MULTIVARIATE TIME SERIES ANALYSIS FOR SHORT-TERM FORECASTING OF GROUND LEVEL OZONE (O_3) IN MALAYSIA

AHMAD FAUZI BIN RAFFEE

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DEDICATION

To the Almighty Allah, for sparing our lives and providing the wisdom and guidance to carry out this study.

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ABSTRACT

The declining of air quality mostly affects the elderly, children, people with asthma, as well as a restriction on outdoor activities. Therefore, there is an importance to provide a statistical modelling to forecast the future values of surface layer ozone (O_3) concentration. The objectives of this study are to obtain the best multivariate time series (MTS) model and develop an online air quality forecasting system for O_3 concentration in Malaysia. The implementations of MTS model improve the recent statistical model on air quality for short-term prediction. Ten air quality monitoring stations situated at four (4) different types of location were selected in this study. The first type is industrial represent by Pasir Gudang, Perai, and Nilai, second type is urban represent by Kuala Terengganu, Kota Bharu, and Alor Setar. The third is suburban located in Banting, Kangar, and Tanjung Malim, also the only background station at Jerantut. The hourly record data from 2010 to 2017 were used to assess the characteristics and behaviour of O_3 concentration. Meanwhile, the monthly record data of O_3, particulate matter (PM_{10}), nitrogen dioxide (NO_2), sulphur dioxide (SO_2), carbon monoxide (CO), temperature (T), wind speed (WS), and relative humidity (RH) were used to examine the best MTS models. Three methods of MTS namely vector autoregressive (VAR), vector moving average (VMA), and vector autoregressive moving average (VARMA), has been applied in this study. Based on the performance error, the most appropriate MTS model located in Pasir Gudang, Kota Bharu and Kangar is VAR(1), Kuala Terengganu and Alor Setar for VAR(2), Perai and Nilai for VAR(3), Tanjung Malim for VAR(4) and Banting for VAR(5). Only Jerantut obtained the VMA(2) as the best model. The lowest root mean square error (RMSE) and normalized absolute error is 0.0053 and <0.0001 which is for MTS model in Perai and Kuala Terengganu, respectively. Meanwhile, for mean absolute error (MAE), the lowest is in Banting and Jerantut at 0.0013. The online air quality forecasting system for O_3 was successfully developed based on the best MTS models to represent each monitoring station.

ABSTRAK

Penurunan tahap kualiti udara memberikan kesan kepada warga tua, kanak-kanak dan mereka yang mempunyai asma serta larangan untuk aktiviti luar. Oleh sebab itu, adalah penting untuk menyediakan pemodelan statistik bagi membuat ramalan kepekatan lapisan permukaan ozon (O_3). Tujuan utama kajian ini untuk mendapatkan siri masa multivariat (MTS) yang terbaik dan membina sistem ramalan kepekatan untuk O_3 dalam talian di Malaysia. MTS memberikan penambahbaikan kepada model statistik sedia ada untuk peramalan jangka pendek dalam kualiti udara. Sepuluh stesen kualiti udara yang terletak di empat jenis kawasan berbeza dipilih dalam kajian ini. Kawasan pertama adalah industri yang diwakili oleh Pasir Gudang, Perai dan Nilai, kawasan kedua adalah bandar yang diwakili oleh Kuala Terengganu, Kota Bharu dan Alor Setar. Kawasan ketiga adalah luar bandar yang terletak di Banting, Kangar dan Tanjung Malim, juga Jerantut sebagai stesen rujukan. Rekod data setiap jam dari 2010 hingga 2017 digunakan untuk menilai perlakuan bagi O_3 di setiap stesen. Manakala, data bulanan bagi O_3, zarah halus (PM_{10}), nitrogen dioksida (NO_2), sulfur dioksida (SO_2), karbon monoksida (CO), suhu (T), kelajuan angin (WS) dan kelembapan relatif (RH) digunakan untuk mengenalpasti MTS yang terbaik. Kajian ini menggunakan tiga kaedah MTS iaitu vektor autoregresif (VAR), vektor purata bergerak (VMA) dan vektor autoregresif purata bergerak (VARMA). Berdasarkan kepada petunjuk prestasi, model MTS terbaik di Pasir Gudang, Kota Bharu dan Kangar ialah VAR(1), Kuala Terengganu dan Alor Setar untuk VAR(2), Perai dan Nilai untuk VAR(3), Tanjung Malim-VAR(4) dan Banting-VAR(5). Hanya Jerantut memperolehi model yang berbeza iaitu VMA(2) sebagai model terbaik. Nilai terendah bagi ralat punca kuasa dua min (RMSE) dan ralat mutlak min (MAE) ialah 0.0053 dan <0.0001 untuk model MTS di Perai dan Kuala Terengganu. Manakala untuk ralat mutlat normal (NAE) nilai terendah di rekodkan di Banting dan Jerantut pada nilai 0.0013. Seterusnya, sistem ramalan kepekatan untuk O_3 dalam talian telah berjaya dibangunkan berdasarkan model terbaik MTS mengikut stesen.

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O_3	-	Ground Level Ozone
PM_{10}	-	Particulate Matter in Size between 2.5 to 10 micrometer in aerodynamic diameter
SO_2	-	Sulphur Dioxide
NO_2	-	Nitrogen Dioxide
CO	-	Carbon Monoxide
NO_X	-	Nitrogen oxide
VOC	-	Volatile Organic Compound
MAAQG	-	Malaysia Ambient Air Quality Guideline
VAR	-	Vector Autoregressive
VMA	-	Vector Moving Average
VARMA	-	Vector Autoregressive Moving Average
UV	-	Ultra Violet
T	-	Temperature
RH	-	Relative Humidity
WS	-	Wind Speed
DOE	-	Department of Environment, Malaysia
API	-	Air Pollution Index
ppm	-	part per million
ppb	-	part per billion
HPE	-	High Particulate Event
ANN	-	Artificial Neural Network
MLR	-	Multiple Linear Regression
PCR	-	Principal Component Regression
PCA	-	Principal Component Analysis
DFD	-	Data Flow Diagram
GUI	-	Graphical User Interface
MySQL	-	My Structured Query Language
PHP	-	Hypertext Preprocessor
HTML	-	Hypertext Markup Language

CHAPTER 1

INTRODUCTION

1.1 Introduction

Air pollution has been a major global issue in recent decades. In developed countries, including Malaysia, air pollution is one of the main environmental problems besides the existing environmental pollution (Lanzi *et al*., 2016). High-income countries, such as the United States of America (USA), Europe, and Western Pacific, are some of the most affected countries due to urbanisation and industrialisation, compared with middle- and low-income countries, such as Asia and Africa (World Health Organization, 2016). In Asia, the most polluted country due to industrialisation and climate change is China (Song *et al.*, 2017). Several measures have been taken to reduce air pollution, including developing a new air pollution policy. However, several areas in China are still facing the exceedance of air quality guideline limit. This situation shows that air pollution is an uncontrolled pollution, compared with water or soil pollution where their pollution can be physically seen and controlled directly by their respective possible control measures.

The ambient air pollution is defined as potentially harmful pollutants to the environment (Orosa, 2011). Seinfeld and Pandis (2006) stated that air pollution is the presence in the air of one or more substances at a concentration or for a duration above their natural levels or concentration, with the potential to produce a harmful effect to human and the environment. Low air quality level can significantly affect the human health, especially to children, the elderly, and people with respiratory problem (Panis *et al*., 2016). The sudden large increase of air pollution concentration could lead to death, thus demonstrating the adverse effect it has on human health (Dockery and

Pope, 1994). In general, there are three classifications of air pollutant, which are natural, primary, and secondary pollutants (Mabahwi *et al*., 2015). Examples of phenomena of pollutants that find their way into the atmosphere are forest fire by lightning or dispersal of pollen defined as natural pollutant (Mabahwi *et al*., 2014). Pollutants that have changed form after being emitted into the atmosphere from sources due to oxidation or decay or reaction with other primary pollutants are referred as secondary pollutant (Standers, 2000).

In recent years, the ground layer ozone (O_3) has become a major concern due to its biggest health threat to the human health compared with other pollutants. Lefohn *et al*. (2018) stated the O_3 concentration is defined as a secondary pollutant that adversely affects the human health and vegetation. The dispersion of O_3 concentration in atmosphere is formed when volatile organic compound (VOC) and oxides of nitrogen (NO_x) react in the presence of solar radiation (sunlight). A study in Europe that examined O_3 pollutant has considered it to be the most dangerous air pollutant in modern days and will be worse in the future in terms of its adverse effects to human, environment, and materials (Pierre *et al*., 2017). Jerrett *et al* (2009) provided information on the association between O_3 concentration and long-term health effect from human exposure to O_3. The finding was widely used in most studies related to O_3 and human health. In 2014, the total premature death recorded in China was 89,391 due to respiratory condition of chronic obstructive pulmonary disease (COPD) attributed to O_3 exposure (Lin *et al*., 2018).

In 2016, the main air pollutant had contributed in atmosphere shift from particulate to O_3 concentration due to rapid industrialisation and urbanisation, which became more and more severe (Liu *et al*., 2018; Lu *et al*., 2019). Several control measures and policies have been implemented but due to uncontrolled industrial processes, the reduction of precursor of O_3 concentration were not performed well (Liu *et al*., 2013). Consequently, the statistical tool used to forecast future O_3 concentration is important to provide early information, if possible, before the limit is exceeded.

As one of the developing countries, the air pollution level in Malaysia may increase due to urbanisation, industrialisation, and increasing number of vehicles from the growing population (Xia *et al*., 2015). Whereas this anthropogenic activity was able to release the precursor of O_3 pollutant. The precursor determined as any substance or primary gases pollutant that appear in atmosphere before form to O_3

pollutant by oxidation of chemical reaction. On the other hand, the O_3 was not formed in its own right. The O_3 pollutant produce by the photochemical reaction between it precursor namely nitrogen dioxide (NO_x) and volatile organic compound (VOC) interact under the action of solar radiation/sunlight (Ghazali *et al.*, 2010).

Thus, in order to accommodate human and industrial needs, the precursor of O_3 is released by power plant for energy supply, processing factory activities, and motor vehicle emissions. These contributors show a slight increase and degradation each year by both power plant and motor vehicle emissions. Power plant contributed 61% in 2010 and increased to 66% in 2016. However, the NO_2 contribution emission by motor vehicle decreased from 29% in 2010 to 26% in 2016. The overall trend of O_3 in Malaysia reported by DOE had exceeded the Malaysian Ambient Air Quality Guidelines for O_3 at 0.10 ppm in urban areas such as 0.016 ppm, 0.014 ppm and 0.012 ppm at Shah Alam, Putrajaya and Cheras respectively (Department of Environment, 2020). This was due to the traffic density and conductive atmosphere that resulted in O_3 formation (Department of Environment, 2016).

The effect of exceeding permissible limit of air pollutant especially O_3 concentration are well established, thus the forecasting of air O_3 would provide an early information about the future exceeding level of concentration. Therefore, by forecasting of O_3, effective strategies for air quality management can be developed. In other hand, the forecasting results obtained were beneficial to assist the related government agency in decision making process related to future environmental management and mitigation measure. The statistical forecasting method offers tool to forecast the air pollutant based on the past concentration values (Singh *et al*., 2013).

On the other hand, statistical forecasting method for accurate and easier especially for non-statistical user were needed nowadays. This would allow the statistical forecasting to reduce the impact of air quality on the human health. Thus, in recent year, several efforts on the research toward statistical forecasting model used to predict the dispersion of air pollutant in ambient air (Eslami *et al.*, 2020). The most popular and widely used multivariate methods for short term forecasting of O_3 concentration is Multiple Linear Regression (MLR) and Artificial Neural Network (ANN) (Suhaimi *et al.*, 2019; Jumin *et al.*, 2020). However, the drawback of MLR is apprehend the nonlinearity and complexity link to the structure of system (Arsić *et al.*, 2019). Meanwhile, ANN have low forecasting capability and not equally handle linear and nonlinear pattern data (Panigrahi and Behera, 2017; Tealab *et al*., 2017). In most previous study, the ANN provide a better forecasting results compared to MLR.

In addition, several studies using single time series method in air quality concluded that the model was better than ANN even it consider on the O_3 pollutant itself (Awang *et al*., 2017). Thus, the multivariate time series is appropriate for forecasting O_3 concentration because it considers other variables, such as particulate matter (PM_{10}), gaseous pollutant of sulphur dioxide (SO_2), nitrogen dioxide (NO_2), carbon monoxide (CO), as well as meteorological variables such as wind speeds, relative humidity, and temperature. In addition, meteorological variables and gaseous pollutants are associated with influence concentration of O_3 (Fortelli *et al*., 2016). Thus, considering other variables in the forecasting analysis could provide more accurate values.

1.2 Problem Statement

Air pollution degrades the ambient air quality and impacts the human health greatly, as well as having a bad influence on materials and crops. In Malaysia, air pollution shows an increasing trend due to rapid development and urbanisation. The increasing number of factories and motor vehicles have contributed to the air pollution in Malaysia. Moreover, the DOE (2020) were reported the O_3 concentration recorded exceeding the MAAQG at several location in Malaysia since few years ago. On the other hand, DOE reported that the increasing O_3 in average from 2010 to 2019 in Malaysia is approximately 9.87%. As such, much attention is being given in monitoring and assessing the air pollution in Malaysia.

Research on air quality, specifically on O_3 concentrations, is mostly related to the assessment of pollutant concentration and descriptive statistics to determine the behaviour of the pollutants (Mohamed *et al*., 2016). In previous studies, single time series method had outperformed several other methods in forecasting short-term air pollution. However, the single model did not consider the effect of other variables, such as particulate matter (PM_{10}), nitrogen dioxide (NO_2), sulphur dioxide (SO_2), carbon monoxide (CO), and meteorological parameters such as wind speed, relative humidity, and temperature to develop the forecasting model. Previous researchers found that there were correlations between the gaseous pollutants, particulate matter, and meteorological parameters that influence the O_3 concentration (Janjai *et al*., 2016; Zhang *et al*., 2017). This is because O_3 is identified as a secondary pollutant. This indicates that other variables might be able to influence the O_3 concentration dispersion and thus should be considered in developing the forecasting model.

To the best of the author's knowledge, there is no comprehensive study on multivariate time series method for short-term air pollution prediction. Therefore, in the current study, multivariate time series model was applied for better and more accurate results. Motivated by this, this work develops statistical tools using multivariate time series to provide better forecasting method for O_3 concentration analysis in Malaysia.

Additionally, local authorities in Malaysia such as city hall, city council and related government agencies do not have any proper system that can help to predict future concentration of ambient air quality level especially O_3 concentration. Thus, a new online air quality forecasting system has been developed, hence, future planning and development will be much easier. Moreover, this online forecasting air quality system is simple and straightforward thus person with very limited knowledge in statistics also can use and the results may be easily understood by an ordinary user.

1.3 Research Hypothesis

As vulnerability to air pollution has increased globally, greater attention has been directed to reducing the risks associated with its occurrence. Thus, the main idea of this research is to determine the most appropriate multivariate time series model for short term forecasting of O_3 concentration in Malaysia. Therefore, the following hypotheses are considered relevant to this research study and substantiated through the evaluation and analysis.

Hypothesis 1: The dispersion of O_3 concentration vary with different types of monitoring stations, and high recorded of O_3 concentration probably expected at industrial and urban monitoring stations compared to sub-urban and background monitoring stations.

Hypothesis 2: The statistical method of multivariate time series as better model to improve the forecasting accuracy of O_3 concentration in a wide range of air quality research study.

Hypothesis 3: The online air quality forecasting system are viable alternative to forecast the future O_3 concentration that help the person with limited statistical knowledge, government agencies and related environmental consultant firm.

1.4 Research Objectives

The aim of this research is to obtain the most appropriate model to predict ground layer ozone (O_3) level in Malaysia using a multivariate time series analysis. Therefore, the objectives of this research are:

i. To describe the characteristics and behaviour of O_3 concentration with different locations, such as in industrial, urban, and suburban areas;
ii. To forecast O_3 concentrations using the most appropriate multivariate time series models for each air quality monitoring station; and
iii. To develop a new online air quality forecasting system for short-term O_3 prediction based on appropriate time series model.

1.5 Scope of Research

Ten (10) monitoring stations were selected for modelling: Jerantut monitoring station in Pahang, Pasir Gudang monitoring station in Johor, Perai monitoring station in Penang, Nilai monitoring station in Negeri Sembilan, Kuala Terengganu monitoring station in Terengganu, Kota Bharu monitoring station in Kelantan, Alor Setar monitoring station situated in Kedah, Kangar monitoring station situated in Perlis, Tanjung Malim monitoring station located in Perak, and Banting monitoring station located in Selangor. The selection of monitoring stations was based on the type of location, which represents the background station: urban, suburban, and industrial areas; and the availability of air quality data provided by the DoE, Malaysia. Two data records were used in this study. Historical data from 2010 to 2017, which were more than 70,000 hours of monitoring records, were used for exploring the characteristics and behaviour of O_3 concentrations. Meanwhile, for developing multivariate time series model, 144 months' historical air pollutants data of O_3 concentration, PM_{10}, NO_2, SO_2, CO, as well as meteorological variables of wind speed, relative humidity, and temperature were used. The monthly data was used from January 2006 to December 2017. The simulation used 138-month record data as training data, meanwhile the remaining of six-month record data was keep for validation. The identification of pattern, characteristics, and behaviour of O_3 concentration at all chosen monitoring stations were conducted via box plot, descriptive statistics, and bar chart analysis. Meanwhile, the t-test analysis was adopted to analyse the significance between night time and day time O_3 concentration in Malaysia. Further analysis regarding the multivariate time series (MTS) model in this work has utilised all three models in MTS: vector autoregressive (VAR), vector moving average (VMA), and vector autoregressive moving average (VARMA). The best model for each monitoring station was used for developing the forecasting model of O_3 concentration. The last part is to develop the online forecasting system based on the appropriate multivariate time series model, which were developed using My Structured Query Language (MySQL) and Hypertext Preprocessor (PHP) for easy access online.

1.6 Thesis Outline

Chapter 1 describes the research background and research objectives. It also provides an overall picture of the research task undertaken in this study.

Chapter 2 presents a comprehensive critical review of the research related to air quality, health effect, relationships among air pollutant and shot-term air pollution analyses. This chapter identifies the current state of knowledge and research gaps in air quality modelling and management.

Chapter 3 provides a description of the study area. The procedures of application of time series analyses are also given. Performance indicators such as root-mean-square-error (RMSE), mean absolute error (MAE), and normalised absolute error (NAE) were employed to validate the time series models and were discussed.

Chapter 4 discusses the results obtained from the analyses done. The characteristics and behaviour for all ten monitoring stations are presented in this chapter. The analyses and results of appropriate model for ten monitoring stations are also discussed in this chapter.

Chapter 5 discusses on the new online air quality forecasting systems.

Chapters 6 presents a summary and conclusions based on the results and discussion in Chapter 4 and Chapter 5. Recommendations for future work are also presented in this chapter.

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