

Concentration of the PM_{2.5} according to the sampling areas associated with the concentration of heavy metals and anions in Penang

Suvennie Saseetheran¹, Bawani Selvam¹, Norrimi Rosaida Awang^{1,*}, Mahani Yusoff² and Mohamed Abdus Salam³

¹Faculty of Earth Science, Universiti Malaysia Kelantan Jeli Campus, 17600 Jeli, Kelantan, Malaysia.

²Faculty of Bioengineering and Technology, Universiti Malaysia Kelantan Jeli Campus, 17600 Jeli, Kelantan, Malaysia.

³Department of Environmental Science and Disaster Management, Noakhali Science and Technology University, Noakhali 3814, Bangladesh.

Received 19 October 2019

Accepted 17 May 2021

Online 30 June 2021

Keywords:

air pollution, particle pollution, ICP-MS, ion chromatography, Pearson correlation

✉*Corresponding author:

Dr. Norrimi Rosaida Awang
Faculty of Earth Science,
Universiti Malaysia Kelantan
Jeli Campus, 17600 Jeli, Kelantan,
Malaysia.

Email: norrimi.a@umk.edu.my

Abstract

Particulate matter (PM) was identified as the main air pollutants in Malaysia which directly impose a treat to human health and understanding this pollutant is also crucial for its mitigation and control. This study aims to determine and characterize the PM_{2.5} with the influence of meteorological parameters. The PM_{2.5} samples were collected at Perai, Nibong Tebal and highway of Penang Bridge represented the industrial, residential, and roadside areas of Mainland Penang, respectively. The descriptive statistical analysis was conducted to understand the variations of PM_{2.5} concentration on the study areas, while its relationship with meteorological parameters were tested using Pearson correlation. Eleven heavy metals and three anions were determined using mass spectrometry (ICP-MS) and Ion Chromatography, respectively. Results showed that the mean concentration of PM_{2.5} are 10.88 µg/m³, 31.96 µg/m³, and 39.35 µg/m³ for residential area, industrial area, and roadside, respectively. The results revealed that mean concentrations of PM_{2.5} (39.35 µg/m³) in the roadside are significantly higher than NAAQG 24-h average of 35 µg/m³. Result also suggested that meteorological parameters were lest significant in controlling the PM_{2.5} concentrations as only the air pressure was found to be significant with the value of correlation coefficient of 0.476. The major components such as SO₄²⁻, K and Na account for about 70-90% of the PM_{2.5}.

© 2021 UMK Publisher. All rights reserved.

1. INTRODUCTION

Air pollution has been a substantial challenge among the various environmental problems to affect the biggest damage to health and loss of welfare from environmental causes in Asian countries (Dominick *et al.*, 2012). Particulate matter (PM) is one of the atmospheric pollutants that has been an environmental and health concern in many developed countries (Sun *et al.*, 2015). In Malaysia, PM also identified as the main air pollutants of concern and two type PM which as particulate matter with aerodynamic diameter less than 10 micron (PM₁₀) and particulate matter with aerodynamic diameter less than 2.5 micron (PM_{2.5}) were this country criteria air pollutants. However, the fine portion of atmospheric particulate matter received higher attention as it imposes higher risk towards human health. As it very smally in size, Figueroa *et al.* (2006) reported that PM_{2.5} have higher capacity to enter human lung and deep deposited in the lung. Some of

the factors that influence water quality and it's chemistry across African coast are enhanced by Na⁺, Ca²⁺, Mg²⁺ and HCO₃⁻, due to silicate and carbonate weathering and enhanced NO₃⁻ from indiscriminate waste disposal from human activities (Wotany *et al.*, 2013). The chemical quality of surface and groundwater is controlled by natural processes such as precipitation, mineral weathering and evaporation-crystallization and significantly influenced by anthropogenic processes (Wotany *et al.*, 2013; Mangoua *et al.*, 2015).

Commonly, similarly to PM, the PM_{2.5} is a compound of horizons as it contains variety of solid and liquid particles with size smaller than 2.5 micrometer. PM_{2.5} also released to the atmosphere by natural and man-made sources such as combustions, vehicular and industrial emissions as well other activities such as mining and constructions. The chemical composition of PM_{2.5} offers valuable information to identify the contributions of specific sources, and to understand aerosol properties and

processes that could affect health, climate, and atmospheric conditions (Solomon *et al.*, 2014; Fatimah, 2016).

USEPA reported that the major components of PM_{2.5} are ammonium sulphate, ammonium nitrate, organic carbonaceous mass, elemental carbon, and crustal material which included heavy metals. Heavy metals in PM_{2.5} that can be breath into the lung show a rise lung or cardiopulmonary damages (Lee and Hieu, 2011). Heavy metals invade the nature environment via three main paths such as deposition of particulates, disposal of metals via sewages and by-product from metal mining operation. In addition, biogeochemical cycle is the major phase of heavy metals as they are absorbed to PM_{2.5} in the atmosphere. They also can travel far away from its original position and unload to the ground through wet and dry deposition, resulting a risk to the environment (Li *et al.*, 2015). For the coarse particles, the ions and its heavy metals exist are sulphate (SO₄²⁻), chloride (Cl⁻), nitrate (NO₃⁻), iron (Fe), potassium (K) and sodium (Na) whereas for the fine particles, the ions and its heavy metals are SO₄²⁻, K and Na (Tahir *et al.*, 2013).

The continuous developments in Penang have raised an important role of PM_{2.5} and its associates in the atmosphere. High emissions of PM_{2.5} has a strong potential for adsorbing environmental toxicants due to the large specific surface area (Sun *et al.*, 2015). According to Predeep (2015), Penang has reached near to the level of unhealthy zone between 100 to 200 based on the API reading in 2013. This problem is the severe issue to be solved and considered by societies especially the authorities. The objective of this study is to determine PM_{2.5} concentrations and their associated selected heavy metals and anion ions in the samples collected from the study areas. It is prerequisite to understand the chemicals composition and concentration of PM_{2.5} of sample area which caused deterioration in human health and environment. The predictable study of PM_{2.5} and its associated chemicals may deliver crucial information of the origin and sources of PM_{2.5} which is vital to invest precautions to decrease pollution in the current sampling area.

2. MATERIALS AND METHODS

2.1. Study Area

PM_{2.5} samples was collected from three sampling areas namely Perai, highway of Penang Bridge, and Nibong Tebal representing industrial area, roadside area and residential area of Penang mainland, respectively from June until September 2015. Perai (5°23.4704N; 100°23.1977E) has high density of industrial and medium density of residential dwellings with the most of air pollutants originated from industrial zone (Zakaria, 2007). It was nominated as station 1 (S1). Second station (S2) was Nibong Tebal (5°10'5"N 100°28'43"E) and can be considered as suburban area with a huge number of

populations representing as residential areas (Shahnon, 2005). Highway of Penang Bridge was notified as Station 3 (S3) and the sampler was placed at Toll Office near to Penang Bridge (5° 21.375 N 100° 23.584 E). A total of nine samples consisting of three samples of each location were collected monthly. Due to a limited number of samplers, the samples were collected simultaneously representing all the three different locations. Duration of sampling was 24 hours per day that was taken from first, middle, and the last week of each month from June to September 2015. The total number of samples collected in these four months was 36. The location of the sampling sites in Penang shown in Figure 1.

2.2. Data Acquisition

The materials used throughout this study were quartz filter paper with 25 mm in diameter by using the instrument named Low Volume Air Sampler (LVAS) with flow rate of 20 l/min for period of 24 hours. The quartz microfibre filters were kept under controlled conditions in the desiccator before and after sampling at relative humidity of 50 + 5% for about 48 hours in order to minimize the influence of water adsorption. The filter papers were weighed using the 5-digit microelectronic balance with 0.01 mg sensitivity before and after sampling. Daily average meteorological parameters data from June until September 2015 were obtained from the Meteorological Department of Penang. The meteorological parameters included surface temperature, relative humidity and precipitation, wind speed, wind direction, and air pressure.

2.3. Data Analysis

The collected data then were analysed using Pearson correlation with the aid of SPSS software to determine the relationship between PM_{2.5} concentrations and the meteorological parameters. The data then were analysed to determine the heavy metals and anions by applying open beaker acid digestion and ion chromatography, respectively.

2.3.1. Extraction and Analysis of Heavy Metals

Before subjecting to the extraction processes on heavy metals, the filter samples (25 mm in diameter) were prepared by cutting them into quarter equal portion using a ceramic scissor. Heavy metals were prepared by using acid digestion using the inductively coupled plasma mass spectroscopy (ICP-MS) analysis. The filter paper was soaked into digestion reagent (3 ml of concentrated nitric acid) in a Teflon vessel and shook for 10 minutes in an ultrasonic system. The vessel was heated in an oven at 180°C for 8 hours for dissolution of the particulate matter. The heated sample was filtered with a cleaned filter paper (Whatman 41, no. 1440-125) into a Teflon beaker. The liquid samples were transferred into centrifuge tube with a

total volume of about 11 ml and then heated on an open beaker at 110°C to reduce the aqueous phase to 2 ml.



Figure 1: The Penang, sampling areas, and nearby industries (Google map, 2019).

Furthermore, 1 drop of concentrated nitric acid (HNO_3) was added to each sample. The samples were subjected to analysis of selected heavy metals (Al, Fe, Na, Mg, K, Mn, Ni, Cu, Zn, V, As) using ICP-MS procedure. ICP-MS was used to examine the heavy metal concentration of Al, Fe, Na, Mg, K, Mn, Ni, Cu, Zn, V and As with 6000cx system (ELAN DRC-e, USA). Calibration standards were prepared by diluting the stock solution with Milli-Q water or 10% nitric acid (HNO_3) with the same matrix in samples from 0.005 to 5 mg/L. In order to use, all the stock solutions were kept in refrigerated at 4°C. Nitric acids (69%), hydrogen peroxide (30%) and hydrochloric acid (36%) were obtained from Merck KGaA (Germany). National Institute of Standards and Technology (NIST) Standard reference material (SRIM) 2709a is a San Joaquin Soil (NIST, USA) and it was applied in this study to examine the behavior of acid digestion procedures. The argon gas was used in Inductively Coupled Plasma (ICP) with the purity $\geq 99.995\%$ bought from Hong Kong Linde Ltd.

2.3.2. ICP-MS Analysis of Heavy Metals

ICP-MS was used to examine the heavy metal concentration of Al, Fe, Na, Mg, K, Mn, Ni, Cu, Zn, V and As. Multi-element calibration standard of ICP-MS were prepared by diluting the stock solution with Milli-Q water or 10% nitric acid (HNO_3) with the same matrix in samples from 0.005 to 5 mg/L. In order to use, all the stock solutions were kept in refrigerated at 4°C. Nitric acid (69%), hydrogen peroxide (30%) and hydrochloric acid (36%) were obtained from Merck KGaA (Germany). The argon gas was used in Inductively Coupled Plasma (ICP) with the purity $\geq 99.995\%$.

The standard solution for ICP-MS were divided into two stages; 1) 10 $\mu\text{g/mL}$ mixed stock standard which contains the elements of Al, Fe, Na, Mg, K, Mn, Ni, Cu, Zn, V and As was prepared. 1 mL of each 100 $\mu\text{g/mL}$ certified standards was pipette into a clean 100 mL volumetric flask and it was diluted with ASTM Type I water containing 2% (w/w) ultrapure nitric acid until reaching 100 mL. Then, the flask was inverted and mixed well before transferring them into a clean 125 mL Teflon

bottle; 2) 100 ng/mL mixed stock standard was prepared. 1 mL of the prepared 10 µg/mL stock standard was pipette into a clean 100 mL volumetric flask and it was diluted with ASTM Type I water containing 2% (w/w) ultrapure nitric acid until reaching 100 mL. Later, the flask was inverted and mixed well before transferring them into a clean 125 mL Teflon bottle. Then, blanks of 0.1, 0.3, 0.5, 0.7, 1.0, 3.0, 5.0, 7.0 and 10.0 µg/mL calibration standards were prepared. For 100 ng/mL multi-element standard, 0, 10, 30, 50, 70, 100, 300, 500, 700 and 1000µL was pipette into ten cleaned and labelled polypropylene 15 mL centrifuge tubes. 10.00, 9.99, 9.97, 9.95, 9.93, 9.90, 9.70, 9.50, 9.30 and 9.00 mL of ASTM Type I water containing 2% (w/w) ultrapure nitric acid were added into each tube, respectively. 100 µL internal standard was pipette into each tube using an Eppendorf repeater pipette and tubes were capped and shook well.

2.3.3. Ion Chromatography (IC) Analysis

For the analysis of anions, ion chromatography method was applied. Ion chromatograph (Dionex, DX-320, USA) with Ion Pac® AS12A (4 x 250 mm) and IonPac® CS12A (4 x 250 mm) associated with guard columns (IonPac® CG12A 4 x 50 mm and IonPac® AG12A 4 x 50 mm) were used to measure anions (Cl⁻, NO₃⁻, SO₄²⁻) ions in the aqueous extract. Electrolytic self-producing suppressor components such as ASRS®300, 4 mm, for anions were consumed. The oven temperature of the LC25 chromatograph was adjusted at 35°C. The samples were injected through a 25-µl loop into an eluent. An eluent of 2.7 mM Na₂CO₃ (Sunnyvale, California) and 0.3 mM NaHCO₃ (Sunnyvale, California) were prepared and used for detection of anions with a pump maintaining the flow rate of 1.0 ml/min.

Multi-element calibration standard of IC was prepared via consecutive additions of leading standard solution with ultrapure water (18 MΩ cm, Milli-Q System Millipore) for each ion. The calibration curves range for all ions were between 0.20 mg/L and 10 mg/L. The main stock solution was prepared from certified reference materials solutions of (1000±2) mg/L nominal ion concentration (CertiPur, Merck). All the prepared solutions were refrigerated at (4±2)°C. The calibration curve was established by plotting the peak areas for each ion against the concentration. The requirement of quality for the acceptance of the calibration function was constructed as a correlation coefficient of $r^2 \geq 0.995$.

Multi-element standard solution for IC was prepared by labelling 15 mL centrifuge tubes to apply for each calibration and control standards. 12 mL of the prepared standard solution was pipette to the tubes and the solution was mixed.

2.3.4. Statistical Analysis

The whole statistical assessment was carried out with the aid of SPSS software to determine significant differences between the mean concentration of insoluble materials, soluble materials, heavy metals and anions in atmosphere (Shakeri *et al.*, 2009). The significant sources of anion and heavy metals concentration was examined using correlation analysis.

Correlation analysis was used to calculate the association between two continuous variables. The output variable was called dependent variable whereas the risk factor was called independent variables. For correlation analysis, the examined sample correlation coefficient was Pearson Product Moment correlation coefficient and the symbol for correlation coefficient was r. The range of correlation coefficient was between -1 and +1 and it calculated the management and strength of the association between the two variables.

3. RESULT AND DISCUSSION

The concentration profile of PM_{2.5} associated together with their selected heavy metals and anions in Penang was illustrated in this section. Table 1 shows the descriptive statistics of daily mass concentration of PM_{2.5} in the study areas. The result revealed that PM_{2.5} concentrations was varied in both among samples and among locations. Standard deviation calculated showed the significant difference between PM_{2.5} concentrations between the residential area, industrial area, and roadside. Overall, the decreasing order of PM_{2.5} concentrations were residential area < industrial area < roadside. This result was in line with a previous study by Beh *et al.* (2013) conducted in Penang as well but in island part, which reported that the PM_{2.5} distributions was highest due to the high number of vehicles on the road. The emission of gas from vehicles contributed to the increment of dust concentration.

Table 1: Descriptive statistics of daily mass concentration of PM_{2.5}.

| Parameters | Residential (µg/m ³) | Industrial (µg/m ³) | Roadside (µg/m ³) |
|--------------------|----------------------------------|---------------------------------|-------------------------------|
| Mean | 10.88 | 31.96 | 39.35 |
| Median | 9.73 | 26.56 | 31.43 |
| Standard deviation | 6.32 | 22.07 | 22.12 |
| Maximum | 28.47 | 80.56 | 79.51 |
| Minimum | 4.86 | 9.03 | 18.06 |
| No. of samples | 12 | 12 | 12 |

According to Dahari *et al.* (2020), due to the industrialization, use of vehicles, and expansion of suburban areas into proximity with industrial areas, the particle pollution in ambient environment is increasing.

Table 2 shows the result of the correlation between PM_{2.5} concentration and meteorological parameters in the sampling areas comprised of residential area, industrial area, and roadside. This correlation was based on the daily concentration of PM_{2.5} in the areas. The

result indicated that negative correlation ($r = -0.207$) was found between $PM_{2.5}$ and precipitation. The similar result was reported by Owoade *et al.* (2012). This is due to the washout process as the rain exhibit wet deposition effect on particulate matter, thus, reduced the mass concentration of the atmospheric particulate. Precipitation also had effectively removed the atmospheric particulate matter, especially due to the smaller size (Wang and Ogawa, 2015).

Table 2: Correlation between $PM_{2.5}$ and the meteorological parameters in the study areas.

| Correlation | R | N |
|-------------------------------|--------|----|
| $PM_{2.5}$ with precipitation | -0.207 | 36 |
| $PM_{2.5}$ with wind speed | 0.081 | 36 |
| $PM_{2.5}$ with temperature | 0.155 | 24 |
| $PM_{2.5}$ with humidity | -0.343 | 24 |
| $PM_{2.5}$ with air pressure | 0.476* | 24 |

*Correlation is significant at the 0.05 level (2-tailed).

Then, positive correlation coefficient with the value of 0.081 was found between $PM_{2.5}$ and wind speed. Wind speed plays a major role in cleansing atmosphere of fine particulates as the pollutant transportation and dispersion agent (Dahari *et al.*, 2020). However, wind speed in study areas affected the turbulence near the ground ineffectively. It means the higher the wind speed, the higher the distribution of $PM_{2.5}$ concentrations in the area. According to Wang and Ogawa (2015), when the wind speed is high enough, it can transport large quantities of pollutants from far away. This result is parallel to the result obtained in Penang, where the dominant wind speed ranges between 6 to 9 m/s. Apart from wind speed, wind direction also a major factor that influenced fine particulate matter by transporting from different neighbouring regions to the sampling location. However, since wind direction only indication of where the direction of the wind came from and not a linear variable, it is not considered in the analysis.

$PM_{2.5}$ exhibits strong positive correlation with temperature. This result is in an agreement with other studies where fine particles being favoured of the transformations which took place in the atmosphere with the presence of solar radiation reached their peak values during the highest temperature days (Pateraki *et al.*, 2012). High temperatures were clearly conducive to intense convection. Atmospheric $PM_{2.5}$ was transported quickly and effectively, allowing its accelerated dispersion. Therefore, the local mass concentrations were decreased. Conversely, low temperatures and the temperature inversion layer caused by radiative cooling weakened convections. In these circumstances, $PM_{2.5}$ remained suspended under the inversion layer, leading to higher concentrations (Li *et al.*, 2015).

$PM_{2.5}$ yielded a negative correlation with relative humidity as well as statistically significant at 0.05

confidence level. Due to the hygroscopic growth, $PM_{2.5}$ concentration decreases when humidity is low. However, when the humidity is high enough, the particles grew heavy to stay in the air. Hence, dry deposition occurred and caused the particles fell to the ground. Consequently, particle numbers reduced, and concentration decreased (Wang and Ogawa, 2015).

Mass concentration displays a strong positive relation with air pressure. The result is corresponding to the result reported by Li *et al.* (2015) suggesting the surface experiences a convergence up draft when controlled by low pressure and the up draft promoted the dispersion of $PM_{2.5}$ from the ground up into the air. Thus, mass concentrations at the sampling point are subsequently reduce. Comparatively, when there was high pressure, the down draft restrained the upward movement of mass concentration caused an accumulation of particles (Li *et al.*, 2015).

3.1. Heavy metals and anion ions concentration levels

The concentration of heavy metals such as Al, Fe, Na, Mg, K, Mn, Ni, Cu, Zn, V and As_s as well as the target anions such as Cl^- , NO_3^- and SO_4^{2-} determined in $PM_{2.5}$ samples collected from industrial, residential and roadside is presented in Tables 3. The result for heavy metal concentration reveals that K, Na, Zn and Mg were dominant at the roadside area and industrial area of Mainland, Penang. Mean concentration of K at the roadside, industrial area and residential areas are 354.82 ng/m^3 , 324.66 ng/m^3 , and 216.80 ng/m^3 , respectively. Na concentrations value are 159.24 ng/m^3 , 143.32 ng/m^3 and 137.96 ng/m^3 at the above mentioned three areas, respectively.

High concentration of K and Na were found at three sampling areas. The highest number of automobile emissions, sea spray (on-shore winds forms ample sea water droplets with marine atmosphere) and coal combustion from nearby construction site may influence the highest concentration of K. K and Na are metals of crustal elements which may be came from doubled soil and road dust resuspension during the respective sampling days and the result of Asian dust which comes from soils in the dry desert and upland areas in spring also influence for these metals. This statement is supported by Ee-Ling *et al.* (2015), saying that the heavy metal such as K is subjected to be the highest emission in $PM_{2.5}$ of the total measured elemental concentration Zn, Mg, Fe, Al, Ni, Cu, As_s , Mn and V were almost similar throughout the sampling period at roadside and industrial area. Roadside is situated nearby industrial area where the emissions come from the burning of fossil fuels, coal combustion, road dusts, traffic pressure and different industry activities travel among those areas. The overall decreasing order of metal concentrations were $K > Na > Zn > Mg > Fe > Al > Ni > Cu > As_s > V > Mn, K > Na >$

Zn> Mg> Fe> Al> Ni> Cu> As, Mn> V and K> Na> Cu> Fe> Mg> Zn> Al> Ni> Mn> V> As, for roadside, industrial areas and residential areas, respectively.

Table 3: Mean concentrations and its standard deviation for anion ions and heavy metals in industrial, residential and roadside areas

| Compo-nents | Industrial | | Residential | | Roadside | |
|-------------------------------|---------------------------|--------|---------------------------|--------|---------------------------|--------|
| | Mean (ng/m ³) | SD | Mean (ng/m ³) | SD | Mean (ng/m ³) | SD |
| Cl ⁻ | 1.01 | 0.85 | 1.33 | 1.00 | 0.91 | 0.55 |
| NO ₃ ⁻ | 1.40 | 1.11 | 0.54 | 0.43 | 1.53 | 1.03 |
| SO ₄ ²⁻ | 4.88 | 3.07 | 1.66 | 1.06 | 4.42 | 3.13 |
| Al | 14.85 | 11.01 | 7.84 | 4.45 | 16.04 | 17.03 |
| Fe | 31.51 | 44.68 | 48.23 | 47.80 | 56.57 | 65.99 |
| Na | 143.32 | 142.81 | 137.96 | 132.02 | 159.24 | 96.00 |
| Mg | 69.25 | 21.25 | 43.43 | 25.26 | 78.85 | 38.63 |
| K | 324.66 | 258.40 | 216.80 | 170.60 | 354.82 | 235.84 |
| Mn | 3.46 | 5.77 | 2.53 | 2.78 | 1.25 | 1.28 |
| Ni | 6.69 | 3.91 | 3.21 | 2.45 | 8.47 | 4.94 |
| Cu | 5.79 | 5.82 | 105.56 | 167.74 | 7.33 | 6.04 |
| Zn | 103.79 | 70.56 | 41.03 | 26.01 | 118.09 | 69.00 |
| V | 1.68 | 1.19 | 1.09 | 0.85 | 1.68 | 0.97 |
| As | 4.17 | 7.27 | 1.03 | 0.62 | 6.55 | 14.27 |

The results reveal that SO₄²⁻ ion is the major constituents of air pollution with the mean concentrations of SO₄²⁻ ion at the industrial area, roadside and residential area are 4.88 µg/m³, 4.42 µg/m³ and 1.66 µg/m³, respectively. The NO₃⁻ concentration is low in residential area compares to the industrial area and roadside. The overall decreasing order of anion concentrations were SO₄²⁻> NO₃⁻> Cl⁻, SO₄²⁻> NO₃⁻> Cl⁻ and SO₄²⁻> Cl⁻> NO₃⁻ for industrial area, roadside, and residential area, respectively.

SO₄²⁻ is the main component of the PM_{2.5} in Penang compares to other anions ions. High amount of coal combustion and petrol combustion become the main role of SO₄²⁻ concentration in Penang (Khan *et al.*, 2010). SO₄²⁻ concentrations are high at the industrial area followed by roadside and residential area. They are oxidized to sulphate in atmosphere before transforming into wet or dry deposition. SO₄²⁻ also resulted from the dispersion of SO_x by industries such as sulphuric acid manufacturing as well as from the production and usage of sulphate minerals in power plant (Wang *et al.*, 2006). This statement is supported by John *et al.* (2007) and Tahir *et al.* (2013), saying that SO₄²⁻ is the most significant portion of PM_{2.5}.

High concentration of K and Na were found at the three sampling areas. The highest number of automobile emissions, sea spray (on-shore winds forms ample sea water droplets with marine atmosphere) and coal combustion from nearby construction site may influence the highest concentration of K. K and Na are metal of crustal elements which may be came from doubled soil and road dust resuspension during the respective sampling days and the result of Asian dust which comes from soils in the dry desert and upland areas in spring also have influence for these metals.

4.0. CONCLUSION

The study concluded that the meteorological parameters play a major role in day-to-day variations of the mass concentration of PM_{2.5} together with its chemical composition such as heavy metals and anion ions. The locations also highly influenced the distribution of PM_{2.5}. The highest mean concentration was found in roadside area with 39.35 µg/m³, followed by industrial area (31.96 µg/m³) and lastly residential area (10.88 µg/m³). Hence, the sources of PM_{2.5} were most likely influenced its anthropogenic sources in the respective areas. Meanwhile, result of Pearson correlation suggested the PM_{2.5} concentration in the study areas less impacted by the meteorological parameters as the only significant correlation coefficient obtained from PM_{2.5} and air pressure with 0.476. SO₄²⁻, K and Na were found as dominant chemical in the PM_{2.5} of Penang. The mean concentration of SO₄²⁻, K and Na were 4.42 µg/m³, 354.82 ng/m³, 159.24 ng/m³ at roadside. The mean concentration of SO₄²⁻, K and Na were 4.88 µg/m³, 324.66 ng/m³ and 143.32 ng/m³ at industrial area. The mean concentration of SO₄²⁻, K and Na were 1.66 µg/m³, 216.80 ng/m³ for K and 137.96 ng/m³ for Na at residential area. Roadside nearby to industrial area where the emissions of burning fossil fuels, coal combustion, road dusts, traffic pressure and different industry activities are the major role for having heavy metal concentrations.

Acknowledgements

The authors would like to thank the Universiti Malaysia Kelantan thanks Universiti Malaysia Kelantan for providing the best facilities for this research. The publication of this paper is funded by Rinsing Start Grant Scheme (R/STAR/A0800/01525A/003/2020/00793).

REFERENCES

Azmi, S. Z., Latif, M. T., Ismail, A. S., Juneng, L., Jemain, A. A. (2010). Trend and status of air quality at three different monitoring stations in the Klang Valley, Malaysia. *Air Quality, Atmosphere & Health*, 3(1), 53-64.

Beh, B., Tan, F., Tan, C., Syahreza, S., Jafri, M. M., Lim, H. (2013). PM₁₀, PM_{2.5} and PM₁ distribution in Penang Island, Malaysia. Paper presented at the AIP Conf. Proc.

Dahari, N., Latif, M. T., Muda, K., Norelyza, N. (2020). Influence of meteorological variables on suburban atmospheric PM_{2.5} in the southern region of peninsular Malaysia. *Aerosol and Air Quality Research*, 20(1), 14-25.

Dominick, D., Juahir, H., Latif, M. T., Zain, S. M., Aris, A. Z. (2012). Spatial assessment of air quality patterns in Malaysia using multivariate analysis. *Atmospheric Environment*, 60, 172-181.

Ee-Ling, O., Mustafa, N. I. H., Amil, N., Khan, M. F., Latif, M. T. (2015). Source contribution of PM_{2.5} at different locations on the Malaysian Peninsula. *Bulletin of Environmental Contamination and Toxicology*, 94(4), 537-542.

Fatimah, D. Q. (2016). Variation in global chemical composition of PM_{2.5}: emerging results from SPARTAN. *Atmospheric Chemistry and Physics (ACP)*, 16(15).

Figuerola, D. A., Rodríguez-Sierra, C. J., Jiménez-Velez, B. D. (2006). Concentrations of Ni and V, other heavy metals, arsenic, elemental

- and organic carbon in atmospheric fine particles (PM_{2.5}) from Puerto Rico. *Toxicology and industrial health*, 22(2), 87-99.
- John, K., Karnae, S., Crist, K., Kim, M., Kulkarni, A. (2007). Analysis of trace elements and ions in ambient fine particulate matter at three elementary schools in Ohio. *Journal of the Air & Waste Management Association*, 57(4), 394-406.
- Khan, M. F., Hirano, K., Masunaga, S. (2010). Quantifying the sources of hazardous elements of suspended particulate matter aerosol collected in Yokohama, Japan. *Atmospheric Environment*, 44(21), 2646-2657.
- Lee, B. K., Hieu, N. T. (2011). Seasonal variation and sources of heavy metals in atmospheric aerosols in a residential area of Ulsan, Korea. *Aerosol and Air Quality Research*, 11(6), 679-688.
- Li, H., Wang, J., Wang, Q. G., Qian, X., Qian, Y., Yang, M., Li, F., Lu, H., Wang, C. (2015). Chemical fractionation of arsenic and heavy metals in fine particle matter and its implications for risk assessment: A case study in Nanjing, China. *Atmospheric Environment*, 103, 339-346.
- Owoade, O., Olise, F., Ogundele, L., Fawole, O., Olaniyi, H. (2012). Correlation between particulate matter and meteorological parameters at a site in Ile-Ife, Nigeria. *Ife Journal of Science*, 14(1), 83.
- Pateraki, St., Asimakopoulos, D., Flocas, H., Maggos, T., Vasilakos, C. (2012). The role of meteorology on different sized aerosol fractions (PM₁₀, PM_{2.5}, PM_{2.5-10}). *Science of the Total Environment*, 419, 124-135.
- Predeep, N. (2015). Penang air quality near 'unhealthy'. Retrieved 27 August, 2015, from: <http://webcache.googleusercontent.com/search?q=cache:oAkPPVG8soUJ:www2.nst.com.my/nation/general/penang-air-quality-near-unhealthy-1.326892+&cd=2&hl=en&ct=clnk>
- Shahnon, S. (2006). Building a Performance-based Management System: Increasing the Impact of Community Engagement in Local Authorities. Network of Asia-Pacific Schools and Institutes of Public Administration and Governance (NAPSIPAG), 489.
- Shakeri, A., Moore, F., Mohammadi, Z., Raeisi, E. (2009). Heavy metal contamination in the Shiraz industrial complex zone groundwater, South Shiraz, Iran. *World Applied Science Journal*, 7(4), 522-530.
- Solomon, P. A., Crumpler, D., Flanagan, J. B., Jayanty, R. K. M., Rickman, E. E., McDade, C. E. (2014). US National PM_{2.5} Chemical Speciation Monitoring Networks—CSN and IMPROVE: Description of networks. *Journal of the Air & Waste Management Association*, 64(12), 1410-1438.
- Sun, J.-L., Jing, X., Chang, W.-J., Chen, Z.-X., Zeng, H. (2015). Cumulative health risk assessment of halogenated and parent polycyclic aromatic hydrocarbons associated with particulate matters in urban air. *Ecotoxicology and Environmental Safety*, 113, 31-37.
- Tai, A. P., Mickley, L. J., Jacob, D. J. (2010). Correlations between fine particulate matter (PM_{2.5}) and meteorological variables in the United States: Implications for the sensitivity of PM_{2.5} to climate change. *Atmospheric Environment*, 44(32), 3976-3984.
- Tahir, N. M., Suratman, S., Fong, F. T., Hamzah, M. S., Latif, M. T. (2013). Temporal distribution and chemical characterization of atmospheric particulate matter in the eastern coast of Peninsular Malaysia. *Aerosol and Air Quality Research*, 13(2), 584-595.
- Wang, X., Bi, X., Sheng, G., Fu, J. (2006). Chemical composition and sources of PM₁₀ and PM_{2.5} aerosols in Guangzhou, China. *Environmental monitoring and assessment*, 119(1-3), 425-439.
- Wang, J., Ogawa, S. (2015). Effects of Meteorological Conditions on PM_{2.5} Concentrations in Nagasaki, Japan. *International Journal of Environmental Research and Public Health*, 12(8), 9089-9101.
- Zakaria, R. (2007). Sustainable housing for residential-industrial neighbourhoods in Malaysia: a study on the elements of indoor environmental quality improvements.