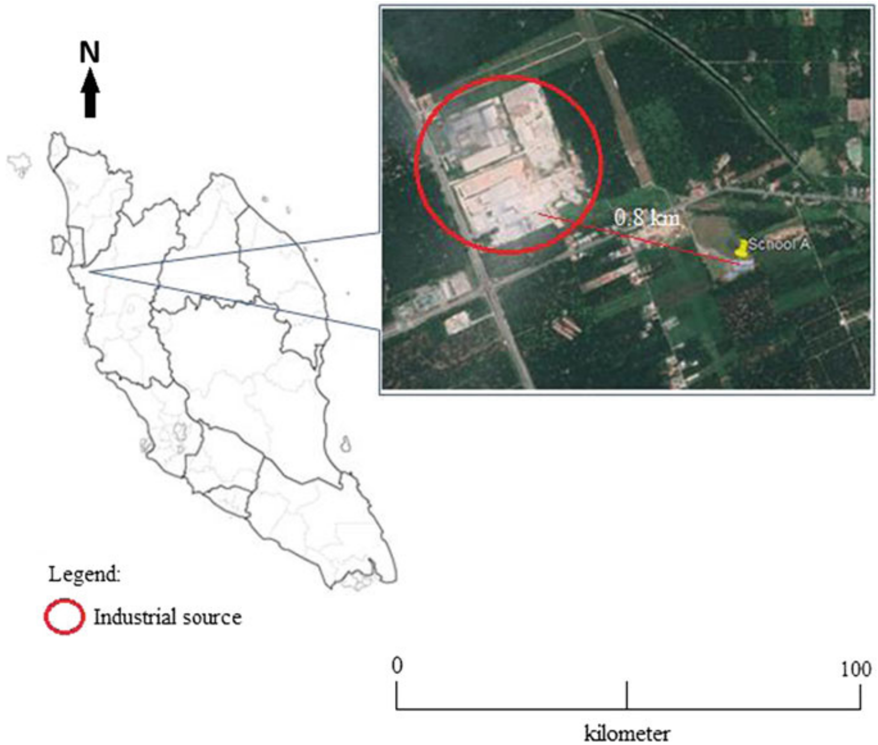


Fig. 1 Location of study area

of k-factor is 0.3397. The glass fiber filter papers with diameter 47 mm were utilized for indoor samples of $PM_{2.5}$ and for ambient; the samples were collected using glass fiber filter tape.

2.3 Physical Characteristic Analysis Using Field Emission Scanning Electron Microscopic (FESEM) on Indoor and Ambient $PM_{2.5}$ at School

The collected samples of indoor and outdoor $PM_{2.5}$ were analyzed for morphological characteristic and elemental components. For outdoor samples, samples were punched using a steel puncher with a diameter of 12 mm from glass fiber filter tape. Filtered samples for indoor and outdoor were cut into half using disposable scalpel because the other half filtered samples will be used for other analysis. Samples were mounted with carbon tape on a stub, and then coated with a thin layer of gold by coater Model Quorum 150T. The coated samples were examined manually using Field Emission Scanning Electron Microscope (FESEM) Model Quanta FEG 650 coupled with Energy Dispersive X-ray Spectrometer (Oxford Instrument) at magnifications ranging between 5000× and 35,000× in order to obtain the morphological characteristics and elemental composition of particles. Based on Salma et al. [17], Field-Emission Scanning Electron Microscopy (FESEM) coupled with Energy Dispersive Spectrometry (EDX) is a beneficial approach in distinguish the particles originating from variation of sources regarding on information about the elemental composition, size and shape of particulate matter.

2.4 Association Between Indoor and Outdoor $PM_{2.5}$ and Meteorological Variables Using Pearson's Correlation Analysis

Correlation analysis had been used in order to measure strength of linear relationship between two variables or paired data. Pearson's correlation result could be categorized into three types which is positive correlation, negative correlation and no correlation. Positive correlation shows that there is directly proportional relationship among two variables or parameters, as the factor (x) increase, the other variable (y) will be increased too. For negative correlation, the relationship is indirectly proportional which as the factor (x) increased, the other variable (y) will be decreased. The third type of correlation named as no correlation which is the other variables (y) do not influence by increasing or decreasing factor (x). The strength of correlation had been determined by correlation coefficient (r) in the range between −1 and +1 [5, 8]. The value of correlation coefficient is determined by using Eq. (1) and Table 1 shows the strength of correlation coefficient based on Guildford's Rule of Thumb [5, 8].

$$r = \frac{\sum \left(X - \overline{X}\right)\left(Y - \overline{Y}\right)}{\sqrt{\left(X - \overline{X}\right)^2 \left(Y - \overline{Y}\right)^2}} \tag{1}$$

where r = Pearson's correlation coefficient; X = concentration of outdoor $PM_{2.5}$, temperature, relative humidity, and wind speed; Y = concentrations of indoor $PM_{2.5}$, temperature, relative humidity and wind speed; $\overline{X}$ = mean outdoor $PM_{2.5}$ concentrations, temperature, relative humidity, wind speed; and $\overline{Y}$ = mean indoor $PM_{2.5}$ concentrations, temperature, relative humidity and wind speed.

3 Results and Discussion

3.1 Variations of $PM_{2.5}$ and Meteorological Variables for Indoor and Ambient Air at School

Table 2 shows descriptive statistics for indoor and outdoor $PM_{2.5}$ and meteorological parameters (i.e. temperature, relative humidity and wind speed) at school A. Average indoor $PM_{2.5}$ was 26 ± 18 μg/m^3 which slightly higher than outdoor $PM_{2.5}$ which was 24 ± 10 μg/m^3. The maximum concentration of indoor $PM_{2.5}$ measured was 81 μg/m^3 and the minimum concentration was 9 μg/m^3. A maximum concentration of outdoor $PM_{2.5}$ was 43 and 11 μg/m^3 was the minimum concentration. Average indoor and outdoor $PM_{2.5}$ did not exceed indoor limit by ASHRAE 62.1 standard [2] that is 35 μg/m^3 and for outdoor, New Malaysia Ambient Air Quality Standard Interim Target-2 (IT-2) (DOE 2014) that is 50 μg/m^3. Figure 2 shows indoor $PM_{2.5}$ started to increase at 7.45 a.m. which was during that time children began to occupy the classroom after morning assembly activity. Indoor concentrations of $PM_{2.5}$ started to decline at 8.45 a.m. because children left the

Table 1 Correlation coefficient by Guildford's Rule of Thumb [5, 8]

Size of correlation	Interpretation
0.90 to 1.00 (−0.90 to −1.00)	Very high positive (negative) correlation
0.70 to 0.90 (−0.70 to −0.90)	High positive (negative) correlation
0.50 to 0.70 (−0.50 to −0.70)	Moderate positive (negative) correlation
0.30 to 0.50 (−0.30 to −0.50)	Low positive (negative) correlation
0.00 to 0.30 (0.00 to −0.30)	Little if any correlation

classroom for physical activity at school field until 9.45 a.m. and during that time fans were switched off. After recess, the children reenter the classroom and caused the concentrations of indoor $PM_{2.5}$ began to increase until 10.45 a.m. This is because they continued with teaching and learning activity inside the classroom and the children movements had given an effect on indoor $PM_{2.5}$. As the classroom was occupied after recess time, indoor $PM_{2.5}$ was gradually increased again due to the effects of children movement. Children movement had caused the resuspension of $PM_{2.5}$ and lead to the indoor concentrations to be increased. This is similar with finding by Othman et al. [14], concentrations of indoor $PM_{2.5}$ was greater than outdoor during weekdays or school days due to children movements around before recess and entering the classroom after recess. This is also supported by Van der Zee et al. [22] which stated that children's activities inside the classroom could cause resuspension of dust especially for fine particles which are able to float or suspended for a longer period. In addition, there was an influence from outdoor $PM_{2.5}$ towards indoor concentrations of $PM_{2.5}$ because during that time (10.50 a.m.–11.50 a.m.) outdoor $PM_{2.5}$ was increased. This is similar with Mohammadyan et al. [12] which found that outdoor $PM_{2.5}$ could influence on indoor concentrations of $PM_{2.5}$ due to emission from industrial and vehicular emissions.

For meteorological parameters, average indoor and outdoor temperature recorded was 30.8 ± 1.5 °C and 30.6 ± 3.3 °C while average for indoor and outdoor relative humidity was 51 ± 2% and 72 ± 14%. Figure 3 shows trend of indoor and outdoor temperature and relative humidity which is a normal condition whereby the relative humidity decline when temperature increased. For indoor condition, trend of relative humidity slightly declined due to small changes of indoor temperature. This might be influenced by low wind speed in the classroom as shown in Fig. 4. Outdoor wind speed at this school was higher than indoor as shown in Fig. 4. Average wind speed was 0.8 ± 0.4 m/s for outdoor and for indoor, the average was 0.3 ± 0.0. Maximum and minimum wind speed for outdoor was 1.6 and 0.3 m/s while for indoor, the maximum wind speed was 0.4 m/s and minimum was 0.3 m/s. The variations of wind speed was small because the fans only functioned at a certain speed.

Table 2 Descriptive statistic of indoor and ambient $PM_{2.5}$ and meteorological variables at school A

	$PM_{2.5}$ (μg/m³)		Temperature (°C)		Relative humidity (%)		Wind speed (m/s)	
	I	O	I	O	I	O	I	O
Avg ± SD	26 ± 18	24 ± 10	30.8 ± 1.5	30.6 ± 3.3	51 ± 2	72 ± 14	0.3 ± 0.0	0.8 ± 0.4
Max.	81	43	32.9	34.5	57	75	0.4	1.6
Min.	9	11	28.1	25.2	49	56	0.3	0.3

Note Avg = average; SD = standard deviation; Max. = maximum; Min. = minimum; I = indoor; O = outdoor

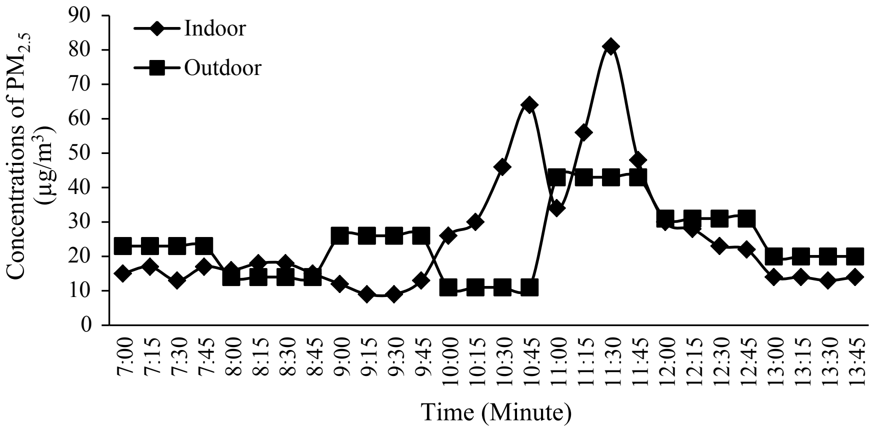


Fig. 2 Average concentrations of indoor and outdoor $PM_{2.5}$ at school A

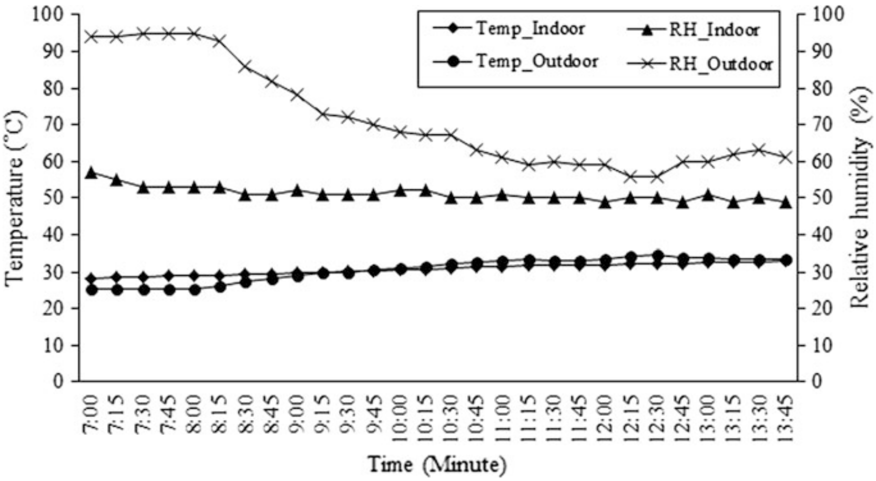


Fig. 3 Average of indoor and outdoor meteorological parameters (Temp. and RH) at school A

3.2 Association Among Indoor and Ambient $PM_{2.5}$, Temperature, Relative Humidity and Wind Speed

Pearson's correlation analysis in Table 3 shows that there is a significant (p = 0.04) relationship among indoor and ambient $PM_{2.5}$ in this school. The strength of relationship was classified in medium category with r = 0.376. Effects of meteorology (i.e. temperature, relative humidity and wind speed) also had been identified by using Pearson's correlation and it shows outdoor $PM_{2.5}$ concentrations were significantly affected by temperature (r = 0.378, $p < 0.05$) and relative humidity

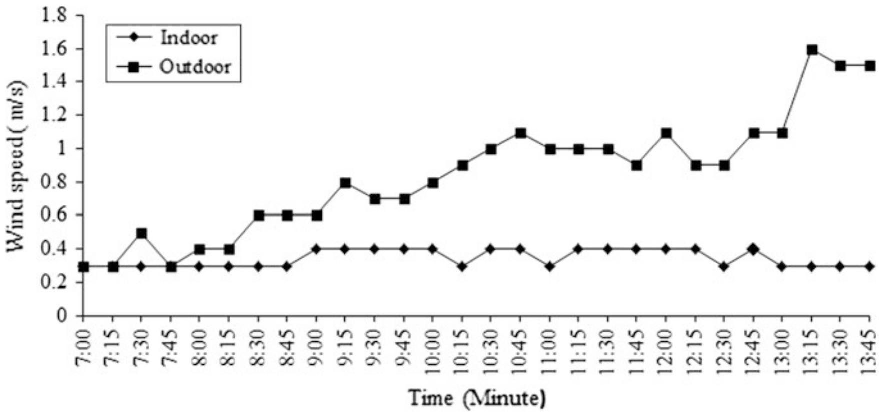


Fig. 4 Average of indoor and outdoor meteorological parameter (WS) at school A

Table 3 Pearson's correlation between indoor and ambient parameters

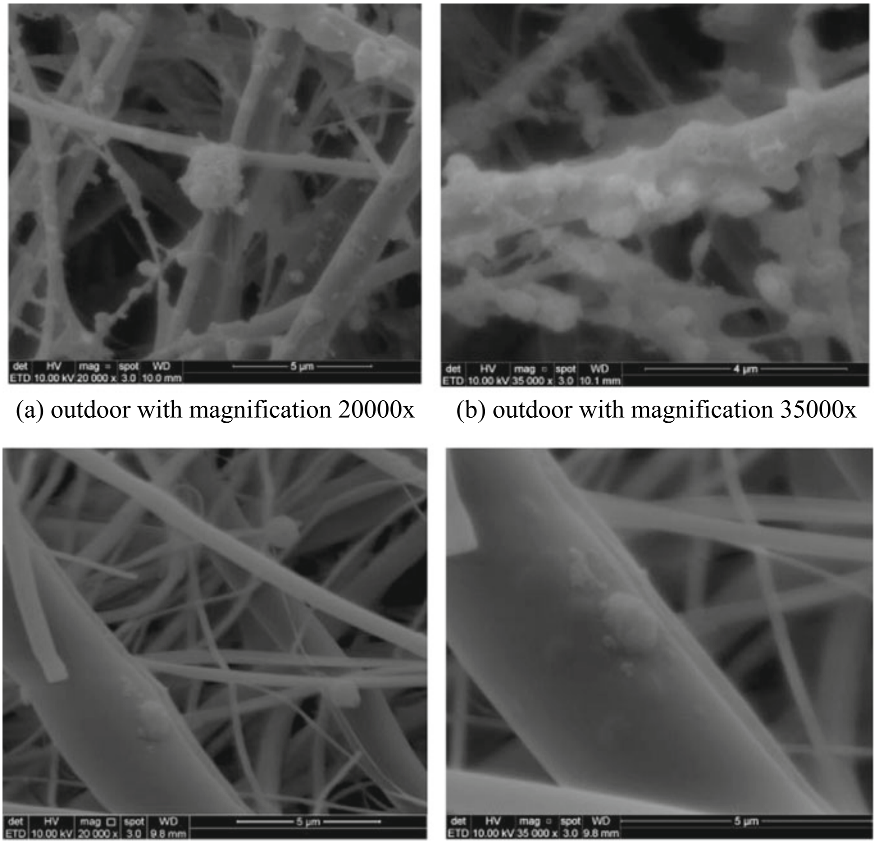
	$PM_{2.5}$ In	$PM_{2.5}$ Out	Temp. In	Temp. Out	RH In	RH Out	WS In	WS Out
$PM_{2.5}$ In	1	0.376[b]	0.330	0.450[b]	−0.323	−0.440[b]	0.455[b]	0.240
$PM_{2.5}$ Out	0.376[b]	1	0.331	0.378[b]	−0.255	−0.419[b]	0.337	0.144
Temp. In	0.330	0.331	1	0.962[a]	−0.852[a]	−0.936[a]	0.247	0.913[a]
Temp. Out	0.415[b]	0.378[b]	0.962[a]	1	−0.833[a]	−0.994[a]	0.394[b]	0.864[a]
RH. In	−0.323	−0.255	−0.852[a]	−0.833[a]	1	0.822[a]	−0.403[b]	−0.814[a]
RH. Out	−0.440[b]	−0.419[b]	−0.936[a]	−0.994[a]	0.822[a]	1	0.457[b]	−0.830[a]
WS. In	0.455[b]	0.337	0.247	0.394[b]	−0.403[b]	−0.457[b]	1	0.152
WS. Out	0.240	0.144	0.913[a]	0.864[a]	0.814[a]	0.830[a]	0.152	1

[a]Correlation is significant at the 0.01 level (2-tailed)
[b]Correlation is significant at the 0.05 level (2-tailed)

(r = −0.419, $p < 0.05$). For indoor, wind speed gave significant influence on $PM_{2.5}$ concentrations. This present finding is parallel with Mohammadyan et al. [12], Hassanvand et al. [9], Wichmann et al. [23] which found significant relationships among indoor and ambient $PM_{2.5}$ in classroom, school dormitory and a retirement home in Sari (Northern Iran), Tehran (Iran) and Stockholm's city which due to the contribution from outdoor sources mainly from industrial emission and vehicles emissions.

3.3 Morphology Properties and Elemental Components of Indoor and Ambient $PM_{2.5}$

The influenced of ambient $PM_{2.5}$ towards $PM_{2.5}$ inside the classroom were also supported by morphological characteristic as in Fig. 5a–d. Based on Fig. 5a–d, it can be seen that indoor and outdoor $PM_{2.5}$ have similar irregular shape, agglomerate and transition metal particles might be influenced by the distance between school and potential source which approximately 0.8 km apart. This finding is similar with Jan et al. [10] and Maskey et al. [11] whereby the sampling locations were located close to a highway and industrial complexes and suggested that industrial and traffic sources as main producer of transition metal particles.



(a) outdoor with magnification 20000x (b) outdoor with magnification 35000x

(c) indoor with magnification 20000x (d) indoor with magnification 35000x

Fig. 5 High resolution of FESEM of ambient and indoor in school C. **a** Irregular shaped agglomerate particles, **b** transition metal for outdoor, **c** irregularly shaped agglomerate particles and **d** irregularly shaped agglomerated particles-transition metal of indoor particles in school A

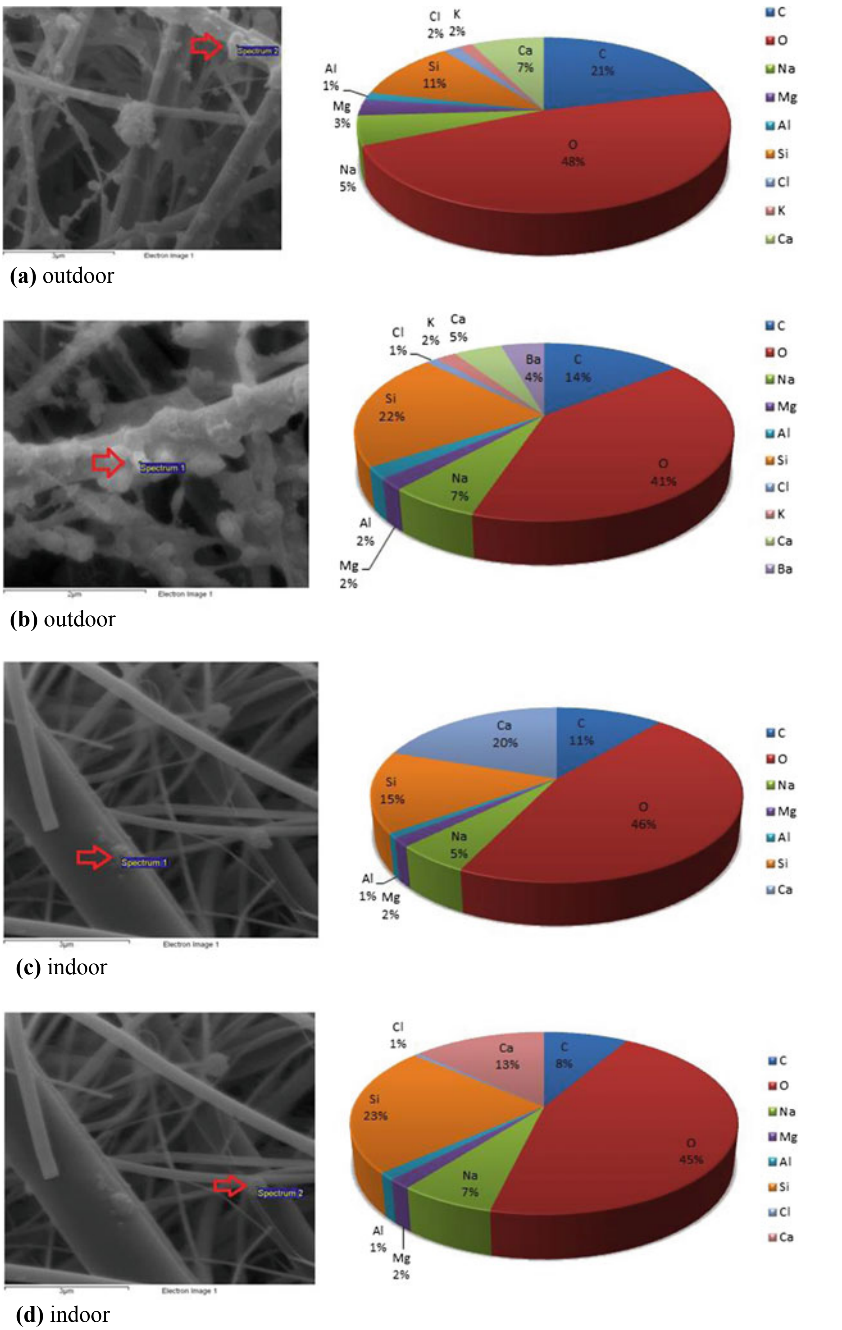


Fig. 6 High resolution of FESEM micrographs with percentage of each element for outdoor (**a**, **b**) and indoor (**c**, **d**)

The elements that contained within the $PM_{2.5}$ is identified as aluminum (Al), barium (Ba), carbon (C), calcium (Ca), chlorine (Cl), magnesium (Mg), oxygen (O), potassium (K) silica (Si), and sodium (Na). Based on weight percentage of elements in Fig. 6a, b, it could be recognized that for outdoor $PM_{2.5}$, oxygen become major elements followed by silica, sodium, calcium, barium, aluminum, magnesium, potassium and chlorine which are O > Si > Na > Ca > Ba > Al > Mg > K > Cl. For indoor $PM_{2.5}$ in Fig. 6c, d, the major element is oxygen followed by silica, calcium, carbon, sodium, magnesium, aluminum and chlorine which are O > Si > Ca > C > Na > Mg > Al > Cl. The elements found in indoor $PM_{2.5}$ is similar with outdoor $PM_{2.5}$ and this finding could support the Pearson's correlation analysis between indoor and outdoor concentrations of $PM_{2.5}$ in order to state that there is significant influence by outdoor towards indoor $PM_{2.5}$.

4 Conclusions

The variations of $PM_{2.5}$ concentration, morphology properties and elemental composition for indoor and outdoor school classroom located nearby industrial source in Perak, were investigated. It had been found that the average of indoor $PM_{2.5}$ concentration was 26 ± 18 $\mu g/m^3$ and the outdoor was 24 ± 10 $\mu g/m^3$. Indoor $PM_{2.5}$ concentrations did not exceed the permissible limit by ASHRAE 62.1 standard which is 35 $\mu g/m^3$ while ambient $PM_{2.5}$ concentrations were below the permissible limit of National Ambient Air Quality Standards by USEPA (35 $\mu g/m^3$) and the New Malaysia Ambient Air Quality Standard for $PM_{2.5}$ Interim Target-2 (IT-2) (50 $\mu g/m^3$). Pearson's correlation analysis shows that there is significant relationship between indoor and outdoor $PM_{2.5}$ with the value of $p = 0.04$ and r = 0.376. The strength of relationship between indoor and outdoor $PM_{2.5}$ was classified as medium. The morphology analysis shows that similar shapes which are irregular shaped and transition metal particles had been recognized of indoor and outdoor $PM_{2.5}$ in this school. The elemental composition that content inside the $PM_{2.5}$ for indoor and outdoor show the similar elements which the range are oxygen, silica, calcium, sodium, magnesium, aluminum, potassium, barium, and chlorine. The range of elemental composition are O > Si > Ca > C > Na > Mg > Al > Cl (indoor) and O > Si > Na > Ca > Ba > Al > Mg > K > Cl (outdoor). As a conclusion, there is significant contribution from outdoor specifically industrial source towards indoor $PM_{2.5}$ concentrations in school classroom.

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