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Research paper

Identification Source of Variation on Regional Impact of Air Quality Pattern using Chemometric Techniques in Kuching, Sarawak

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Abstract

Air pollution has been considered a devastating environmental issue that can negatively impact human health and the environment. Kuching as one of the capital cities in Malaysia is also affected by air pollution and unsatisfactory air quality condition. Thus, the main objective is to identify the source of variation on regional impact of air quality pattern in Kuching, Sarawak. A seven-year (2009-2015) database was acquired from the Malaysia Department of Environment (DOE). The data were analysed using several Chemometric Techniques. The findings demonstrated strong positive correlation of Particulate Matter below than 10 microns (PM_{10}) and API (r = 0.994). In addition, Principal Component Analysis (PCA) and Artificial Neural Network (ANN) revealed that Carbon Monoxide (CO), Ozone (O_3) and PM_{10} were the most significant air pollutants in Kuching. Based on the results in the Statistical Process Chart (SPC) analysis, PM_{10}, CO and O_3 values exceeded the Control Limit (CL) of SPC. This study concluded that the application of air quality model in this study is relevant for mitigating action plan of air quality in Kuching, Sarawak, as it is of paramount importance to continuously monitor and manage the quality of air for the sustainability of the environment and human health.

Keywords: *Air Quality; Chemometric Techniques; Correlation; Principal Component Analysis; Artificial Neural Network.*

1. Introduction

Air pollution occurs when particulate toxicants and harmful gaseous are discharged into the atmosphere in adequate concentration to deteriorate human health [1]. Air pollution and haze phenomenon are examples of common environmental hazard conditions in Malaysia. Haze can be denoted as sufficient smoke, dust moisture and suspended vapour in air that can reduce visibility [2]. Haze in Malaysia have occurred due to transboundary haze pollution from Indonesia since 1994 [3].

Kuching is one of the area located in Sarawak of East Malaysia that is affected by air pollution and haze [4]. The API in Kuching has once exceeded 850 during haze condition in 1997 implying the worst haze in Malaysia [5]. It was a forest fire in Kalimantan during this year and this incident trigger the trans-boundary pollution that affecting the district of Kuching [5-6]. The condition worsened by the El Nino Phenomenon which contributes to hot and dry weather [4]. Kuching is one of the capital cities in Malaysia that undergoes rapid growth and urbanisation. Sarawak's economy is dominated by primary commodities such as liquefied natural gas (LNG) and petroleum [7].

Agriculture and forestry are also considered as the main industrial sectors in Sarawak by the fact that it has produced about 9 to 10 million cubic metres of agriculture products and steadily produces commercial crops such as oil palm, sago and pepper yearly [8]. The rapid economic development in Sarawak can lead to poor air quality.

Urbanisation and industrial development induce air pollution and prompt the occurrence of greenhouse gases that may lead to urban heat island [9]. Ambient air is also negatively altered due to agriculture activities such as land clearing as it can cause pollution and fire hazard [8].

Air pollution can affect human health and reduce the degree of wellbeing in both, short term and long term [10]. Respiratory and cardiovascular diseases are the main maladies associated with air pollution [11]. There were 33 studies that exposed a significant association between air pollution with respiratory and cardiovascular hospital admission. Those studies include researches from [12].

Hence, air pollution control is needed to prevent the situation from getting worse in the future. Air quality monitoring network is one of the preliminary strategies to control air pollution in Malaysia [13]. One of important tools that efficiently applied by previous researchers for this purposed is Chemometric technique [14]. Chemometric techniques can be considered as one of the best tool to analyse air quality as it can identify the source of pollution [15]. It also aids in the recognition of impending sources that are possible for variation in air quality [13]. Thus, once the sources of the pollution were recognized and identified, some proper mitigation measures can be taken to minimize the impact of the air pollution.

2. Materials and Method

2.1. Study Area

Sarawak is located in Borneo Island and also is the biggest state in Malaysia. Kuching, Sarawak (Latitude: 1° 36' 27” N; Longitude: 110°22'42” E) was selected as the main research site in this study. Kuching district is the capital city of Sarawak and it is being classified as the most well developed city in Sarawak. The location of this city is situated close to Kalimantan, Indonesia. Kuching was badly affected from forest fire activities in Kalimantan.
Therefore, the selection of this specific area is to visualize and represent the implication of forest fire activities from neighbouring countries towards Malaysia. These criteria also adequate enough to reflect the magnitude of impact face by Malaysia caused by irresponsible action from people in Kalimantan. The sampling station was named as Kuching air monitoring station (Latitude: 1° 33' 44" N; Longitude: 110° 23' 19" E). This area was selected to give overall representation and inference of the air quality level in Kuching, Sarawak.

2.2. Data Collection

A seven-year database (2009-2015) was acquired from the Air Quality Division of the Malaysia Department of Environment (DOE). The database is comprised of Air Pollutant Index (API) and five major air pollutants such as Carbon Monoxide (CO), Nitrogen Dioxide (NO2), Sulphur Dioxide (SO2), Ozone (O3) and Particulate Matter below than 10 microns (PM10). These variables were recorded by hourly basis.

2.3. Data Analysis

Spearman’s correlation test and three Chemometric Techniques were implemented in this research. Spearman’s correlation test was applied to analyze the association between air pollutants and Air Pollutant Index (API).
Correlation test was used to calculate and construe the strength of a linear or non-linear relationship between two incessant variables and it was abridged as correlation coefficient, r [16]. Pearson’s correlation is used for the normally distributed data while Spearman’s correlation is used for not normally distributed data [16].
Principal Component Analysis (PCA) was used to identify the most significant parameters that affects air quality in the study area. PCA was applied to minimize the number of features used to represent data and produce the most significant variables. It also created new variables in the database and known as principal components (PCs) [15]. PCA is also the main multivariate technique that was used to analyze and recognize any complex database [1]. The consistent variables were construed by PCA to recognize the source of air pollution and the most significant parameters in this study. PCA was calculated based on equation 1 below:

zij = ai1x1j+ai2 x2j+ai3 x3j+⋯+aim x3j (1)

Definition 2.1: *Where, z is component score, a is component loading, x is the measured value of variables, I is the component number, j is the sample number, m is the total number of variables.*

PCs which are not readily inferred were rotated using varimax rotation [15]. Varimax rotation can provide a better solution compared to the original and it can be exerted to the PCs with eigenvalues equal to or more than 1. This rotation will produce new variables known as varimax factors (VFs) and factor loading [1]. VFs with values of 0.7 and above were set as the benchmark. This is because the VFs with values of 0.7 and above were the most significant value as the selection threshold. It is also considered as strong, firm and stable value [15]. VFs calculation can be derived from Equation (2):

zij = af1 x1i+af2 x2i+⋯afm fmi+efi (2)

Definition 2.2: *Where z is the measured value of a variables, a is the factor loading, f is the factor score, e is the residual term for errors or other source of variation, I is the sample number and j is the variable number and ‘m’ is the total number of factors.*

Subsequently, the most significant parameters obtained from PCA were further analyzed using Artificial Neural Network (ANN) to determine the accuracy of prediction performance on the respective most significant variables. ANN was used to identify nonlinear pattern in the database [17].
It is also a technique that provides a better flexibility, efficiency, consistency and accuracy as it follows the great feature of human brain neurons [17-18]. ANN can be a great tool to estimate the long term impact and can be used to monitor the concentration of air pollutants [17]. ANN comprises of three layers namely input layer, hidden layer and output layer. Correlation of determination R2 and root mean square error (RMSE) were utilized in this modelling protocol. The ANN was calculated using the formula as displayed in Equation (3) and (4):

R^2 = 〖SS〗_reg/〖SS〗_tot = (〖SS〗_reg/ n)/ (〖SS〗_tot/ n) (3)
RMSE = √((∑_(j=1)^n (y_j- (y_j)̂)^2)/n) (4)

Definition 2.3: *Where, y_j are the measured value, (y_j)̂ is the estimated value of the dependent variable and n is the number of observations.*

Finally, Statistical Process Control (SPC) was implemented to determine the pattern of the major air pollutants and air pollutant index (API) in Kuching, Sarawak. SPC can be a great tool to define a complete quantitative procedure in observing and assessing environmental performance [19]. SPC (individual chart) was conducted to assess the pattern of the most significant air pollutants in Kuching, Sarawak utilizing seven years of database (2009-2015).
The most significant air pollutants were obtained from the factor loadings in the PCA. Three straight lines were established which represented Upper Control Limit (UCL), Central Line (CL) and Lower Control Limit (LCL) [19]. The pattern of air pollutants were compared to the control limits and the national air quality standard limit [19].

3. Results and Discussion

3.1. The Association between Air Pollutants and Air Pollutant Index (API)

Spearman’s correlation test was the best statistical analysis that could be implemented to determine the association between air pollutants and Air Pollutant Index (API) [20]. The results in table 1 exhibited the correlation coefficient, r, between air pollutants (O_3, CO, SO_2, PM_{10} and NO_2) and API. The result shows that API values had strong positive correlation with PM_{10}. The correlation coefficient value between these variables was 0.994.
The association between PM_{10} with API were influenced by the developments and traffic flow that is located close to the air monitoring station. The monitoring station is located next to main roads such as Jalan Belian and Jalan Utama. The fair correlation demonstrated by CO was impelled by the emission of motor vehicles as it was the main source for both pollutants [21]. Lead content in PM_{10} and CO negatively impact the quality of the ambient air [21].

NO_2 and O_3 had fair negative correlation in which one of the variables was increased with the decreasing of another variable. The concentration of O_3 can be affected by several factors such as local precursor emissions, transportation of O_3 and its precursor, and meteorological factors [22].

Table 1: Spearman's correlation coefficient (r) between variables for 7 years (2009-2015)

Variables	API	O_3	CO	SO_2	PM_{10}	NO_2
API	-	0.145	**0.454**	0.222	**0.994**	0.166
O_3	0.145	-	-0.111	-0.008	0.125	**-0.325**
CO	**0.454**	-0.111	-	0.183	**0.458**	0.260
SO_2	0.222	-0.008	0.183	-	0.222	0.091
PM_{10}	**0.994**	0.125	**0.458**	0.222	-	0.168
NO_2	0.166	**-0.325**	0.260	0.091	0.168	-

Note: Bold = $r \geq 0.26$

The photolysis process of NO_2 in the lower layer of atmosphere will lead to the formation of O_3. Thus, it was the major factor that leads to the association between NO_2 and O_3. On the other hand, vehicle emission was the chief source of those pollutants [22]. Besides, the concentration of pollutants can be altered by topography, climate and economic activities [19].

The strong positive correlation between API and PM_{10} indicated that the higher the concentration of the PM_{10}, the higher the level of API. The higher value of PM_{10} represented the most significant pollutant that contributes to the increasing of API and air pollution [23].

3.2. Identification of the Most Significant Parameters That Affect Air Quality in Kuching, Sarawak

Further analysis was conducted to analyze the most significant air pollutants that lead to the variation of air pollution source in Kuching, Sarawak. PCA was performed on the database that comprised of the following variables, SO_2, NO_2, CO, O_3 and PM_{10}.

The results revealed that only two PCs out of six came up with an eigenvalue of more than one (> 1.0). Those values encompass of 60.34% of the total variance in the database. Therefore, the Varimax Rotation process was executed by using these two PCs. PCs with eigenvalues of less than one (< 1.0) were omitted from further analysis [19, 15].

According to [14], the eigenvalue with result more than one is the significant indicator to represent the frequency of Varimax rotation that should be implemented in the PCA analysis of the study. The PC_s with eigenvalue < 1 being classified as not significant to be counted for additional frequency Varimax rotation in the analysis.

The scree plot diagram (Figure 1) was used to identify the end point of the strong factors selected for interpretation and explanation.

Fig. 1: Scree Plot for PCA

Two Varimax factors (VFs) or known as factor loadings were obtained after Varimax Rotation which represented 60.34% of the cumulative variance of the data. Table 2 below emphasized the verdicts of factor loadings after Varimax Rotation. The total variance in the first factor loadings (VF1) was approximately 33.17%. It consists of two strong positive factor loadings such as PM_{10} with the factor loading value of 0.836 and CO with the factor loading value of 0.752.

The second factor loadings (VF2) exhibited the total variance of 27.17% with one strong negative factor loading and one strong positive factor loading. It was demonstrated by O_3 with the value of -0.858. The negative sign of O_3 indicated the change and decreasing pattern of the variable [24]. Factor loadings with values of more than 0.75 (> 0.75) were nominated for elucidation as these values were considered as firm, stable and strong. Lastly, the positive changes of NO_2 will not affect any changes in PM_{10}, CO and SO_2.The plot diagram for factor loading after varimax rotation was illustrated in Figure 2.

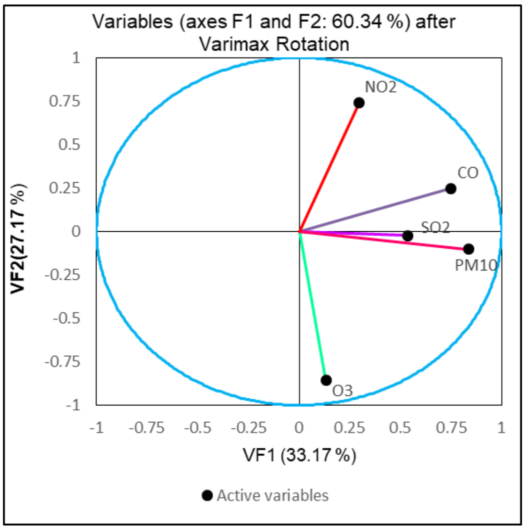

Fig. 2: Factor loadings plot after Varimax Rotation

As referred to Table 2, the PM_{10} and CO came up with positive signs and higher factor loading values compared to the others. This indicated that PM_{10} and CO became the major contributors which affecting air quality in this area. The higher the concentration of PM_{10} and CO, the lower the quality of the air at the study area. On the other hands, both pollutants are primary pollutants in which cannot be affected by any process or reactions [25].

Table 2: Factor loadings after Varimax Rotation for Air Quality Data in Kuching, Sarawak

Parameter	VF1	VF2
O_3	0.133	**-0.858**
CO	**0.752**	0.249
SO_2	0.537	-0.023
PM_{10}	**0.836**	-0.103
NO_2	0.298	0.742
Eigenvalue	1.755	1.262
Variability (%)	33.167	27.173
Cumulative (%)	33.167	60.340

Note: Bold = Factor loading > 0.75

Industrial emanation, motor vehicles emission and open burning activities in the study area disgorged PM_{10} into the air [13]. Moreover, the elevation of PM_{10} concentration was related to the occurrence of transboundary haze pollution from Indonesia due to Sumatra bush burning for agriculture purposes [5]. The smoke then travel to other countries and affected the air quality in those travelled areas [26]. In addition, the emission of PM_{10} was also associated with agriculture activities at the area. Activities of land clearing in oil palm plantations in Sarawak using forest burning method can lead to the discharge of pollutants especially PM_{10} and greenhouse gases [27]. Hence, it can adversely impact human health and environment.

The elevation of CO was a result of motor vehicles emission and the condition of traffic circulation. Traffic congestion and busy junctions could elevate the level of CO in Kuching, Sarawak [28]. They also revealed that automobiles in inactive position with incessant engine exuded more CO compared to in free flow condition. The elevation of CO values in Sarawak is also triggered by biomass incineration, transportation activities, agricultural activities (land clearing) and industrial activities [29].

The different circumstance occurred in VF2 as the value of O_3 showed negative value. The negative value indicated inverse relationship among the variables [24]. O_3 is known as the secondary pollutant which created through photochemical oxidation between Nitrogen Oxide (NO_x) and Volatile Organic Compound (VOC) [15, 30]. Hence, the value of O_3 can be affected by this process. As the emanation of NO_x is higher due to traffic-originated emission, the concentration of O_3 will decrease as it was disbursed during the oxidation of NO_x. Thus, it gave a negative contribution of O_3 [31]. The main sources of NOx are from complete combustion processes which include vehicle and power plant emissions. In addition, biogenic VOC (isoprene) also potentially increased the concentration of surface O_3 [30]. Isoprene is the chief component in fabricating synthetic rubber, surgical glove and other industrial products. It is also discharged from the process of fossil fuel production [32]. The process of oil and gas production led to the emission of O_3 and NO_2. It subsequently resulted in poor air quality in certain areas. Moreover, the usage of gas in Sarawak is likely to escalate promptly due to higher ultimatum or demand from power and industrial areas [33]. The stipulated pollutants such as PM_{10}, CO and O_3 were further analyzed to determine the accuracy of prediction performance on the most significant variables from PCA (ANN) and recognize the pattern of the air pollutants (SPC).

3.3. The Accuracy of Prediction Performance on the Most Significant Variables from PCA

ANN was executed to measure the prediction performance of API and the most significant variables from PCA. The coefficient of determination (R^2) and root mean square error (RMSE) revealed the efficiency of ANN to identify the accuracy of the prediction performance on the most significant variables [1]. Table 3 demonstrated the prediction performance of the ANN. For training, the highest R^2 recorded was 0.9968836 while the lowest RMSE was 0.7732627. The network was validated at R^2 and RMSE at 0.996900 and 0.7679406 respectively. Lastly, the result for the test process came out with the value of 0.9989941 for R^2 and 0.924999 for RMSE.

The network structure for the ANN model was performed several times for the training process of the network. The patterns of the parameters could be estimated and learnt through the training process while validation process was applied to check the trained network. Lastly, test process was implemented to assess the overview of the trained network [14]. This study had applied 60% of training, 20% of validation and 10% of test. The optimum gauge for ANN network was the best prediction that can be utilized [1]. Additional optimization would lead to the decreasing of prediction capability and consistency. It can be concluded that the result from PCA tallied with the prediction performance by ANN. It could strengthen the decision of the most significant variables from PCA.

3.4. Pattern of the Major Air Pollutants and Air Pollutant Index (API) in Kuching, Sarawak

CO, O_3 and PM_{10} were selected for further analysis in order to identify the pattern of air pollutants in Kuching, Sarawak. The pattern of API and the most significant air pollutants were figured through time series analysis by utilizing Statistical Process Control (SPC). A control chart for every variable were derived to observe the real-time concentration of air pollutants and to determine the incidence of any values that outstrip the allowed values.

Figure 3 represented the control chart of CO in Kuching, Sarawak (2009-2015). The chart exposed the trend and pattern for CO and was assorted with several number of peaks. The average of CO was 0.411ppm. Whereas, the UCL was 0.578ppm and the LCL was 0.243ppm. The highest value was measured at 3.554ppm on 18th January 2011 followed by 3.300ppm on 13th October 2011 and lastly at 3.348ppm on 22nd June 2012.

95% of CO was predominantly emitted from motor vehicles exhaustion and the concentration of CO in city areas would be enhanced in correlation with the increasing of traffic flow and the demand of transportations [19, 27, 34]. The subsequent air pollutant, O_3 illustrated fluctuation values over the 7 years period in Kuching, Sarawak (2009-2015). The standard control limit for O_3 was 0.011ppm, and the value for UCL and LCL were 0.018ppm and 0.003ppm respectively. The highest peak was recorded at 0.089ppm on 10th December 2009. Nevertheless, the values of O_3 obtained in Kuching were in amenability to the RMAQG of 0.10ppm.

Table 3: Predictive Performance Based on R_2 and RMSE

Training		Validation		Test	
R^2	RMSE	R^2	RMSE	R^2	RMSE
0.9967543	0.7891354	0.9967375	0.7878141	0.9988543	0.9871711
0.9955319	0.9258958	0.9952189	0.9536956	0.9988375	0.9943807
0.9968809	0.7735988	0.9968673	0.7719759	0.9986451	1.0735241
0.9968836	**0.7732627**	**0.996900**	**0.7679406**	**0.9989941**	**0.924999**
0.9953901	0.9404772	0.9950114	0.9741739	0.9989196	0.958642

O_3 was probably discharged through agriculture activities and anthropogenic sources. Besides, the concentration of nitrogen oxides which are produced by photochemical processes affect the amount of O_3 in the ambient air [29, 35]. The process of oil and gas production could also alter the pattern of O_3 as the process are continuously produced and manufactured [33].

Hence, unremittingly emission of O_3 would affect the air quality in Kuching [31]. The concentration of O_3 could be influenced by the intensity of solar radiation and its formation led to the increase of ambient temperature [34-35].

Based on Figure 4, the mean reading of PM_{10} was 37.845µg/m^3. The LCL displayed a value of 35.955µg/m^3 while the value of UCL was 39.731µg/m^3. The value of PM_{10} exceeded the RMAQG in certain period of times. The highest reading of PM_{10} were recorded at 319.750µg/m^3 on 17th December 2015. A previous study demonstrated that the pattern of PM_{10} was similar as the pattern of API [26]. The high volume of PM_{10} in Kuching, Sarawak resulted from the vehicles emission and forest burning for agriculture purposes [27-28]. Moreover, transboundary haze pollution from Indonesia also contributed to elevation of PM_{10} concentration. The highest concentration of PM_{10} was recorded at 356.15µg/m^3 on 17th September 2015.

The haze pollution was mainly caused by the land clearing of palm oil estates in Sumatra and Kalimantan, Indonesia [36]. The periodic slash and burn in large scales led to the formation of smokes and dust which triggered the emission of PM_{10} [34]. Another haze pollution which occurred between April to September 2011 was associated with burning and fire hazards from Sumatra and Northern Kalimantan [19, 36].

The Haze Technical Task Force was established in 1995 by ASEAN to engage and address the problems. Apart from that, the ASEAN Agreement on Transboundary Haze Pollution (AATHP) was formulated to identify the best mitigation measures and activities that can be implemented to overcome this problem [34].

The trend of API in Kuching, Sarawak (2009-2015) revealed that most of the API values in Kuching were below than 100. The CL for API was 35.709, while the UCL and LCL were between 37.662 and 33.756. The CL fell under good status of API. As shown in Figure 6, the highest peak of API was 209.000 (unhealthy) on 17th September 2015. The unhealthy status of API occurred during mid-year between August to October. These patterns resulted from the transboundary haze pollution that migrated from Northern Kalimantan [5].

The API trend was influenced by the total reading of the pollutants. The major pollutants that contribute to the increase of API were PM_{10}, CO and O_3 [26]. Prompt urbanisation and vehicular emissions were the chief factors contributing to the increase of PM_{10} concentration in the air [34]. It is also stated that the concentration of PM_{10} was higher during the South-West Monsoon where the elevated level of winds were principally swept from South-westerly [37].

The trends for CO, O_3 and PM_{10} unveiled notable decrease between 2011 and 2015 because of the restriction of open burning at fire prone areas. This was implemented in March 2010 in compliance to the Environmental Quality (Declared Activities) (Open Burning) Order in 2003 to minimize air pollution from domestic sources. The Eleventh Malaysia Plan (2016-2020) on air quality accentuated on minimization usage of carbon mobility. It could be applied by exercising the use of Energy Efficient Vehicles (EEVs), promote biofuels and Compressed Natural Gas (CNG) usage and elevate the utilization of public transportation [19]. There are several mitigation measures that could be implemented to control the emission of air pollutants. The invention of hybrid electric automobiles could be the best way to minimalize the generation of air pollutants and lessen reliance on fuels [38]. The enactment of EQA1974 with several regulations could provide the best guidelines to confront this environmental issue [39]. It was also advised to properly maintain the heavy machineries and vehicles to decrease the emission of smokes from those transportations [40].

Moreover, the use of urban forest was considered very efficient and quite handy in lessening the temperature and diminishing the emission of air pollutants. Urban forest is an approach that manages tree population in urban setting, it can assist in improving the urban environment. The enhancement of public knowledge and awareness regarding this matter can help to minimize the emanation of air pollutants from it sources [41].

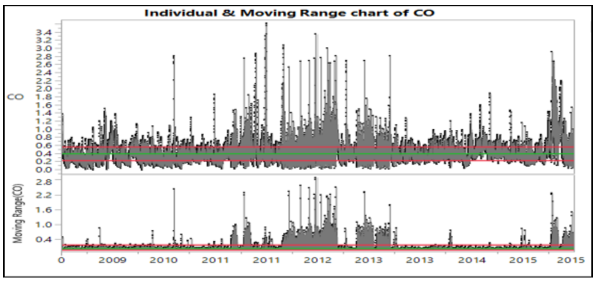

Fig. 3: The individual and moving range chart of CO for Kuching, Sarawak (2009-2015)

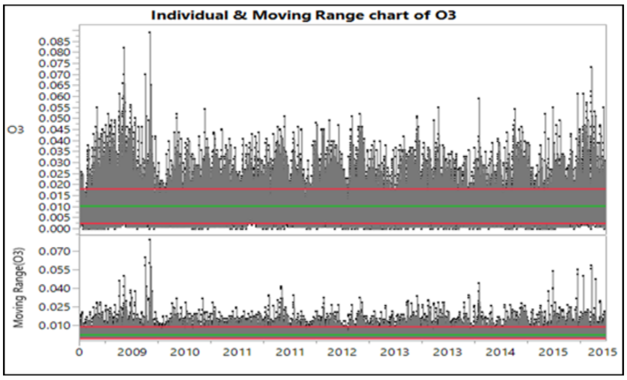

Fig. 4: The control chart of O_3 for Kuching, Sarawak (2009-2015)

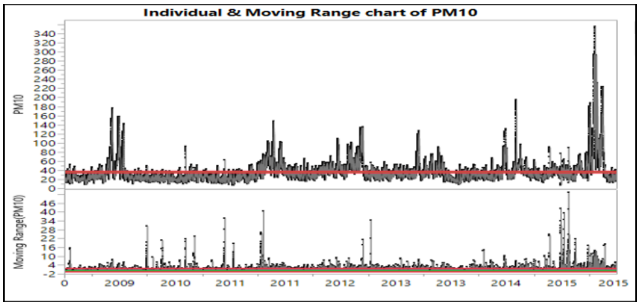

Fig. 5: The Individual and Moving Range Chart of PM_{10} in Kuching, Sarawak (2009-2015)

4. Conclusion

In conclusion, PM10, CO and O3 were the major pollutants that led to the increasing of API level in Kuching, Sarawak. The pollutants were generally emitted by vehicles exhaustion, industrial activities, biomass burning and transboundary haze pollution. Most of the air pollutants level conformed to the RMAQG. Conversely, several data of PM10 surpassed the RMAQG due to transboundary haze pollution from Sumatera and Kalimantan, Indonesia.

The study also revealed that the API trend in Kuching, Sarawak was comparable to the patterns of PM10. The O3 trend show consistent patterns with increasing emission due to the process of oil and gas manufacturing that had been running continuously. It was also discovered that the trend for CO was affected by the traffic flow in Kuching, Sarawak. The level of CO was elevated due to traffic congestion and increase of transportation demands. Accordingly, effective and efficient air monitoring and management need to be executed for the future's better quality of environment.

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