TRENDS AND PREDICTION OF AIR POLLUTANTS IN PASIR GUDANG INDUSTRIAL AREA, JOHOR, MALAYSIA

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To my family, especially my beloved Parents.

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ABSTRACT

The trends and prediction of the air quality of Pasir Gudang industrial area in Johor are discussed and presented in this thesis. An attempt was also made to study the pollutants concentrations recorded by the Larkin monitoring station. However, studies on the trends, meteorological influences and the predictions of atmospheric pollution were given a greater emphasis for the Pasir Gudang industrial area. The statistical analysis based on a simple correlation coefficient and regression analysis showed that although there is a relationship between each pollutant i.e ozone (O_3), particulate Matter with diameter of 10 micrometers or less (PM_{10}), nitrogen dioxide (NO_2), sulfur dioxide (SO_2) and carbon monoxide (CO) concentrations and a combination of meteorological parameters such as wind speed, temperature, humidity rate and solar radiation in Pasir Gudang with the correlation coefficient (r) of 0.64, 0.42, 0.71, 0.55 and 0.49, respectively, the inclusion of the previous day's pollutants concentrations significantly presents better prediction models with the correlation coefficient of 0.73, 0.68, 0.83, 0.68 and 0.67, respectively. Subsequently, the prediction of PM_{10} based on its previous day's concentrations through artificial neural network resulted in a much better model prediction with the value of r=0.69 and 0.70 compared to the statistical model with the value of r=0.64. The spatial variation of SO_2, NO_2 and PM_{10} emitted from various industrial sources in Pasir Gudang were also predicted using American Meteorological Society/Environmental Protection Agency Regulatory Model (AERMOD) air dispersion model. The Weather Research and Forecasting (WRF) model was applied to simulate the required meteorological variables for the selected date i.e 2-16 July, 2010. The WRF output values i.e. temperature, wind speed and wind direction were compared with the onsite measured data in Pasir Gudang, Senai, KLIA and Kluang stations. The results showed the accuracy of WRF model performance in simulating temperature and wind speed with the Mean Absolute Error (MAE) and Root Mean Square Error (RMSE) value of less than 2.8 and 3.5, respectively, while it has some difficulties in simulating the wind direction near a coastal area. The maximum ground level concentration of pollutants i.e SO_2, NO_2 and PM_{10} simulated through AERMOD coupled with WRF in Pasir Gudang industrial area was 36.2, 59.8 and 5.4 $\mu g/m^3$, respectively, which were within the Malaysia ambient air quality guidelines over the receptor grid. The evaluation of AERMOD through the quantile-quantile (Q-Q) plots showed that most of the predicted and observed pair points are lying close to the one-to-one line. Besides, the sensitivity of AERMOD model to its input parameters i.e stack characteristics and meteorological variables showed that the model is more sensitive to stack gas temperature and stack height as well as wind speed.

ABSTRAK

Trend dan ramalan kualiti udara di kawasan perindustrian Pasir Gudang di Johor dibincangkan dan dibentangkan dalam tesis ini. Percubaan juga dibuat untuk mengkaji kepekatan bahan pencemar direkodkan di stesen pemantauan Larkin. Walau bagaimanapun, kajian mengenai trend, pengaruh cuaca dan ramalan pencemaran atmosfera telah diberi penekanan yang lebih besar bagi kawasan perindustrian Pasir Gudang. Analisis statistik berdasarkan pekali korelasi dan analisis regresi yang mudah menunjukkan bahawa walaupun terdapat hubungan antara setiap bahan pencemar seperti kepekatan ozon (O_3), zarahan berdiameter 10 mikrometer atau kurang (PM_{10}), nitrogen dioksida (NO_2), sulfur dioksida (SO_2) dan karbon monoksida (CO) dan gabungan parameter meteorologi seperti kelajuan angin, suhu, kadar kelembapan dan sinaran suria di Pasir Gudang, dengan pekali korelasi (r) masing-masing iaitu 0.64, 0.42, 0.71, 0.55 dan 0.49, pada hari sebelumnya menunjukkan model ramalan yang lebih baik dengan pekali korelasi masing-masing iaitu 0.73, 0.68, 0.83, 0.68 dan 0.67. Seterusnya, ramalan PM_{10} berdasarkan kepekatan hari sebelum ini melalui rangkaian neural tiruan menghasilkan model ramalan yang lebih baik dengan nilai r=0.69 dan 0.70 berbanding dengan model statistik dengan nilai r=0.64. Perubahan ruang SO_2, NO_2 dan PM_{10} dilepaskan dari pelbagai sumber perindustrian di Pasir Gudang juga diramalkan menggunakan Persatuan Meterologi Amerika/Model Regulatori Agensi Perlindungan Alam Sekitar (AERMOD) model serakan udara. Model Penyelidikan dan Ramalan Cuaca (WRF) telah digunakan untuk mensimulasi pembolehubah meteorologi yang diperlukan bagi tarikh yang dipilih iaitu 2-16 Julai, 2010. Nilai hasil WRF iaitu suhu, kelajuan angin dan arah angin dibandingkan dengan data yang diukur di kawasan Pasir Gudang, Senai, KLIA dan stesen Kluang. Hasil kajian menunjukkan bahawa ketepatan prestasi model WRF cukup baik dalam mensimulasi suhu dan kelajuan angin dengan nilai ralat mutlak min (MAE) dan ralat punca kuasa dua min (RMSE) masing-masing kurang daripada 2.8 dan 3.5, meskipun ia menghadapi beberapa kesukaran dalam mensimulasi arah angin berhampiran kawasan pantai. Kepekatan maksimum paras tanah bahan pencemar seperti SO_2, NO_2 dan PM_{10} disimulasi melalui AERMOD bersama WRF di kawasan perindustrian Pasir Gudang masing-masing iaitu 36.2, 59.8 dan 5.4μg/m^3, yang berada dalam garis panduan kualiti udara Malaysia melebihi grid reseptor. Penilaian AERMOD melalui plot quantile-quantile (Q-Q) menunjukkan kebanyakan titik pasangan yang diramalkan berada berdekatan dengan garis satu sama satu. Selain itu, kepekaan model AERMOD untuk parameter input seperti ciri-ciri cerobong dan pembolehubah meteorologi mendapati model ini lebih sensitif kepada suhu gas cerobong dan ketinggian cerobong serta kelajuan angin.

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LIST OF ABBREVIATIONS

AERMOD	–	Atmospheric Meteorological Society/Environmental Protection Agency Regulatory Model
AERMAP	–	AERMOD terrain Pre-Processor
AERMET	–	AERMOD Meteorological Data Pre-Processor
AFWA	–	Air Force Weather Agency
AMS	–	American Meteorological Society
ANN	–	Artificial Neural Network
ArcGIS	–	Aeronautical Reconnaissance Coverage Geographic Information System
ARW	–	Advanced Research WRF
ARWpost	–	WRF Post-Processing
CAMx	–	Comprehensive Air Quality Model with extensions
CMAQ	–	Community Multiscale Air Quality
CO	–	Carbon Monoxide
CO	–	Control Pathway
DOE	–	Department of Environment
FAA	–	Federal Aviation Administration
FFN	–	Feedforward Network
FNL	–	Final Operational Global Analysis
ISC	–	Industrial Source Complex
FSL	–	Forecast Systems Laboratory
GIS	–	Geographic Information System
GLC	–	Ground Level Concentration
GrADS	–	Grid Analysis and Display System
KLIA	–	Kuala Lumpur International Airport
LH	–	Latent Heat Flux
MAAQS	–	Malaysia Ambient Air Quality Standard
MAE	–	Mean Average Error
ME	–	Meteorology Pathway

MSE	–	Mean Square Error
MLP	–	Multi Layer Perceptron
MM5	–	Mesoscale Model
NCAR	–	National Center for Atmospheric Research
NCDC	–	National Climatic Data Center
NCEP	–	National Centers for Environmental Prediction
NO_2	–	Nitrogen Dioxide
NOAA	–	National Oceanic and Atmospheric Administration
NWS	–	National Weather Service
O_3	–	Ozone
OU	–	Output Pathway
PBL	–	Planetary Boundary Layer
PCDDs	–	Polychlorinated Dibenzo-p-Dioxins
PCDFs	–	Polychlorinated Dibenzofurans
PM_{10}	–	Particulate Matter less than 10 μ
PSU	–	Pennsylvania State University
Q-Q plots	–	Quantile-Quantile plots
RE	–	Receptor Pathway
RRTM	–	Rapid Radiative Transfer Model
RMOL	–	Reverse Monin-Obukhov Length
RMSE	–	Root Mean Square Error
SCRAM	–	Support Center for Regulatory Air Models
SCREEN	–	Screening Procedures for Estimating the Air Quality Impact of Stationary Sources
SO_2	–	Sulphur Dioxide
SPSS	–	Statistical Package for Social Sciences
SO	–	Source Pathway
USEPA	–	United States Environmental Protection Agency
UTC	–	Coordinated Universal Time
WPS	–	WRF Pre-Processing
WRF	–	Weather Research and Forecasting
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LIST OF SYMBOLS

i.e	–	For Example
T	–	Temperature
°C	–	Degree centigrade
°K	–	Degree kelvin
%	–	Percent
R^2	–	coefficient of determination
r	–	correlation coefficient
km^2	–	Kilometer squareparent domain
d1	–	Parent domain
d2	–	intermediate domain
d3	–	innermost domainSensible heat flux
H	–	Sensible heat flux
u^*	–	Friction velocity
w^*	–	Convective velocity scale
$\partial\theta/\partial z$	–	Potential temperature
Z_{ic}	–	Convective mixing height
Z_{im}	–	Mechanical mixing height
L	–	Monin-Obukhov length
Z_0	–	Surface roughness
B_0	–	Bowen ratio
R	–	Albedo
u_{ref}	–	Reference wind speed
T	–	Surface temperature
	–	

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CHAPTER 1

INTRODUCTION AND OVERVIEW

1.1 Introduction

Rapid process of industrialization and urbanization cause a tremendous amounts of energy consumption consequently increased the rate of pollutant emissions. Therefore, the economic growth related to the social development and environmental protection should be of more concern (Jiang *et al.*, 2010). The emission mitigation requires investigation of different human activities especially in the industrial and transportation sectors.

Recent studies have presented the health effects of air pollution associated with exposure to pollutants such as nitrogen dioxides (NO_2), sulfur dioxides (SO_2), carbon monoxide (CO), ozone (O_3), and particulate matter of less or equal to 10 micrometer in size or PM_{10} (Mangia *et al.*, 2013). The increase in air pollutants cause the undesirable effects on human health with increased mortality rates and hospital admissions for example respiratory and cardiovascular diseases.

The atmospheric pollutants concentrations are usually measured only in hot spot campaigns while makes assessing the population exposure quite difficult. establishing suitable monitoring sites require large amounts of finances. Furthermore, the sole use of direct measures i.e proximity as an indicator of exposure does not consider the influence of meteorological conditions and process characteristics such as stack height, plume temperature and velocity, fugitive emissions, etc. on the zones surrounding the industrial site and may lead to some misclassification. Therefore, in the absence of continuous measurements of pollutants concentrations some indirect methods such as dispersion modeling are used to evaluate the air quality and measure the exposure in epidemiological studies (Zou *et al.*, 2009).

Dispersion models incorporate information on meteorology, emission, and topography and can be a valid tool to predict ground level concentration around emission sources. Hence, the use of air quality models is concerned for evaluating the spatial and temporal distribution of pollutants concentrations and their potential exposure in a much wider areas (Tiwary and Colls, 2010). However, the required meteorological data as the critical inputs in air quality models are usually not available at most sites of interest. Therefore, the use of comprehensive meteorological models is desired for providing the required meteorological variables for air quality models at the site of interest (Carbonell *et al.*, 2013).

Because of the drastic economic growth in Iskandar region in the south of Johor, concern about poor air quality will soon be surfaced. Pasir Gudang industrial area is one of the five focal points of development in Iskandar region. The Malaysia government has started some efforts to improve the life quality of the people. The growing awareness of public about the adverse effects of air pollution leads the policy-making agencies to include the air pollution control strategies as an integral part of urban planning.

This study presents the trends and prediction of air pollutants i.e SO_2, CO, NO_2, O_3 and PM_{10} monitored in Pasir Gudang and Larkin stations in the south of Johor, Malaysia over a period of three years i.e 2008-2010. The secondary pollutants concentrations and meteorological data were obtained from the monitoring made by the Department of Environment and Malaysian Meteorological Department, respectively. The study attempts to assess the trends, prediction and inter-relationship between the pollutants as well as their relationships with local meteorological parameters. In addition, the attempt is to solicit the distribution of pollutants resulted from industrial sources of Pasir Gudang using integrated WRF (Weather Research and Forecasting)-AERMOD (Atmospheric Meteorological Society/Environmental Protection Agency Regulatory Model) modeling technique.

1.2 Background

Cities with dense population are of fundamental concern due to huge energy consumption. The economy growth in many developing countries has caused tremendous increase in fuel consumption and released of pollutants. The presence of pollutants resulted from different activities especially from the industrial and transportation sectors caused the high level of air pollution and consequently affecting human health and environment (Li *et al.*, 2010). Hence, the concern about health issues has increased all over the world as the result of air pollution and changes in atmospheric balance (Chen *et al.*, 2007; Morra *et al.*, 2006).

Because of the drastic economic growth in Iskandar region in the south of Johor, concern about poor air quality has been surfaced. The Malaysia government has started some efforts to improve the life quality of the people. The aim to have a low carbon city in the future has been considered in Iskandar Malaysia based on the different low carbon strategies and defined scenarios (Fong *et al.*, 2009). Chen *et al.* (2007) estimated the useful effects of some low carbon policies on the air pollution reduction and public health impact. However, most of the low carbon studies have not considered directly the behavior of air pollutants resulted from different scenarios. The air quality modeling provides the opportunity to investigate the future trends of pollutants and their behavior in the environment, while the monitoring stations give only a limited data.

Air quality standards and predicted pollution concentrations comparison are not adequate for human health protection. Even the chronic exposure to acceptable threshold values of pollutants leads to adverse human health impacts (Zou *et al.*, 2009). Estimation of air pollutants concentrations can be performed by air quality modeling such as dispersion models. Convection and turbulence in the air mainly effects on the dispersion of air pollutants. Velocity and temperature of exit gases are two main factors which effect on plume rise in dispersion model. Velocity and temperature of exit gases give plume momentum and buoyancy in ambient air respectively. Besides, source characteristics and meteorological factors are the fundamental parameters in the pollution dispersion (Narayanan, 2007).

USEPA (United States Environmental Protection Agency) has developed different dispersion models in the air quality management. A simple dispersion model, SCREEN (Screening Procedures for Estimating the Air Quality Impact of Stationary Sources), has been used in some studies to analyze pollutant dispersion (Patel and Kumar, 1998; Mehdizadeh and Rifai, 2004; Taha *et al.*, 2006). Industrial source complex model (ISC) has also been applied in estimating air pollutant concentrations in different studies (Patel and Kumar, 1998; Manju *et al.*, 2002; Mehdizadeh and Rifai, 2004; Orloff *et al.*, 2006). The comparison of SCREEN and ISC models shows that ISC is more precise because of estimating crosswind concentrations and using the actual meteorological data (Mehdizadeh and Rifai, 2004).

Presently, AERMOD as the replacement to ISC is the preferred dispersion model by USEPA. Orloff *et al.* (2006) executed ISC and AERMOD models in estimating hydrogen cyanide concentrations and concluded that the AERMOD prediction data is more precise due to incorporating more complex algorithms in complex terrain. Steib (2005) introduced AERMOD as an appropriate model to be used in Hungary. Some recent studies have applied AERMOD model in predicting the dispersion of both the point (Mazur *et al.*, 2009; Onofrio *et al.*, 2011) and mobile emission sources (Zou *et al.*, 2009). Besides, ArcGIS is considered as a useful tool in preparing the maps by having the modeling predicted data of discrete points (Morra *et al.*, 2009; Mazur *et al.*, 2009).

However, the required meteorological data as the critical inputs used in AERMOD are usually not available at most sites of interest. Therefore, the prognostic comprehensive meteorological models are desired for providing the required meteorological variables of air quality models i.e AERMOD at the site of interest. Some studies have presented the application of meteorological models such as WRF and MM5 in supporting the air quality models for example Community Multiscale Air Quality (CMAQ), Comprehensive Air Quality Model with extensions (CAMx), AERMOD and CULPUFF dispersion models (Koo *et al.*, 2012; Wu *et al.*, 2012; Isakov *et al.*, 2007; Abdul-Wahab *et al.*, 2011).

The target for Iskandar Malaysia is to achieve environmental sustainability, meeting the green aspects in all developments and enhancing the air quality within Iskandar, especially in urban areas and areas of high concentration of human activity. Analysing the air quality condition of a city is an important policy in having a clean city in the future. This study presents the trends and prediction of urban air pollutants i.e SO_2, CO, NO_2, O_3 and PM_{10} monitored in the Pasir Gudang and Larkin monitoring stations over a period of three years from 2008 to 2010. The recorded data on pollutants concentrations were obtained from the department of environment, Malaysia. The aim of the study is to assess the trends of air pollutants and inter-relationship between the pollutants as well as their inter-relations with local meteorological parameters influencing the quality of air in the industrial area of Pasir Gudang. Besides, the atempts to predict the ground level concentration of SO_2, NO_2 and PM_{10} from the industrial point sources of Pasir Gudang in the surrounded areas were studied by developing AERMOD air dispersion model coupled with WRF prognostic model.

1.3 Statement of the Problem

Pasir Gudang is located in the eastern gate development of Iskandar Johor, Malaysia. It covers an area of 31,132 ha. with a total population of 100,000 people. Pasir Gudang is considered as the main industrial areas in Iskander region. Currently, most of the high impact factories are situated in Pasir Gudang which as the source of pollution affect the residents living in and within the area.

Although the ambient air quality is monitored in Pasir Gudang and some other areas, unfortunately there is the lack of study and assessment on the effects of meteorological parameters on the pollutants concentrations and their distribution surrounding the area. Thus, the proposed study is an attempt to fulfill this requirement towards better understanding on the nature of the air pollution within the developing region.

1.4 Objective of the Study

In general, the purpose of the study is to assess the urban air quality within the south of Johor focusing in Pasir Gudang industrial area based on the available secondary data, which has been monitored over a period of three years at two monitoring stations. Besides, this study is an attempt to estimate pollutant concentrations by using meteorological and air quality modeling. Thus, in order to achieve the main theme of the study, the following specific objectives had been drawn, while each of the objectives is addressed and assessed in respective chapters presented in this thesis.

i. To investigate and assess the trends of air pollutants, their prediction and interrelationship with meteorological variables in the study area by using statistical analysis and artificial neural network.

ii. To simulate and evaluate the meteorological parameters using WRF prognostic model and provide the required meteorological data for the initialization of AERMOD air quality dispersion model in the study area.

iii. To predict the ground level concentration of SO_2, NO_2, and PM_{10} from the 45 major industrial point sources in Pasir Gudang using AERMOD air dispersion model coupled with WRF prognostic model.

1.5 The Scope of the Study

Initially, the study is based on the data collected at two monitoring stations of Pasir Gudang and Larkin in the south of Johor over a period of three years from 2008 to 2010. Data on meteorological variables collected at Pasir Gudang monitoring station a period of three years from 2008 to 2010 was also included in the study.

The scope of the study covers the analysis on the trends of the air pollutants parameters such as SO_2, CO, NO_2, O_3 and PM_{10} monitored at the Pasir Gudang and Larkin monitoring stations. The attempt is to solicit if there is inter-relationship among the pollutants as well as if there is any influence of meteorological factors on air pollutants level in the Pasir Gudang monitoring station. It also considers the prediction of pollutants through regression analysis and artificial neural networks.

This study also investigates the simulation of the meteorological parameters using WRF prognostic model for the initialization of AERMOD dispersion model. The performance of the WRF model in simulating meteorological variables is evaluated against observation data i.e temperature, wind speed and wind direction from some monitoring stations including Pssir Gudang, Senai, KLIA and Kluang.

Meanwhile, this study presents the simulation of the ground level concentration of pollutants i.e SO_2, NO_2 and PM_{10} from the 45 major industries in the industrial area of Pasir Gudang in the south of Johor, Malaysia along with the performance evaluation of AERMOD model. It also presents the sensitivity analysis of AERMOD to some of its input parameters i.e source characteristics and meteorological variables. The study solicits possible effects of air pollution in the study area and will be the first attempt to utilize the AERMOD air dispersion model coupled WRF prognostic model applied for the region.

1.6 The Significance of the Study

Johor City is developing steadily like any other cities in the world. The industrial development in the south of Johor might deteriorate the quality of life particularly the quality of air in the city area and hence should be greatly taken into consideration. Although the efforts have been made by the local authorities to monitor the ambient air quality at several sites within the south of Johor for the last years, no attempt is still performed to study and assess the available data for better understanding on the nature of the pollutants ground level concentrations within the region.

The trends and prediction of the air pollutants is yet to be analysed in Pasir Gudang industrial area. Therefore, this study attempts to provide information on the state of the air pollutants and their interrelationship with meteorological parameters as well as prediction of the ground level concentration of pollutants resulted from Pasir Gudang industrial sources. Evidently, the findings of this study can facilitate and assist the local government authorities and policy makers in managing the urban air quality. This research will help the managers in applying appropriate policies for pollutant mitigation and air pollution control. It shows the most balance between economy growth and environmental protection in the future expansion way of industrial area which is called as sustainable development.

1.7 Overview of Thesis

The study is to assess the air pollutants monitored at two monitoring stations in the south of Johor, Malaysia, while more emphasis is given on the Pasir Gudang industrial area. It presents the air pollutants concentrations relationship with meteorological variables and their previous day's concentrations for Pasir Gudang monitoring station. In addition, it includes the prediction of pollutants concentration through developing statistical methods as well as comparing the results with artificial neural network for the example of PM_{10}. The selected pollutants concentrations i.e SO_2, NO_2 and PM_{10} and their spatial and temporal distribution is predicted through AERMOD dispersion model while the WRF comprehensive meteorological models is used to equip the AERMOD model with the required meteorological variables.

Chapter 1 presents the introduction and background of the study. This chapter provides the objectives, the scopes and the significance of the study, where air pollution research is very limited in the study area. Brief information about the study in general is provided in this chapter, while detailed description of the specific topic is presented in the incoming chapters.

Chapter 3 introduces the conducted methodology of the whole study involving the collection and analysis of the secondry data. It describes the location of the study area as well as models used in the study. It presents the statistical model and artificial neural network approach in pollutants prediction. A brief description on the WRF model for deriving the required meteorological parameters used in the air quality model is given in the chapter. In addition, a description on the AERMOD air dispersion model is also presented in this chapter. Finally, it discusses the sensitivity analysis of AERMOD input parameters i.e stack characteristics and meteorological variables.

Chapter 4 presents a review on the overall trends of atmospheric pollutants for a period of three years i.e 2008-2010 in the Pasir Gudang and Larkin monitoring stations in the south of Johor, Malaysia while mostly focuses on Pasir Gudang station, its trend and air pollution prediction. It presented if the pollutants concentrations are correlated with meteorological variable as well as their previous day's concentrations. In addition, it elaborates the application of statistical methods such as regression analysis and developing artificial neural network in the prediction of pollutants concentration and compares their results specifically on PM_{10} concentration.

Chapter 5 presents the simulation of the meteorological parameters using WRF prognostic model. The WRF model is developed to derive the required meteorological data for the initialization of AERMOD dispersion air quality model in the absence of required local meteorological observations. The results of WRF model against observation data i.e temperature, wind speed and wind direction from some monitoring stations i.e Pasir Gudang, Senai, KLIA and Kluang meteorological stations are analyzed in this chapter to validate the results from WRF model. Finally, the derived meteorological parameters required in the initialization of AERMOD dispersion model are presented.

Chapter 6 presents the simulation of the ground level concentration of pollutants i.e SO_2, NO_2 and PM_{10} from a total of 45 major industries in the industrial area of Pasir Gudang in the south of Johor, Malaysia. AERMOD dispersion model is developed in this study using WRF model to derive the required meteorological parameters. The performance evaluation of the AERMOD model is also presented by comparing the observed and predicted concentration of SO_2, NO_2, and PM_{10} at the discrete receptor of Pasir Gudang monitoring station. Meanwhile, the sensitivity of AERMOD to its input parameters i.e source characteristics and meteorological parameters was investigated in this chapter.

Chapter 7 of the thesis summarizes the study, restate the overall conclusions of the study and suggests recommendation for possible research work in the future.

both the WRF model and observations to analyse their impact on the predicted GLC of pollutants.

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