FUDMA Journal of Sciences (FJS)
ISSN: 2616-1370
Vol. 2 No. 2, June, 2018, pp 88 - 100

ANALYSIS OF SEASONAL LEVELS OF ATMOSPHERIC POLLUTION IN TERENGGANU, MALAYSIA

[*1, 2]Ahmad, H. I., [2]Mustapha, A., [2]Juahir, H., [1]Alhaji, M. and [1]Adamu, H.

[1]Department of Geography, Faculty of Earth and Environmental Sciences,
Kano University of Science and Technology Wudil, 3244 Kano, Nigeria
[2]East Coast Environmental Research Institute (ESERI), Universiti Sultan Zainal Abidin,
Gong Badak Campus, 21300 Kuala Terengganu, Terengganu, Malaysia
*Corresponding author: amustapha494@gmail.com.

ABSTRACT

This study aims to investigate the seasonal fluctuation in the level of air quality, determine the most discriminating parameters in each season and identify the possible sources of pollution over a period of 13years (1999-2011). Two monsoon seasons (northeast and southwest monsoon) were selected because of their difference in formation, time of occurrence and climatic characteristics. The air quality and meteorological observation data such as particulate matter (PM_{10}), carbon monoxide (CO), nitrogen dioxide (NO_2), sulfur dioxide (SO_2), ozone (O_3), ambient temperature and wind speed for a period of thirteen years (1999-2011) were obtained from Department of Environment Malaysia (DOE). The results revealed that, the Discriminant Analysis (DA) provided better results with great discriminatory ability using six (6) parameters ($p < 0.05$) with a correct assignation of 82.13%. Further, Principal Component Analysis (PCA) for the northeast and southwest monsoon accounted for more than 51% and 61.40% of the total variance respectively. The sources of pollutants for both seasons are from anthropogenic activities and natural factors (point and non-point sources). The bar chart plotted for each season show that atmospheric air pollutants reaches maximum level during the southwest monsoon season and drops during the northeast monsoon. Multivariate technique serves as a tool for understanding the seasonal variation in air pollution. These findings can be used for planning and policy making by stakeholders by re-enforcing the Malaysian air quality standard.

Keywords: *Pollutants; Emission; Atmospheric; Anthropogenic; Seasonal, Environmetrics; Malaysia*

INTRODUCTION

Human has become an integral part of the urban environment and about one third of the world's population now live in city centres (UN-Habitant, 2011). A report by the UN-Habitant (2011) also suggested that global population growth in urban areas will increase from 49% in 2005 to 60% by the year 2030. However, human civilization and quality standard of living is proportional to an adequate availability of energy (Hodgson, 2000). This energy is needed to power our industries, heavy machines, cars, heavy duty vehicles, smelting, and constructions. Over the years, due to industrialization, and modern transport system, most energy sources are obtained without considering safety in health and environmental implication especially in urban centres (Hodgson, 2010). Likewise, the characteristics of urban morphology in terms of change in vegetation cover, urban surface, building and other human practices have triggered a natural resilience in the capacity of the atmosphere (Jacob and Winner, 2009; Richter, 2010). The implication is a change in the transport and dispersion of pollutants from point source and non-point sources. This scenario has made the quantity and sizes of environmental pollutants to exceeded the normal requirement in the atmosphere, and in some places has become toxic to the ecosystem in general (Shakir et al 2016). Long term exposure to ambient particulate matter is a major risk factor to the global burden diseases.

Anthropogenic discharge of air pollutants exhibits a strong influence in the characteristics of atmospheric composition (Mallik and Lal, 2014). The rate of urbanization in Asia has grown to an unprecedented scale compared with other regions of the world (Roth et al 2011). According to Asia Development Bank in 2008, by the year 2025, 16 out of the 29 world mega cities will be in Asia and characterized by severe environmental quality problems. Atmospheric pollution is aggravated by natural processes (meteorological factors) and human-induced emissions (burning of fossil fuel and vehicular emission (Guttikunda and Gurjar 2012). Although, over the past few decades the government of Malaysia through the department of environment have developed strategies to monitor the sources, concentration and possible health impact of pollutants. In 2008, the status of good air quality in Malaysia was around 59% and 55.6% in 2009. In 2010, it rises to about 63% and 55% in 2011 DOE 2012). A simultaneous assessment of air pollutants and meteorological parameters can reveal the necessary information on emission sources and seasonal fluctuations over a given area. The quality of air is usually polluted when there is high discharge of pollutants and unfavorable weather condition. Different time periods are characterized by different pollutant concentration and dispersion capabilities (Dominick 2012). Dawson et al (2007) argued that when the relative humidity and velocity of wind in an area is low, it provides a favorable condition to trap more pollutant concentration. As such, high rainfall and strong wind help disperse air pollutants.

The state of Terengganu houses one of the largest explorer of crude oil in Kertih (PETRONAS). PETRONAS Petrochemical Integrated Complex (PPIC) is a primary stakeholder in petroleum exploration, and its activities integrate the entire range of oil and gas value chain (Petronas 2013; Azid et al 2014). The highly populated city center (Kuala Terengganu) is made up of a substantial commercial activities, traffic congestion, primary industries and high population density (DOE, 2007). Mutallib et al (2013); Dominick et al (2014); found out that emissions from mobile sources (automobiles) are the primary origin of pollution in Malaysia (82% of pollution load). Stationary source (manufacturing activities, industrial fuel burning, power stations) Is another important point of emission. While trans-boundary pollutants are transported by wind from neighboring location and Malaysia experienced the worst haze episode in 1997 (Jamal et al 2004). The climatic characteristic of Malaysia is influenced by two main monsoon seasons (Northeast monsoon and Southwest monsoon). During winter, the continental landmass cools rapidly due to tilting of the earth (Huffman et al 1997) which results in extreme low temperature over central Asia (Camerlengo and Demmler, 1997). As temperature decreases, atmospheric pressure rises and an intense high-pressure system known as anticyclone developed over Siberia (MMD 2012;2013). Whereas in Australia, a low-pressure system is enhanced due to rising in temperature (Camerlengo and Demmler, 1997). These two scenario makes cold air to flow out of Siberia as northwesterly which later turns into northeasterly on reaching the coastal water of China before heading towards southeast Asia as northeast monsoon season from November to March (Camerlengo and Demmler, 1997). The aim of this study is to examine the seasonal variation in air quality, to determine the most discriminating parameters in each season and to identify the major possible source of air pollutants in Terengganu.

METHODS

Data Collection and Data Treatment

The study area comprises of three air quality monitoring sites; Kemaman (ST02), Kertih (ST24) and Kuala Terengganu (ST34) (DOE 2007). Table 1 and Figure 1 describe the location of the study area based on latitude and longitude. The air quality and meteorological observations recorded for a period of thirteen years (1999-2011) were sourced from the Department of Environment Malaysia (DOE). Parameters under consideration comprise of particulate matter (PM_{10}), carbon monoxide (CO), nitrogen dioxide (NO_2), sulfur dioxide (SO_2), ozone (O_3), ambient temperature and wind speed. The average period over which measurements are monitored and reported to assess the possible health impacts of specific air pollutants varies from 1 - 24 hours (DOE 1997; 2007). The raw data were also treated by logarithmic transformation (log scaling), column scaling, and column auto-scaling. All log transformed variables were also z-scale standardized to minimize the effects of different units and variance of variables and equally to transform the data into dimensionless format. The data were analyzed using descriptive statistics, and were interpreted into tables, histograms and box plot. All statistical analyses were conducted using Statistical Packages for Social Sciences (SPSS) version 21. The data were in the form of hourly reading and converted to daily average reading. A total of 50841 data sets (7263 observations × 7 parameters) were used for the analysis. The nearest neighbor method was applied in the XLSTAT add-in software 2014 to estimate the missing values Azid, 2013; Dominick 2014). Nearest neighbor is used to predict unknown values using the known values at neighboring locations where sample points lack [7]. This equation can be written as:

$$y = y_1 \text{ if } x \leq x_1 + (x_2 - x_1) / 2] \text{ or}$$
$$y = y_1 \text{ if } x \geq x_1 + [(x_2 - x_1)/2] \quad (1)$$

Where y is the interpolate, x represents the time point of the interpolate, y_1 and x_1 are the coordinates of the starting point of the gap and y_2 and x_2 are the end points of the gaps.

Table 1: Location and coordinates (Longitude and Latitude) of air quality monitoring stations in the study area

ST ID	Location	Latitude	Longitude
ST02	Kemaman	N0 4° 16.260	E103° 25.826
ST24	Paka-Kertih	N0 4° 35.880	E103° 26.096
ST34	Kuala Terengganu	N05° 18.455	E103° 07.213

Source: Department of Environment (DOE) Malaysia

Fig. 1: Air quality monitoring sites of Terengganu

Discriminant Seasonal Pollutants

Discriminant Analysis (DA) is used to determine the variables that best discriminate between seasons and construct new discriminant functions (DFs) to each group in order to evaluate the seasonal variation in atmospheric air quality. DFs are calculated using Eq:

$$F(Gi) = Ki + \sum_{j}^{n}{=1}\, W_{ij}P_{ij} \qquad (2)$$

Where i = the number of group G; k_j = constant inherent to each group; n = the number of parameters used to classify a set of data into a given group; w_j = the weight coefficient assigned by discriminant function analysis (DFA) to a given parameter P_j.

DA was applied on the two monsoon seasons using the standard, forward and backward stepwise mode. To achieve this, the two seasons were selected as the dependent variables and the parameters were independently applied. In the forward stepwise mode, the most significant variables were included step by step to the least, while in the backward stepwise mode, variables were removed step by step beginning from the less important variable until no significant changes were observed Juahir et al 2011).

Identification of Seasonal Source of Variation

Principal component analysis (PCA) is used to extract the most significant parameter that account for the source of pollution by eliminating the less important parameter with minimal loss of the original variables. PCA can help to identify the source of pollutants (Azid et al 2013). It will also help in reducing the dimensionality of a giving set of data by forming new variables that are uncorrelated called principal components (PCs) (Daigle et al 2011). The equation is expressed as:

$$Z_{ij} = a_{i1}x_{1j} + a_{i2}x_{2j} + a_{i3}x_{3j} + \ldots\ldots\ldots\ldots + a_{im}x_{mj} \qquad (3)$$

Where z is the component score, a is the component loading, x is the measured value of variables, i is the component number, j is the sample number and m is the total number of ariables.

According to (Juahir et al 2011) the PCs generated by PCA are complex for proper interpretation. Therefore, a varimax rotation of the PCs is required with an eigenvalue greater than 1. The varimax rotation is considered significant in order to obtain new groups of variables called varimax factors (VFs) (Brumelis et al 2000; Love et al 2004). However, the coefficient greater than 0.75 is considered as strong significant factor loading, from 0.74-0.50 have moderate loading. While those from 0.40 downward have weak have less significant loading (Liu et al 2003).

$$Z_{ij} = af_1\, x_{1i} + a_{f2}\, x_{2i} + \ldots\ldots\ldots + a_{fm}\, f_{mi} + e_{fi} \qquad (4)$$

Where Z is the measured value of variables, a is the factor loading, f is the factor score, $\boldsymbol{e}$ is the residual term accounting for errors or other sources variation, i is the sample number, j is the variable number and m is the total number of factors.

RESULTS AND DISCUSSION

Descriptive Statistics

Table 2 show a summary of the entire data sets comprising of the mean, standard deviation, unit of measurement, average time, minimum, maximum observations and the recommended Malaysia air quality guide.

Table 2: (a) Descriptive statistics of daily average air quality parameters 1999-2011

Variables	Statistic	Seasons		Avg time	RMAQG
		Northeast monsoon	Southwest monsoon		
CO, ppm	Min	0	0	1-h	30
	Max	2.74	2.43		
	Mean	0.333	0.48		
	Std dev	0.289	0.347		
O_3, ppm	Min	0	0	1-h	100
	Max	0.38	49.625		
	Mean	0.018	0.421		
	Std dev	0.02	3.888		
PM_{10}, µg/cu.m	Min	0	0	24-h	150
	Max	306	470		
	Mean	46.11	58.623		
	Std dev	21.56	28.93		
SO_2, ppm	Min	0	0	1-h	130
	Max	0.07	0.05		
	Mean	0.001	0.002		
	Std dev	0.002	0.003		
NO_2, ppm	Min	0	0	1-h	170
	Max	0.05	49.167		
	Mean	0.003	0.335		
	Std dev	0.004	3.532		

(b) Descriptive statistics of daily average meteorological parameters 1999-2011

Variables	Statistics	Seasons	
		Northeast monsoon	Southwest monsoon
Ambient temp, °C	Min	20.635	21.325
	Max	30.217	31.971
	Mean	25.885	27.782
	Std dev	1.26	2.138
Wind speed KM/h	Min	5.525	1
	Max	210.2	126.7
	Mean	13.368	11.773
	Std dev	10.729	4.263

3.3 Seasonal Variation in Atmospheric Air Pollution

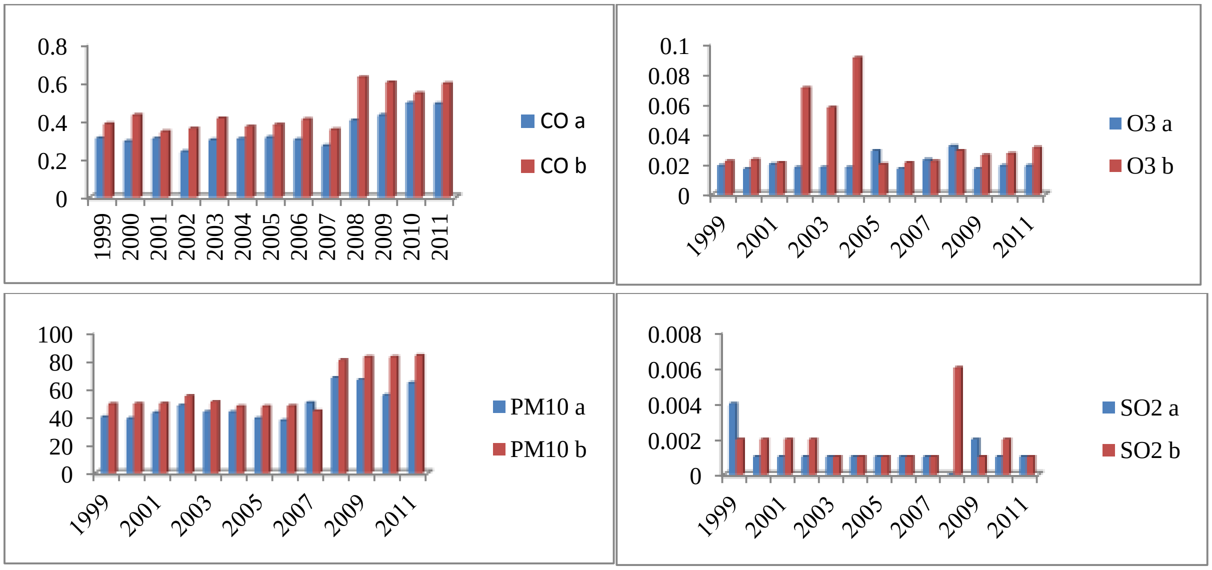
DA was used to identify the most significant parameters associated with the difference between seasons using the northeast and southwest monsoon as dependent variables, and PM_{10}, NO_2, SO_2, CO, O_3 wind speed and ambient temperature as independent variables. The result for DA is displayed in Table 3.

Table 3: Classification matrix for DA based on seasonal variation in air pollution

Monsoon seasons	Seasons assigned by DA		% Correct
	Northeast monsoon	Southwest monsoon	
Standard DA mode (7 parameters)			
Northeast monsoon	3174	566	84.87%
Southwest monsoon	735	2788	79.14%
Total	3909	3354	82.09%
Forward stepwise mode (6 parameters)			
Northeast monsoon	3176	564	84.92%
Southwest monsoon	734	2789	79.17%
Total	3910	3353	82.13%
Backward stepwise mode (7 parameters)			
Northeast monsoon	3174	566	84.87%
Southwest monsoon	735	2788	79.14%
Total	3909	3354	82.09%

Using the standard and backward stepwise mode, the accuracy of the temporal classification in the confusion matrix for seasonal variation in air quality yielded a correct assignation of 82.09%. This indicates that all the seven parameters discriminate temporally with P-value <0.0001in the two monsoon seasons.

The result for the forward stepwise mode shows that the accuracy of the temporal classification yielded a correct assignation of 82.13%. This indicates that only six parameters (PM_{10}, CO, O_3, SO_2, ambient temperature and Wind speed) in the unidimensional test of equality of the means of classes have a p-value < 0.0001 out of the seven monitored parameters with the exception NO_2. The seasonal variation associated with these parameters are highlighted in Figure 2.



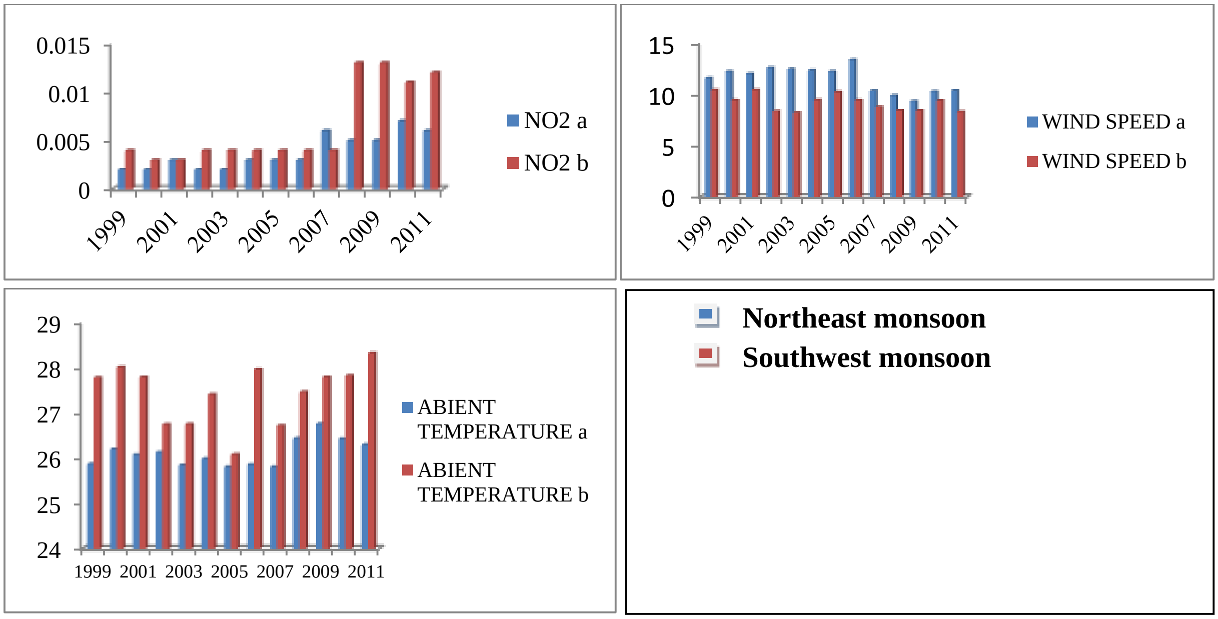


Fig. 2: Seasonal variation in the level of air pollution

Evidently, the statistical findings showing the six most discriminating parameters with $p<0.0001$ and highest correct assignation of 82.13% compared to other modes could be linked to the variation in the climatic characteristics of the two monsoon seasons (northeast and southwest monsoon) as shown in Figure 2.

The concentration of PM_{10} during the southwest monsoon season is usually high due to rise in temperature as shown in Figure 2. According to (Jayamurugan et al 2013) high temperature during the summer increases the concentration of PM_{10}. More evidence can be found in the work of (Zaharim et al 2009). Further justification is provided in the findings of (Dawson et al 2007; Kleeman, 2007) which shows that sulfate formation increases with an increase in temperature due to faster SO_2 oxidation, that act as an important precursor for the formation of PM_{10} (Iiten and Tülay, 2008). Weak wind of below 15 knots and low relative humidity dominates southwest monsoon (MMD, 2010), which provides a favourable condition for high concentration of particulate matter (Iiten and Tülay, 2008). Whereas during the northeast monsoon season, the concentration of PM_{10} decreases with an increase in precipitation because rainfall deposit help to sink particulate matter (Jacob and Winners 2008). Rainfall also wet settled particles and reduce their ability of been re-suspended. According to [14] the east coast Malaysia (Terengganu) exhibit a very strong wind of about 30 knots during northeast monsoon, which helps to disperse PM_{10} thereby reducing its concentration level in the atmosphere (Dawson and Adams, 2007). However, high humidity is observed during the northeast monsoon season (MMD, 2012) which reduces the concentration of PM due to increasing water vapor in the atmosphere (Dawson and Adams, 2007). It was pointed out that the concentration O_3 is at its peak during the transport period in the northeast monsoon (wind 30 knots in Terengganu) due to multi- scale circulations of precursors (CO, NOx, and hydrocarbon). This indicates that the distinct seasonal variation of O_3 is a resultant effect of regional and sub-regional transport of anthropogenic pollutants. Although O_3 is also formed when nitrogen dioxide and VOCs react under heat and sunlight (Wennberg et al 1998; Bauer et al 2002; DOE, 2007). During the northeast monsoon, skies are overcast thereby reducing the amount of solar radiation received (MMD, 2010). Reduction in temperature limits photochemical oxidation of VOCs thereby reduces the level of O_3 formation (Jacob and Winners (2008). High temperature during the southwest monsoon season (MMD, 2012) encourages chemical reactions and provides favorable condition for O_3 Precursors to react which accelerate O_3 formation (Wennberg et al 1998; Bauer, 2002; DOE 2007). Kovac-Andric et al (2009); Ghazali et al (2009) also argued that temperature play a significant role in photochemical oxidation for O_3 formation.

NO_2 is produced when nitrogen in fuel is burnt and when at a very high temperature (southwest monsoon) nitrogen in the air reacts with oxygen (Steiner et al 2006). Bush burning by farmers to cultivate land is an important source of CO as well as residential wood burning. As identified by DA, box and whisker plots of the parameters base on their seasonal variation are shown in Figure 3.

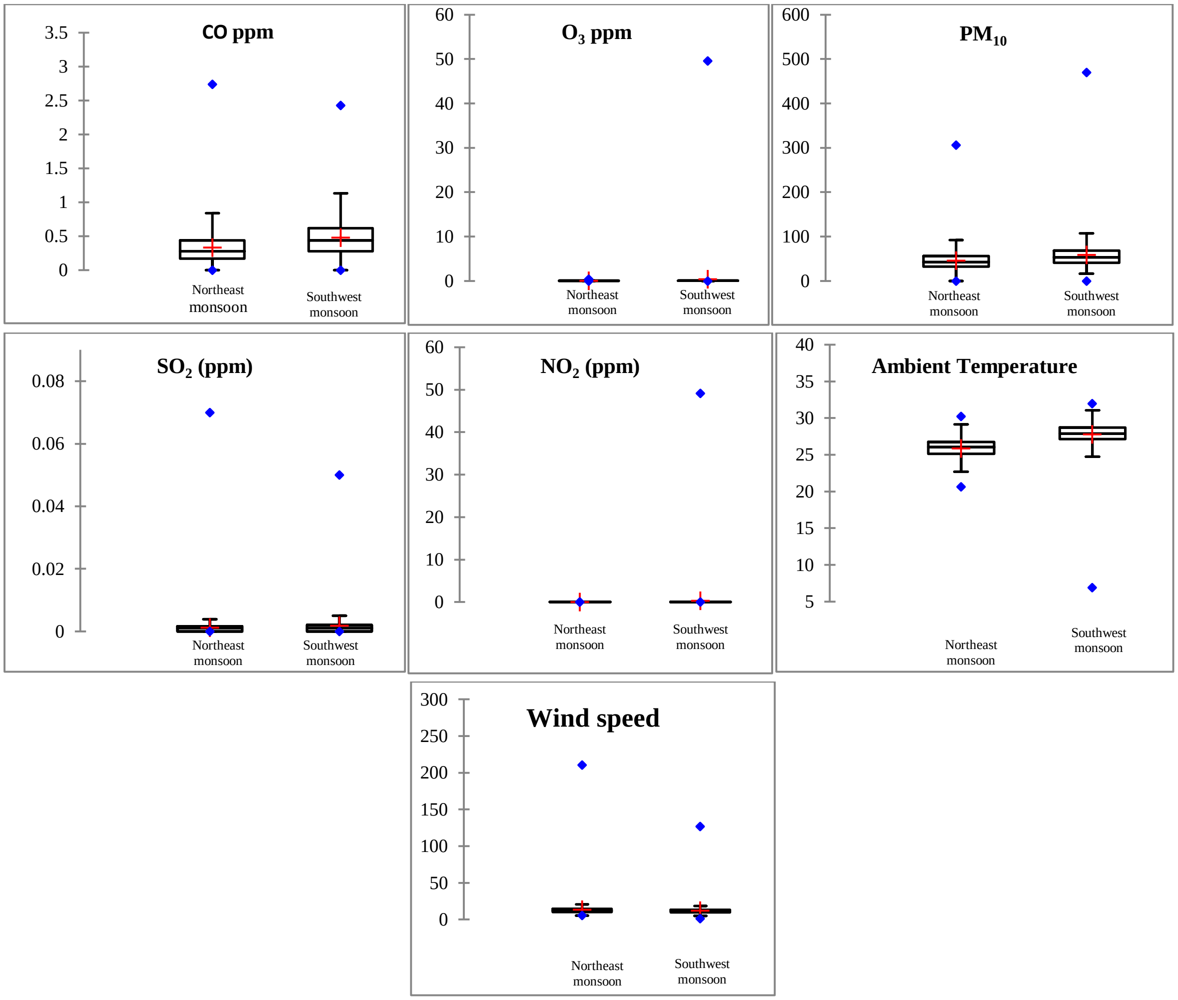


Fig. 3: Box and whisker plots showing seasonal variation in air quality

Identification of Major Pollution Source

PCA was performed on the data sets separately for the two monsoon seasons in order to identify the major possible source of pollution in the study area.

Three PCs were obtained for the northeast monsoon season and two PCs for the southwest monsoon with eigenvalues greater than 1. This account for more than 59% and 61.40% of the total variance as described in the PCA loading plot in Figure 4. For the first season, three varifactors (VFs) were obtained and two (VFs) for the second season respectively through the FA performed on the PCs. The result of FA is presented in Table 4 comprising of factor loadings, eigenvalues, total variance and cumulative percentages.

Table 4: The Factor loadings after PCA varimax-rotation of monsoon seasons

	Northeast monsoon seasons			Southwest monsoon season	
Parameters	VF1	VF2	VF3	VF1	VF2
CO	**0.85**	0.183	-0.109	0.092	**0.851**
O_3	0.278	**0.611**	0.307	**0.972**	-0.081
PM_{10}	**0.707**	-0.258	0.202	-0.138	**0.806**
SO_2	-0.047	**0.638**	0.004	0.117	-0.222
NO_2	**0.792**	-0.026	-0.174	**0.972**	-0.081
ABT	0.147	-0.533	0.244	-0.881	-0.041
WSP	-0.135	-0.018	**0.89**	-0.056	-0.384
Eigenvalue	1.978	1.169	1.018	2.733	1.564
Variability (%)	28.252	16.693	14.537	39.048	22.347
Cumulative%	28.252	44.945	59.481	39.048	61.395

NORTHEAST MONSOON SEASON

The first varimax factor in the northeast monsoon season (VF1) accounts for 28.3% of the total variance, which shows a strong positive loading for CO (0.850), PM_{10} (0.707), NO_2 (0.792) and a strong negative loading for SO_2 (- 0.047) and wind speed (-0.135). The seasonal variation in the source of CO can be linked to the incomplete combustion of fuel in automobiles (motor vehicles, motorcycles, engine boats) (Janssen, 2001; Brunekreef and Holgate 2002). Gases and particles discharged from transport exhaust, construction sites, resuspension of soil dust, trans-boundary pollutants and industrial practices are the primary sources of PM_{10} (Morawska et al 2002). According to [36] Industrial activities are important sources of NO_2. Furthermore, a report by Intergovernmental Panel on Climate Change (IIPC, 1999) and study carried out by Banan et al (2013) shows that aircraft is an important source of NOx which accounts for 1.5% of the total global pollution. However, the negative strong loading of wind speed helps to trap more pollutant concentration since strong wind help disperse air pollutants (Dawson et al 2007).

The second factor (VF2) account for 16.7% of the total variance that shows a moderate factor loading for both O_3 and SO_2 (0.611), (0.638) respectively. O_3 is strongly related to secondary pollutants produced by photochemical oxidation and forms the principal component of smog [7]. Its moderate concentration is produced by mono-nitrogen oxide (NOx) (Banan et al 2013) and O_3 precursors (CO and VOCs) from industrial activities and motor vehicle emission from traffics in Kuala Terengganu (Minoura and Ito, 2010). According to a report on Compendium of Environment Statistics, Malaysia is located in the tropical region near the equator and experiences a tropical climate that helps to accelerate O_3 precursors in Terengganu to undergo chemical reactions under high temperature (Bauer and Langmann, 2002). The source of the moderate variation in SO_2 can be attributed to combustion of fuel in automobiles, aircraft as well as burning of fuel in factories and other industrial activities (Janssen et al 2001; Brunekreef and Holgate 2002).

The third varimax factor (VF3) explains 14.5% of the total variance with a high positive loading on wind speed (0.890) and a weak loading for ambient temperature. It has been proven that wind speed helps to disperse PM_{10} from the source point to the non-source point while wind mixing depth dilutes the level of pollutant concentration (Dawson et al 2007).

SOUTHWEST MONSOON SEASON

The temporal variation in the source of pollutants in the southwest monsoon season can be seen from two-factor loadings after varimax rotation (Fig. 4). The first factor (VF1) account for 39% of the total variance with a strong positive loadings for O_3 (0.972) and NO_2 (0.972) as well as a strong negative loading for temperature and wind speed.

The source of variation in O_3 during the southeast monsoon can be attributed to residual wood burning, bush burning by farmers to clear land for cultivation and incomplete combustion in motor vehicle emission over time (DOE 2007). Seasonal variation in the source of NO_2 is largely due to industrial activities in Kemaman and Kertih as well as emission due to heavy traffic jam in the city center of Kuala Terengganu. In Malaysia, about 69% of NO_2 emission are from industrial practices and power stations, 28% from motor vehicles and the remaining 3% are from other sources (DOE, 2007). The Kemaman supply base (KSB) for instance, is an onshore support base dedicated solely to service and provide the offshore petroleum operation, established since 1982 with over 220 petroleum supply and service capacities (Azid et al 2013). While Kertih houses the PETRONAS Petrochemical Integrated Complex (PPIC) linking the entire range of oil and gas value chain beginning from the upstream exploration and production to final storage of petrochemical manufacturing (Azid et al 2013). The negative loading on wind and temperature indicates an absence of temperature inversion, making the ascending air which helps to clean up pollutants accumulated in the surface layer of the atmosphere to cease (de Souza et al 2014).

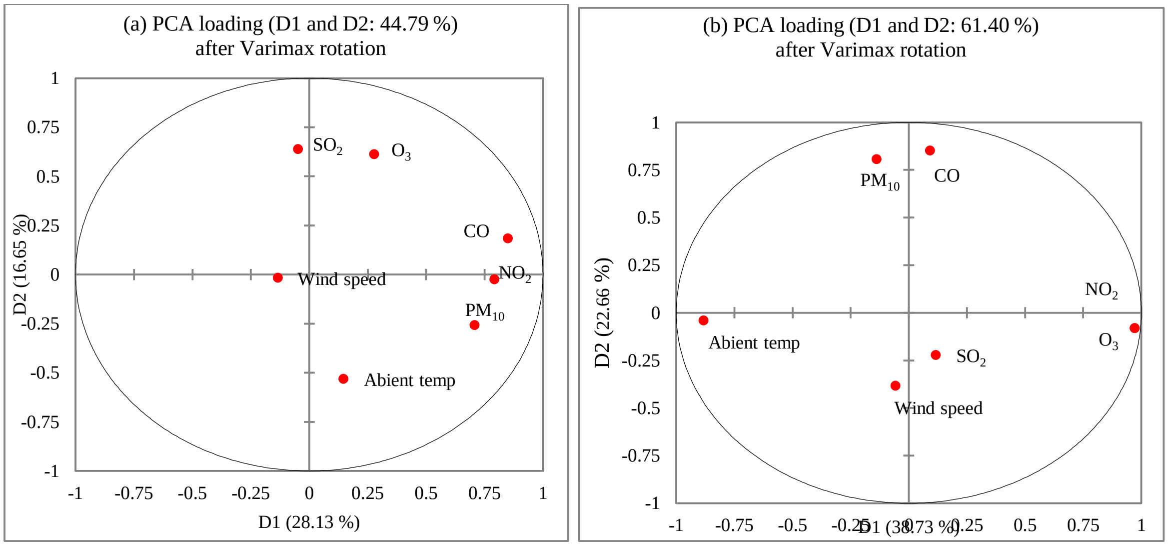


Fig. 4: plot diagram after rotation for PCA loadings (a) northeast monsoon (b) southwest monsoon

The second factor (VF2) records 22% of the total variance with strong positive loadings on CO (0.851) and PM_{10} (0.806). The seasonal variation in the source of CO is from engine boats and motor vehicles, especially when the engines are not turned properly which causes incomplete combustion. Janssen et al 2001). The primary particulate matter directly pollute the air through diesel soot, dust fall and trans-boundary, while photochemical transformation of gases forms the secondary pollutants through chemical reaction such as nitrate and sulfate formation due to reaction with nitric and sulfur dioxide (SO_2).

CONCLUSION

In this study, different multivariate techniques were applied to investigate the seasonal variation in atmospheric air pollution in Terengganu, Malaysia. DA was performed on the raw data sets to determine the most significant parameters in each seasons and to identify the seasonal variation in the level of air pollution using a box and whisker plots as well as bar charts. Principal Component Analysis was used to identify major possible sources of pollution and the most significant sampling parameters contributing to this variation. The varifactors generated by rotated PCA proves that only five parameters (CO, O_3, PM_{10}, NO_2, and WSP) out of seven have strong positive loading greater than 0.75 and are responsible for the variation in the two monsoon seasons. The five parameters indicates that anthropogenic activities (Motor vehicles, boat engines, aircraft, industrial activities, power plants and construction sites) are the major factors contributing to the seasonal variation in the source of air pollution in Terengganu. This study will provide an understanding of the seasonality in the level of air pollution as well as understand the primary sources of these pollutants.

ACKNOWLEDGEMENT

The authors wish to extend their profound gratitude to the Department of Environment Malaysia for providing the data used for this study. East Coast Environmental Research Institute (ESERI), Universiti Sultan Zainal Abidin, Malaysia is highly appreciated for the wonderful assistance it provided in putting this work to reality.

REFERENCES

Azid, A., Juahir, H., Toriman, M. E., Kamarudin, M. K. A., Saudi, A. S. M., Hasnam, C. N. C., & Yamin, M. (2014). Prediction of the Level of Air Pollution Using Principal Component Analysis and Artificial Neural Network Techniques: a Case Study in Malaysia. *Water, Air, & Soil Pollution*, *225*(8), 1-14.

Banan N, Latif MT, Juneng L, & Ahamad F; Characteristics of surface ozone concentrations at stations with different backgrounds in the Malaysian Peninsula. *Aerosol and Air Quality Research*, 2013; *13*(3), 1090-1106.

Bauer, S. E., & Langmann, B. (2002). Analysis of a summer smog episode in the Berlin-Brandenburg region with a nested atmosphere--chemistry model. *Atmospheric Chemistry and Physics*, *2*(4), 259-270.Brumelis, G., Lapina, L., Nikodemus, O., Tabors, G. (2000) Use of an artificial model of monitoring data to aid interpretation of principal component analysis. *Environmental Modelling & Software*, 15 (8), 775-763.

Brunekreef, B., & Holgate, S. T. (2002). Air pollution and health. *The lancet*, *360*(9341), 1233-1242.

Camerlengo, A., Demmler, M.I. (1997). Wind-Driven Circulation of Peninsular Malaysia Eastern Continental Shelf Sci. Mar, 61 (2): 203-211.

Daigle, A., Andre', S., Dan, B., Daniel, C., Loubna, B. (2011). Multivariate analysis of low-flow regimes in eastern Canadian river California to global change. *Climatic Change*, 87,S273–S292.

Dawson, J. P., Adams P. J, & Pandis., S.N. (2007): Sensitivity of PM 2.5 to climate in the Eastern US: a modeling case study. *Atmospheric Chemistry and Physics*, (16), 4295-4309.

Dawson, J.P., Adams, P.J., Pandis, S.N. (2007) Sensitivity of PM 2.5 to climate in the Eastern US: a modeling case study. *Atmospheric Chemistry and Physics*, (16), 4295-4309.

de Souza A, Aristones F, Pavão HG, & Fernandes WA. Development of a Short-Term Ozone Prediction Tool in Campo Grande-MS-Brazil Area Based on Meteorological Variables. *Open Journal of Air Pollution*, 2014; *3*(02), 42.

de Souza, A., Aristones, F., Pavão, H.G., & Fernandes, W.,A. (2014). Development of a Short-Term Ozone Prediction Tool in Campo Grande-MS-Brazil Area Based on Meteorological Variables. *Open Journal of Air Pollution*, *3*(02), 42.

Department of Environment Malaysia (DOE) (1997). A Guide to Air Pollution Index in Malaysia (API). Ministry of Science, Technology and Environment, Kuala Lumpur.

Department of Environment Malaysia (DOE) (2007). Malaysia Environmental Quality Report, Ministry of Science, Technology and Environment, Kuala Lumpur.

Department of Environment Malaysia (DOE) (2012). Malaysia Environmental Quality Report, Ministry of Science, Technology and Environment, Kuala Lumpur.

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

Ghazali, N. A., Ramli, N. A., & Yahaya, A. S. (2009). A study to investigate and model the transformation of nitrogen dioxide into ozone using time series plot. *European Journal of Scientific Research*, *37*(2), 192-205.

Guttikunda, S. K., & Gurjar., B. R. (2012). Role of meteorology in seasonality of air pollution in megacity Delhi, India Environmental Monitoring and Assessment, 184, 3199– 3211.

Hodgson, A. (2000). Volatile Organic Compound and emission rates in new manufactured and sites-built houses. *Indoor Air*, 10(3): 178-192.

Huffman, G.., Adler, R.F., Arkin, P., Chang, A., Ferraro, R., Gruber, A., Janowiak, J., M. Nab, A., Rudolf, B., Schneider, U. (1997). The global precipitation climatology project (GPCP) combined precipitation dataset. *Bulletin of the American Meteorological Society*, 78 (1), 5e20.

Iiten, N., Tülay, A. (2008). investigating the impact of some meteorological parameters on air pollution in Balikesir Turkey. *Environmental Monitoring & Assessment*, 140: 276-277

Intergovernmental Panel on Climate Change (IIPC). "IIPC Special Report: Aviation and the Global Atmosphere", Summary for Policy Makers. 1999; IIPC - XV/DOC 99.

Jacob, D.J., Winner, D. (2008). Effect of climate change on air quality. *Atmospheric Environment*, 43, 51-63.

Jamal, H.H., Pillay, M.S., Zailina, H., Shamsul, B.S., Sinha, K., Zaman Huri, Z., Khew, S.L., Mazrura, S., Ambu, S., Rahimah, A., Ruzita, M.S., (2004). A Study of Health Impact & Risk Assessment of Urban Air Pollution in Klang Valley. UKM Pakarunding Sdn Bhd, Malaysia, Kuala Lumpur.

Janssen, N. A., van Vliet, P. H., Aarts, F., Harssema, H., & Brunekreef, B. Assessment of exposure to traffic related air pollution of children attending schools near motorways. *Atmospheric environment.* 2001; *35*(22), 3875-3884.

Jayamurugan, R., Kumaravel, B., Palanivelraja, S., Chockalingam, MP. (2013) Influence of Temperature, Relative Humidity and Seasonal Variability on Ambient Air Quality in a Coastal Urban Area.International, *Journal of Atmospheric Sciences*, Article ID264046. http://dx.doi.org/10.1155/2013/264046

Juahir, H., Zain, S. M., Yusoff, M. K., Hanidza, T. T., Armi, A. M., Toriman, M. E., & Mokhtar, M. (2011). Spatial water quality assessment of Langat River Basin (Malaysia) using environmetric techniques. *Environmental Monitoring and Assessment*, *173*(1-4), 625-641.

Kleeman, M.J. (2007). A preliminary assessment of the sensitivity of air quality in California to global change. *Climatic Change* 87, S273–S292

Kovac-Andric, E. Brana, J. Gvozdic, V. (2009). Impact of meteorological factors on ozone Concentrations modelled by time series and multivariate statistical methods. *Ecological Informatics*, 4 (2), 117-122.

Liu, C. W., Lin, K. H., & Kuo, Y. M. (2003). Application of factor analysis in the assessment of groundwater quality in a blackfoot disease area in Taiwan. *Science of the Total Environment*, *313*(1), 77-89.

Love, D., Hallbauer, D., Amos, A., Haranova, R. (2004). Factor analysis as a tool in groundwater quality management: two southern African case studies. Physics & Chemistry of the Earth, 29, 1135-1143.

Malaysia Meteorological Department (MMD) (2010). General Climate of Malaysia. Kuala Lumpur: Ministry of Science, Technology and Innovation.

Malaysia Meteorological Department (MMD) (2012). General Climate of Malaysia. Kuala Lumpur: Ministry of Science, Technology and Innovation.

Malaysia Meteorological Department (MMD) (2013). General Climate of Malaysia. Kuala Lumpur: Ministry of Science, Technology and Innovation.

Mallik, C., and Lal, S. (2014). Seasonal characteristics of SO_2, NO_2, and CO emissions in and around the Indo-Gangetic *Environmental Monitoring and Assessment*, 186:1295–1310 DOI 10.1007/s10661-013-3458-y

Minoura H, Ito A; Observation of the primary NO2 and NO oxidation near the trunk road in Tokyo. *Atmospheric Environment* 2010; 44, 23-29

Morawska L, Jayaratne ER, Mengersen K, Jamriska M, & Thomas S; Differences in airborne particle and gaseous concentrations in urban air between weekdays and weekends. *Atmospheric Environment*, 2002; *36*(27), 4375-4383

Mutalib, S. N. S. A., Juahir, H., Azid, A., Sharif, S. M., Latif, M. T., Aris, A. Z., Zain, S. M., & Dominick, D. (2013). Spatial and temporal air quality pattern recognition using environmetric techniques: a case study in Malaysia. *Environmental Science, Processes & Impacts* 1-12, doi: 10. 1039/c3em00161j.

Petrolian Nasional Berhad (2013). Annual report.

Roth, M., Emmanuel, R., Ichinose, T., Salmond, J. (2011). ICUC-7 Urban Climate Special Issue. *International Journal of Climatology*, 31(2), 159–161.

Sadanaga Y, Sengen M, Takenaka N, & Bandow H. (2012) Analyses of the ozone weekend effect in Tokyo, Japan: regime of oxidant (O3+ NO2) production. *Aerosol Air Quality Research*, *12*, 161-168.

Shakir, S.K., Azizullah A., Murad, W. Daud., M.K., Nabeela F, Rahman., H., Rehman., S., Häder., D. (2016) Toxic Metal Pollution in Pakistan and Its Possible Risks to Public Health Volume 242 of the series *Reviews of Environmental Contamination and Toxicology*, pp 1-60

Singh, K.P., Malik, A., Sinha, S. (2005). Water quality assessment and apportionment of pollution source of Gomti River (India) using multivariate statistical techniques - a case study. *Analytical Chimica Acta*, 538 (1-2) 355 - 374.

Steiner, A. L., Tonse, S., Cohen, R. C., Goldstein, A. H., & Harley, R. A. (2006). Influence of future climate and emissions on regional air quality in California. *Journal of Geophysical Research: Atmospheres (1984–2012)*, *111*(D18).

UN-Habitat, 2011. Global Report on Human Settlements: Cities and Climate Change. Earthscan Publications.

Wang, L., Li, J., Lu, H., Gu, Z., Rioual, P., Hao, Q., Mackay, A.W., Jiang, W., Cai, B., Xu, B., Chu, G. (2012). The East Asian winter monsoon over the last 15,000 years: its links to high-latitudes and tropical climate systems and complex correlation to the summer monsoon. *Quaternary Science Reviews*, 32, 131-142

Wennberg, P.,O. Hanisco, T.,F. (1998). Hydrogen radicals, nitrogen radicals and the production of O_3 in the upper troposphere. *Science Journal* Vol. 279 No. 5347, pp.49-53

Zaharim, A., Shaharuddin, M., Nor, M.J., Karin, A.O., Soptan, K. (2009). Relationship between airborne particulate matter and meteorological variables using non-decimated wavelet transform. *European Journal of Scientific Research*, Vol. 27 No. 2 pp 308-312