SELECTED AIR POLLUTANTS AND THEIR EFFECTS ON LUNG FUNCTION AMONG PETROL STATION WORKERS IN JOHOR

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By

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DECLARATION

I, Md Faizul Bin Abd Razak, declare that the work presented bin this thesis is originally mine. The information that has been derived from other sources is clearly indicated in the thesis.

Md Faizul Bin Abd Razak

Signed on 25th February 2023

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LIST OF SYMBOLS

%	Percentage
=	Equal to
Z	Z score
Δ	Precision of estimation
P	Population's proportion
n	Number of subjects
m	Ratio between two groups
α	Alpha
β	Beta
σ	Population standard deviation
η^2	Partial eta squared
$<$	Less than
$\geq$	More than or equal to
$>$	More than
&	And
$\sum$	Sum
r	Correlation coefficient
b	Regression coefficient
R^2	Coefficient of determination
F	F statistic
t	t statistic
°C	Degree Celsius
kPa	Kilopascal
µg/m^3	Micrograms per cubic metre
µm	Micrometre
mL	Millilitres
mL/year	Millilitres per year
mL/year	Millilitres per second
L/min	Litre per minute
kg/m^2	Kilogram per square metre
km^2	Kilometre square

LIST OF ABBREVIATIONS

24-H	24 Hours
Adj. *b*	Adjusted Regression Coefficient
Adj. OR	Adjusted Odds Ratio
AIC	Akaike Information Criterion
ANOVA	Analysis of Variance
ATS	American Thoracic Society
AQG	Air Quality Guidelines
BAM	Beta Attenuation Monitor
BMI	Body Mass Index
BTEX	Benzene, Toluene, Ethylbenzene and Xylene
CFM	Cubic Feet per Minute
CI	Confidence Interval
CO	Carbon Monoxide
CO_2	Carbon Dioxide
CODO	Company Owned Dealer Operate
COPD	Chronic Obstructive Pulmonary Disease
DALYs	Disability-Adjusted Life Years
DODO	Dealer Owned Dealer Operated
DOSH	Department of Occupational Safety and Health
DOSM	Department of Statistics Malaysia
EPA	U.S. Environmental Protection Agency
FEV_1	Forced Expiratory Volume in One Second
FVC	Forced Vital Capacity
GOLD	Global Initiative for Chronic Obstructive Lung Disease
HWE	Healthy Worker Effect
IQR	Interquartile Range
LR	Likelihood Ratio
MLH	Mixing Layer Height
MVV	Maximal Voluntary Ventilation
NAAQS	Malaysia National Ambient Air Quality Standards

NO_2	Nitrogen Dioxide
NO_X	Oxides of Nitrogen
O_3	Ozone
OR	Odds Ratio
OSH	Occupational Safety and Health
PEFR	Peak Expiratory Flow Rate
PEL	Permissible Exposure Limit
PID	Photoionisation Detector
ppb	Parts per Billion
ppm	Parts per Million
$PM_{2.5}$	Fine Particulate Matter
PM_{10}	Coarse Particulate Matter
PPE	Personal Protective Equipment
PR	Prevalence Ratio
RM	Repeated Measures
ROC	Receiver Operating Characteristic
ROS	Reactive Oxygen Species
RR	Relative Risk
SD	Standard Deviation
SO_2	Sulphur Dioxide
SOP	Standard Operating Procedures
TEOM	Tapered Element Oscillating Microbalance
TM	Territory Manager
TVOC	Total Volatile Organic Compounds
VIF	Variance Inflation Factor
VOC	Volatile Organic Compounds
WHO	World Health Organisation
WMD	Weighted Mean Difference

ABSTRAK

PENCEMAR UDARA TERPILIH DAN KESANNYA TERHADAP FUNGSI PARU-PARU DALAM KALANGAN PEKERJA STESEN MINYAK DI JOHOR

Latar Belakang: Pekerja stesen minyak terdedah kepada banyak pencemar udara di tempat kerja mereka. Pencemar udara ini termasuklah jirim zarahan ($PM_{2.5}$ dan PM_{10}) dan sebatian organik meruap (VOC) yang telah terbukti berbahaya kepada kesihatan terutamanya sistem pernafasan. Dengan peningkatan jumlah stesen minyak, polisi layan diri yang tidak dikuat kuasa, dan tiada program keselamatan dan kesihatan khusus, pekerja stesen minyak mungkin mengalami kemerosotan fungsi paru-paru disebabkan pendedahan kepada pencemar udara.

Objektif: Kajian ini bertujuan untuk mengkaji kepekatan min pencemar udara dan kaitannya dengan penyakit pernafasan dalam kalangan pekerja stesen minyak di Johor.

Metodologi: Kajian keratan rentas ini dijalankan dari Januari hingga Disember 2022 di stesen minyak terpilih di Johor yang disampel menggunakan persampelan rawak berstrata mengikut nisbah. Kepekatan $PM_{2.5}$, PM_{10}, dan jumlah sebatian organik meruap diukur. Kemudian, pekerja stesen minyak dari stesen minyak yang terpilih akan di temu ramah berkenaan gejala pernafasan menggunakan borang soal selidik dan mereka akan menjalani ujian fungsi paru-paru. Semua maklumat akan dianalisis secara diskriptif dan pengukuran berulang ujian ANOVA sehala dijalankan untuk mencari perbezaan min dalam kepekatan pencemar udara. Analisis regresi logistik dan regresi linear digunakan untuk mengenalpasti faktor-faktor berkaitan dengan kemorosotan fungsi paru-paru dan parameternya.

Keputusan: Kepekatan min $PM_{2.5}$ and PM_{10} stesen minyak di Johor adalah 93 μg/m^3 untuk $PM_{2.5}$ dan 42.02 μg/m^3 untuk PM_{10}. Ianya tidak melebihi had standard 24 jam dari Pertubuhan Kesihatan Sedunia (WHO) dan Standard Kualiti Udara Ambien Malaysia. Terdapat perbezaan signifikan kepekatan min jirim zarahan antara masa yang berlainan [$F (1.2, 52.6) = 95.587$, $p < 0.001$ untuk $PM_{2.5}$ dan $F (1.2, 53.3) = 158.294$, $p < 0.001$ untuk PM_{10}]. Perbezaan kepekatan min jumlah sebatian organik meruap antara aliran atau situasi kerja yang berlainan juga didapati signifikan [$F (1,43) = 3295.59$, $p < 0.001$]. Sebanyak 93 (38.3%) daripada 243 pekerja stesen minyak mempunyai sekurang-kurangnya satu gejala pernafasan dan batuk adalah gejala pernafasan yang paling kerap dilaporkan (25.9%). Prevalens kemerosotan fungsi paru-paru dalam kalangan pekerja stesen minyak ialah 28.8% dengan kebanyakannya adalah corak paru-paru obstruktif (15.6%). Analisa regresi logistik berganda mendapati bahawa bekerja sebagai juru pam (Adj. OR = 6.75; 95% CI: 2.70, 16.90; $p < 0.001$), tempoh bekerja (Adj. OR = 1.05; 95% CI: 1.01, 1.08; $p = 0.016$), gejala pernafasan (Adj. OR = 13.44; 95% CI: 5.28, 34.23; $p < 0.001$), sejarah kesihatan yang signifikan (Adj. OR = 20.77; 95% CI: 5.57, 77.45; $p < 0.001$) dan kepekatan PM_{10} di tempat kerja (Adj. OR = 1.11; 95% CI: 1.06, 1.16; $p < 0.001$) adalah faktor-faktor berkait dengan kemorosotan fungsi paru-paru.

Kesimpulan: Kemerosotan paru-paru masih berlaku dalam kalangan pekerja stesen minyak di Johor walaupun kepekatan min pencemar udara tidak melebihi had. Ini menunjukan keperluan untuk kajian yang lebih mendalam untuk mngesahkan hubungan antara pencemar udara dan kemerosotan fungsi paru-paru dan keperluan untuk melaksanakan satu program keselamatan dan kesihatan untuk pekerja stesen minyak.

KATA KUNCI: pencemar udara, jirim zarahan, sebatian organik meruap, ujian fungsi paru-paru, stesen minyak

ABSTRACT

SELECTED AIR POLLUTANTS AND THEIR EFFECTS ON LUNG FUNCTION AMONG PETROL STATION WORKERS IN JOHOR

Background: Petrol station workers are exposed to various air pollutants in their workplaces. These air pollutants include particulate matters ($PM_{2.5}$ and PM_{10}) and VOC that were proven hazardous to health, especially respiratory systems. With the increasing number of petrol stations, no enforcement on self-service, and no specific safety and health programmes, petrol station workers may develop abnormal lung function due to exposure to air pollutants.

Objectives: This study aimed to assess the mean concentrations of air pollutants and their associations with respiratory illness among petrol station workers in Johor.

Methodology: This cross-sectional study was conducted from January to December 2022 at selected petrol stations in Johor sampled using proportionate stratified random sampling. The concentrations of $PM_{2.5}$, PM_{10}, and TVOC at the petrol stations were measured. Subsequently, workers from the selected petrol stations were interviewed regarding respiratory symptoms using standardised questionnaires and underwent the lung function test. All data were analysed descriptively, and the One-way Repeated Measures ANOVA test was conducted to look for the mean differences in air pollutants concentrations. Logistic and linear regression analyses were used to identify associated factors of abnormal lung function and its parameters.

Results: The mean concentrations of $PM_{2.5}$ and PM_{10} at the petrol stations in Johor were 12.93 $\mu g/m^3$ and 42.02 $\mu g/m^3$, respectively, which did not exceed the 24-hour standard of WHO and NAAQS. There were significant mean differences in particulate matter concentrations between the different periods of the day [F (1.2, 52.6) = 95.587, $p < 0.001$ for $PM_{2.5}$ and F (1.2, 53.3) = 158.294, $p < 0.001$ for PM_{10}]. Mean differences in TVOC concentrations between various work processes or conditions were also found to be significant [F (1,43) = 3295.59, $p < 0.001$]. Ninety-three (38.3%) out of 243 petrol station workers had at least one respiratory symptom in which cough was the most commonly reported (25.9%). The prevalence of abnormal lung function among petrol station workers was 28.8%, predominantly obstructive impairment pattern (15.6%). Multiple logistic regression revealed that being a pump attendant (Adj. OR = 6.75; 95% CI: 2.70, 16.90; $p < 0.001$), duration of employment (Adj. OR = 1.05; 95% CI: 1.01, 1.08; p = 0.016), respiratory symptoms (Adj. OR = 13.44; 95% CI: 5.28, 34.23; $p < 0.001$), significant past medical history (Adj. OR = 20.77; 95% CI: 5.57, 77.45; $p < 0.001$) and workplace PM_{10} concentration (Adj. OR = 1.11; 95% CI: 1.06, 1.16; $p < 0.001$) were significantly associated with abnormal lung function.

Conclusion: Abnormal lung function was quite prevalent among petrol station workers in Johor, even though the mean concentrations of air pollutants did not exceed the standard. This warranted more confirmatory studies to establish the causal relationship between air pollutants and abnormal lung function and the development of safety and health programmes for petrol station workers.

KEYWORDS: air pollutants, particulate matter, VOC, lung function test, petrol station

CHAPTER 1

INTRODUCTION

1.1 Background

1.1.1 Petrol stations in Malaysia

A petrol station is a facility that sells fuel and engine lubricants for motor vehicles. It is considered a downstream service in the petroleum industry. The term petrol station is interchangeable with many terms such as fuelling station, gas station, gas bar, gasoline stand, service station, servo, fuel station, and petrol bunk. In Malaysia, there are three types of petrol stations described by the Ministry of Domestic Trade and Consumer Affairs Malaysia (2019):

i. Petrol Station / Petrol Service Station: A facility that sells fuel and lubricants for motor vehicles. It may include a convenience store, a car wash centre, and a fast-food restaurant. Its received supply from major fuel suppliers in Malaysia includes Petronas, Shell, Petron, Caltex, BHPetrol, and Xcel.
ii. Mini Petrol Station: A small-scaled petrol station in terms of capital, business sites, and operating in rural or remote areas for rural residents' convenience. According to the government-designated supplier company's operating zone, it obtained petroleum supply from fuel supplier companies like Buraqoil, Smart, and Teguh.

iii. Portable Container System: Portable petrol stations for the temporary supply of petroleum materials located in areas permitted by the government.

Petrol station ownership in Malaysia is based on two dealers' programmes known as CODO (company owned dealer operated) and DODO (dealer owned dealer operated). In CODO, petrol stations are owned by fuel supplier companies and entrepreneurs (dealers) appointed by the companies. As opposed to the DODO programme, petrol stations are fully funded and wholly owned by individuals and companies (dealers) (Ministry of Domestic Trade and Consumer Affairs Malaysia, 2019). In Malaysia, there is no standard guideline for operation hours for petrol stations and their workers. Generally, petrol stations in Malaysia operate either for 18 hours (6 am to 12 am) or 24 hours a day. Petrol station workers work 8 hours per shift in a day, and the number of shifts depends on the operating time of the petrol stations (three shifts per day for 24-hour petrol stations and two shifts per day for 18-hour petrol stations).

1.1.2 Air pollution and petrol stations

Air pollution refers to the emission of harmful pollutants into the atmosphere that are hazardous to human health and the environment. Both ambient (outdoor) air pollution and household (indoor) air pollution are considered the most significant single environmental risk for health, climate, and sustainable development (WHO, 2015). The burden of air pollution trends is changing from household air pollution to ambient air pollution. It is evident by the decreasing number of deaths attributable to household air pollution in low-income countries. Since 1990, liquefied petroleum gas and renewable energy sources have replaced biomass (wood, straw, and manure) as domestic cooking and heating fuels. At the same time, ambient air pollution is becoming a major concern due to the uncontrolled development of megacities, rapid industrialisation, widespread use of pesticides and chemicals, and increased use of motor vehicles (Landrigan, 2017).

From 1960 to 2009, the global mean population-weighted fine particulate matter ($PM_{2.5}$) concentrations increased by 38%, which was highly attributed to increases in China and India. The same pattern was seen in coarse particulate matter (PM_{10}), where China and India showed increasing PM_{10} concentrations, although developed countries like the United States of America showed a decreasing trend (Butt *et al.*, 2017; Yang *et al.*, 2018). Regionally, the trends of particulate matter from 2008 to 2013 showed a more than 5% increase among countries in South-East Asia and Western Pacific (low-middle income) regions (WHO, 2016). Based on Malaysia's Environmental Quality Report, the annual mean concentrations of ambient PM_{10} and $PM_{2.5}$ in 2018 were 24 $\mu g/m^3$ and 19 $\mu g/m^3$, respectively. Based on the current standards set by the National Ambient Air Quality Standard (NAAQS) and WHO, the annual mean concentration of $PM_{2.5}$ in Malaysia exceeded both standards, while the annual mean concentration of PM_{10} only exceeded the WHO's standard but not the NAAQS. (Department of Environment Malaysia, 2019).

Workers at petrol stations are exposed to various types of air pollutants while at work. The partial burning of engine fuel and the volatilisation of organic compounds from the fuel were the main sources of pollutants in the petrol station environment. Many studies have shown the presence of air pollutants in petrol stations, such as particulate matter ($PM_{2.5}$ and PM_{10}), VOC (benzene, xylene, and toluene), carbon monoxide (CO), and oxides of nitrogen (NO_X). The high exposures to air pollutants among petrol station workers as compared to other outdoor workers were evident in a study by Han (2004) that describes the exposure level of traffic-related air pollutants among outdoor workers, which includes drivers, vendors, traffic police, and petrol station attendants in Trujillo, Peru. The findings in the study showed that petrol stations attendants were exposed to the highest level of VOC compared to other workers as their mean concentration of BTEX (benzene, toluene, ethylbenzene, and xylene) exposures were the highest (111 $\mu g/m^3$, 254 $\mu g/m^3$, 43 $\mu g/m^3$ and 214 $\mu g/m^3$ respectively). In comparing the exposure of VOC among petrol station workers with taxi drivers in Iran, Bahrami *et al*. (2007) conducted a study that measures benzene concentrations in air and urinary levels of trans,trans-muconic acid (t,t-MA) (a urinary metabolite of benzene). The findings showed that there were significant differences in mean (SD) concentrations of benzene between petrol station workers and taxi drivers, which were 1.40 (0.80) ppm and 0.31 (0.22) ppm, respectively. Furthermore, the same study also showed a significant and strong positive correlation between urinary t,t-MA, and benzene among petrol station workers ($r = 0.65$; $p < 0.05$).

1.1.3 Health impacts of air pollutants

In 2015, according to the Global Burden of Diseases Study, exposure to ambient air pollution was the fifth leading risk factor for death worldwide, contributing to 4.2 million deaths (7.6% of total global deaths) and 103.1 million disability-adjusted life-years (DALYs) (4.2% of global DALYs) (Cohen *et al.*, 2017). In Malaysia, the total number of premature deaths associated with long-term exposure to $PM_{2.5}$ was 14525 (95% CI: 9665, 18891) (Pahrol *et al.*, 2019). In addition, PM_{10} was responsible for 1491774 (95% CI: 972770, 1960303) premature deaths (age > 30) in 190 Chinese cities between 2014 and 2015. During the same period, it also caused 3,614,064 cases of chronic bronchitis, 13,759,894 cases of asthmatic attacks, 19,1709 chronic obstructive pulmonary diseases (COPD) related hospital admission cases, 499,048 respiratory-related hospital admission, 357,816 cerebrovascular hospital admission, and 308,129 cardiovascular-related hospital admission (Maji *et al.*, 2017). A scooping review of studies that evaluated lung function parameters of petrol station workers found that 25 studies revealed that the forced vital capacity (FVC), forced expiratory volume in one second (FEV_1), FEV_1/FVC ratio, and peak expiratory flow rate (PEFR) of petrol station workers were significantly lower compared to control groups (Razak *et al.*, 2021).

1.2 Problem Statement

Traffic volumes in Malaysia have increased steadily as a consequence of rapid urbanisation and population expansion. According to the Ministry of Works Malaysia (2018), there was a steady and gradual growth of 16-hour traffic volumes in Johor from 2008 until 2017. There was a 2.8% increase in traffic volumes, equivalent to 75,300 vehicles in 2017, as compared to 2016 (Figure 1.1). Although seasonal, episodic, and transboundary air pollution is observed in Malaysia, motor vehicle emissions are the main sources of air pollution, especially in urban areas (Sahani *et al.*, 2016). The government has already carried out numerous initiatives and efforts to reduce traffic and motor vehicle emissions, including improving public transportation infrastructure, using green energy, and organising carpooling programmes. However, because of the increased traffic, more new petrol stations are being developed to meet the rising demand for fuel, evidenced by a 24.07% increase in the number of petrol services stations in Malaysia from 2,883 in 2017 to 3,577 in February 2020 (Ministry of Domestic Trade and Consumer Affairs Malaysia, 2020).

Even though the self-service policy was introduced in 1996, there is no mandatory enforcement, causing pump attendants to still be hired. This demands the need to evaluate the health of petrol station workers as they are potentially exposed to air pollution from motor vehicle emissions and hazardous chemicals from the fuel itself. Internationally, due to ample evidence from previous studies that showed the hazardous air pollutants in the petrol station's environment and their relationship with respiratory illness, a range of countries have imposed legislation, policies, or programmes to protect the health of petrol station workers. For example, in Thailand, through its Fuel Oil Vapour Recovery Act, all petrol service stations are mandatory to install a vapour recovery system (VRS) that is essential in reducing the emission of volatile organic compounds (VOC) during storage, transfer, and refuelling activities (Vapour Recovery Act, 2007). Other countries and regions like Australia, European Union, Hong Kong, and Canada are also implementing the same action by enforcing the mandatory VRS in petrol station services. Although there are general safety and health guidelines and programmes in Malaysia, they are not specifically tailored to petrol station workers. As a result, these workers are left without adequate protection. No effective surveillance systems, guidelines, or safe operating procedures specifically address the health of petrol station workers, causing many health impacts caused by air pollutants to remain undetected and uncounted.

A closer review of the previous studies revealed significant gaps and inadequacies. In Malaysia, there is a growing demand and potential for research on the effects of air pollutants on petrol station workers. Based on the literature review, there were limited local studies that determined the concentrations of air pollutants at the petrol station, and to the best of our knowledge, this study was the first in Malaysia to identify any respiratory illness that may arise from that, as far as publication is concerned.

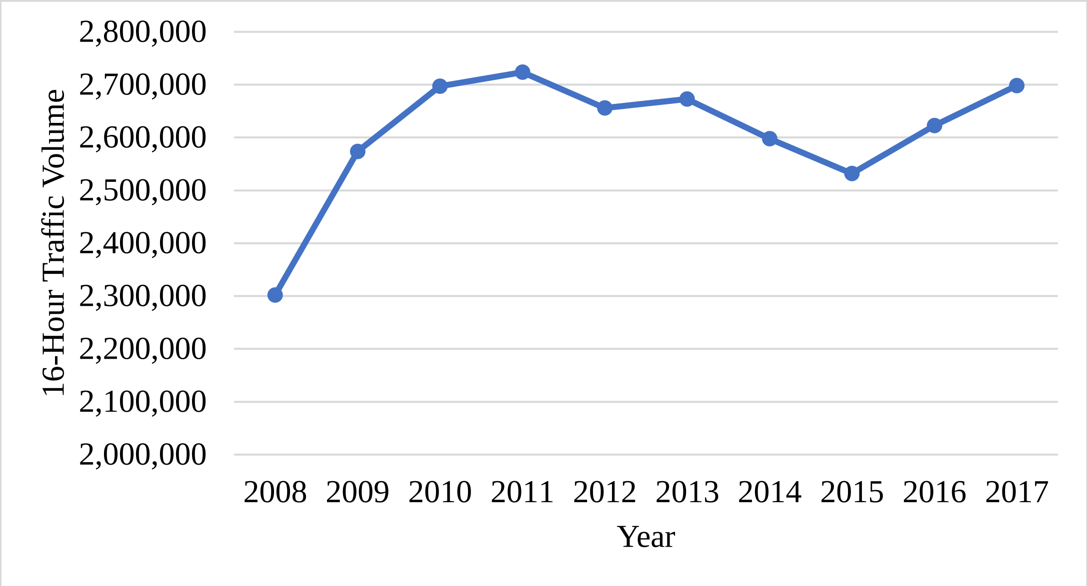

Figure 1.1: 16-Hour traffic volume in Johor, Malaysia from 2008 until 2017 (Ministry of Works Malaysia, 2018)

1.3 Rationale

It is crucial to explore the magnitude and depth of petrol station workers' safety and health issues, given that their services are still needed at petrol stations. The study will give an overview of potential respiratory illness due to exposure to air pollutants at petrol stations and its associated factors. The information is essential to develop a safety and health programme for petrol station workers that is adequate, effective, and practical to minimise the risk of respiratory illness among petrol station workers.

Due to limited local research on this particular topic, this study's results are needed as a basis for future research to be planned accordingly, ultimately enhancing the current knowledge. Subsequently, a causal link between air pollutants and abnormal lung function among petrol station workers can be demonstrated. Thus, preventive efforts can be done on a much larger scale and not limited to a particular petrol station. This includes enforcing and reviewing policies and legislation related to petrol station workers' safety and health.

1.4 Research questions

1. What are the mean concentrations of $PM_{2.5}$ and PM_{10} in the petrol station environment?
2. Are there any differences in mean concentrations of $PM_{2.5}$ and PM_{10} between morning, afternoon, and evening?
3. Are there any differences in mean concentrations of total volatile organic compounds (TVOC) between various work processes/working conditions?
4. Which respiratory symptoms are most experienced by the petrol station workers?
5. What are the prevalence and factors associated with abnormal lung function among petrol station workers?
6. What are the predictors of lung function parameters (FVC, FEV_1, FEV_1/FVC) among petrol station workers?

1.5 Objectives

1.5.1 General objective

To determine the level of air pollutants and their association with the development of respiratory illness among petrol station workers in Johor.

1.5.2 Specific objectives

1.5.2.1 Part 1: Air pollutants parameter

1. To determine the mean concentrations of particulate matter ($PM_{2.5}$ and PM_{10}) in the petrol station's environment.
2. To determine the mean differences in particulate matter concentrations ($PM_{2.5}$ and PM_{10}) at the petrol stations between different periods of the day.
3. To determine the mean differences in TVOC concentrations between various work processes or conditions.

1.5.2.1 Part 2: Respiratory illness and its associated factors

4. To describe the work-related respiratory symptoms (cough, phlegm, chest tightness, dyspnoea, chest pain, and wheezing) and lung function parameters (FEV_1, FVC, FEV_1/FVC) among petrol station workers in Johor.
5. To estimate the proportion and determine factors associated (sociodemographic/individual characteristics, occupational factors, workplace factors, and environmental/air pollutants factors) with abnormal lung function among petrol station workers in Johor.
6. To determine the relationship between lung function parameters (FVC, FEV_1, FEV_1/FVC) and associated factors (sociodemographic/individual characteristics, occupational factors, workplace factors, and environmental/air pollutants factors) among petrol station workers in Johor.

1.6 Research hypotheses

The objectives of this study are to test the following hypotheses:

1. There are significant mean differences in particulate matter concentrations ($PM_{2.5}$ & PM_{10}) at the petrol station between different periods of the day.
2. There are significant mean differences in TVOC concentrations between various work processes or conditions.
3. There are significant associations between abnormal lung function with sociodemographic/individual characteristics, occupational factors, workplace factors, and environmental/air pollutants factors among petrol station workers.
4. There are significant relationships between lung function parameters (FVC, FEV_1, FEV_1/FVC) with sociodemographic/individual characteristics, occupational factors, workplace factors, and environmental/air pollutants factors among petrol station workers.

CHAPTER 2

LITERATURE REVIEW

2.1 Air pollution

2.1.1 Background

Clean air is essential for human health and is often considered a basic human right. However, air pollution continues to pose a significant threat to humans globally and has become one of the important world agendas. Many goals in the United Nations' Sustainable Development Goals (SDG) are related to air pollution; specifically, SDG 3.9 targets "substantially reduce the number of deaths and illnesses from hazardous chemicals and air, water and soil pollution and contamination" by 2030 (United Nations, 2023). WHO defined air pollution as contamination of the indoor or outdoor environment by any chemical, physical or biological agent that modifies the natural characteristics of the atmosphere (WHO, 2023).

Air pollution is a major environmental issue that poses significant risks to human health and the environment. Air pollution's impact on human health can be short-term or long-term. For short-term effects, it can irritate the nose, throat and lungs, causing wheezing, coughing, chest tightness, shortness of breath, pneumonia, bronchitis and exacerbation of asthma. It also can irritate the skin and eyes and cause headaches, nausea, and dizziness. In the long term, air pollution mainly affects the respiratory system, which it can cause respiratory diseases such as COPD, asthma, bronchiolitis, and lung cancer. Air pollution can also cause cardiovascular events, central nervous system dysfunctions, and cutaneous diseases. Apart from that, climate change resulting from environmental pollution affects the geographical distribution of many infectious diseases and natural disasters (Manisalidis *et al.*, 2020).

2.1.2 The layer of the atmosphere

The Earth’s atmosphere consists of a mixture of gases forming a thin air layer surrounding the planet. It is tied to the Earth by gravitational force and magnetic field at high altitudes, extending from the Earth's surface to the edge of space. The main composition of the atmosphere is molecular nitrogen (78%) and molecular oxygen (21%), along with 1% of trace gases like carbon dioxide, ozone and water vapour. There are differences in the composition, temperature, and electromagnetic properties of the atmosphere, causing it to be divided into layers (Tourpali *et al.*, 2016)

The Earth’s atmosphere has five major and several layers. From lowest to highest, the major layers are the troposphere, stratosphere, mesosphere, thermosphere and exosphere. Troposphere, also known as the lower atmosphere, extends from Earth’s surface to about 12 kilometres, with its height lower at Earth’s poles and higher at the equator. Most heat in the troposphere is generated from Earth’s surface, causing the temperature to decrease with height. The troposphere is the densest atmospheric layer, and gaseous composition in this layer is essential for all living being on the surface, where the density of the gases decreases with height. The majority of Earth’s weather occurs here, and almost all clouds that are generated by weather are found here.

Next is the stratosphere, approximately 12 and 50 kilometres above Earth’s surface. It is known for its ozone layer, which protects the Earth’s surface from ultraviolet radiation. In this layer, the temperature increases with the height where the heat is generated from the ozone formation process. The warmer air above the cooler air prevents convection, as there is no upward vertical movement of the gases.

Mesosphere is located between about 50 and 80 kilometres above Earth's surface. The gases in this layer become denser with the altitude as it is thick enough to burn up most meteors. The temperature progressively reduces with altitude, and the average temperature at the top of this layer is about -85 ^{o}C. The stratosphere and mesosphere are considered the middle atmosphere, separated by a transition boundary layer called the stratopause.

Above the mesosphere is a layer called the thermosphere, located about 80 and 700 kilometres above Earth's surface, where the lowest part contains the ionosphere. No cloud and water vapour exist in this layer, and the International Space Station orbits here. A very low density of molecules is found here, and the gases become increasingly less dense with altitude. In terms of the temperature, it increases with altitude generated by the absorption of high energy ultraviolet and x-ray radiation from the sun

Exosphere is the last layer of the Earth's atmosphere before the edge of space. It is located between about 700 and 10,000 kilometres above Earth's surface and merges with the solar wind at the top of the layer. Molecules found here are highly low-density, and molecules escape into space. Most Earth satellites orbit in the exosphere. At the bottom of the exosphere is a transition layer called thermopause (Center for Science Education, 2023; National Oceanic and Atmospheric Administration, 2022; Tourpali *et al.*, 2016).

2.1.3 Air pollutants and their sources

Air pollutants can be classified as primary and secondary pollutants based on their origin. Primary pollutants are substances that are directly emitted into the atmosphere from their sources (Daly and Zannetti, 2007). The sources of air pollutants differ from each other. In Malaysia, the Department of Environment reported that motor vehicles were the highest contributor to CO (95.7%) in 2020. For NO_2, the emission load were contributed by power plants (62%), followed by motor vehicles (24%), industries (9%), and others (5%). The highest contributors to SO_2 were power plants (63%), followed by other categories (26%), industries (6%) and motor vehicles (5%). As for PM, it were mainly contributed by power plants (39%), followed by industries (29%), motor vehicles (12%) and others (20%)(Department of Environment Malaysia, 2020).

Meanwhile, secondary pollutants are pollutants that are formed in the atmosphere from the reaction of primary pollutants (also known as precursors). The examples of secondary air pollutants are as follows:

i. Nitrogen dioxide (NO_2) and nitric acid (HNO_3) formed from nitric oxide (NO)
ii. Ozone (O_3) formed from photochemical reactions of nitrogen oxides and VOC
iii. Sulfuric acid droplets formed from sulfur dioxide (SO_2)
iv. Nitric acid droplets formed from nitrogen dioxide (NO_2)
v. Sulfates and nitrates aerosols formed from reactions of sulfuric acid droplets and nitric acid droplets with ammonia (NH_3), respectively
vi. Organic aerosols formed from VOC in gas-to-particle reactions

The depositions of these secondary pollutants were known to cause hazardous conditions like photochemical smog and acid rain (Daly and Zannetti, 2007).

The type of air pollutants differs based on the air pollutants' location and source. For example, primary pollutants pollute indoor environments, like inside a convenience store, whereas primary and secondary air pollutants pollute outdoor environments.

2.1.4 Air pollution standards and monitoring

2.1.4.1 WHO Air quality guidelines (AQG)

Governments throughout the world are working to enhance air quality and lower the public health burden and costs associated with air pollution due to the large and growing burden of disease linked with exposure to both ambient and household air pollution. Through the latest update of AQG in 2021, WHO offer a quantitative, evidence-based recommendation for levels of key air pollutants to reduce health risks which include sulphur dioxide (SO_2), $PM_{2.5}$, PM_{10}, ozone (O_3), nitrogen dioxide (NO_2), and carbon monoxide (CO)(Table 2.1). Even though it is not legally bound, it served as a global guide for governments, policy-makers, and public health professionals to improve air quality standards and subsequently protect public health (WHO, 2021).

2.1.4.2 Malaysia National ambient air quality standards (NAAQS)

Malaysia NAAQS adopted the WHO AQG, in which six similar air pollutants criteria are included in the standard. From 2015, the air pollutants concentration limit was strengthened in stages until 2020. Malaysia Department of Environment (DOE), which oversee the implementation of the NAAQS, set 3 interim targets, which include interim target 1 (IT-1) in 2015, interim target 2 (IT-2) in 2018 and the full implementation of the standard in 2020. Table 2.1 summarises the air pollutants concentrations for WHO AQG and Malaysia NAAQS (Department of Environment Malaysia, 2013).

Table 2.1: Recommended WHO AQG and Malaysia NAAQS concentrations limit for key air pollutants (adopted from the Department of Environment Malaysia (2013) and WHO (2021)

Pollutant	**Averaging Time**	**WHO AQG (2021)**	**Malaysia NAAQS (2020)**
$PM_{2.5}$ (µg/m^3)	Annual	5	15
	24-hour	15	35
PM_{10} (µg/m^3)	Annual	15	40
	24-hour	45	100
O_3 (µg/m^3)	Peak season	60	-
	8-hour	100	100
	1-hour	-	180
NO_2 (µg/m^3)	Annual	10	-
	24-hour	25	70
	1-hour	200	280
SO_2 (µg/m^3)	24-hour	40	80
	1-hour	-	250
CO (mg/m^3)	24-hour	4	-
	8-hour	10	10
	1-hour	35	30

2.1.4.3 Air pollutants index (API)

API is used as a standardised system to quantify air quality in Malaysia. It is calculated based on the Pollution Standard Index (PSI) that has been accepted at the international level by the United States Environmental Protection Agency (USEPA) using the measurement of six air pollutant parameters that include SO_2, $PM_{2.5}$, PM_{10}, O_3, NO_2, and CO. The higher API values indicate greater air pollution and increased potential for adverse health effects. It is divided into six categories which are 0-50 (good), 51-100 (moderate), 101-200 (unhealthy – for the sensitive group), 201-300 (very unhealthy), > 300 (hazardous) and > 500 (emergency). Every API category was accompanied by specific health effects information and advice. The Department of Environment (DOE) monitors and reports the API through its Air Pollutant Index of Malaysia (APIMS) system. It is reported daily to inform the public and allow them to take necessary precautions to protect their health when the air quality is poor (Department of Environment Malaysia, 2023).

2.1.4.4 Industry code of practice (ICOP) on indoor air quality (IAQ)

Malaysia Department of Safety and Health (DOSH) released an ICOP concerning air quality for indoor air pollutants in 2010 as one of the general duties as prescribed under the Occupational Safety and Health Act 1994 (Act 514) for the employer, and an occupier (including building owner and building management) is to provide a safe workplace to their employees or other people than his employees (occupant). This ICOP on IAQ recommends enhancing indoor air quality and establishes minimum standards for a few parameters that prevent workers and other occupants of indoor or enclosed environments served by mechanical ventilating and air conditioning (MVAC) systems from harmful health effects. The IAQ assessment involved measurements of the specific physical parameters (Table 2.2), measurements of indoor air pollutants (Table 2.3), symptoms, and walkthrough surveys. The assessor will recommend appropriate control measures if the IAQ is not acceptable to avoid any potentially harmful health effects (Department of Occupational Safety and Health [DOSH] Malaysia, 2010).

Table 2.2: Acceptable range for specific physical parameters

Parameter	Acceptable Range
Air Temperature	23 – 26 ^{o}C
Relative Humidity	40 – 70%
Air Movement	0.15 – 0.50 m/s

Table 2.3: List of indoor air contaminants and the acceptable limits

Indoor Air Contaminants	Acceptable limits		
	ppm	mg/m^3	cfu/m^3
Chemical contaminants*			
Carbon monoxide	10	-	-
Formaldehyde	0.1	-	-
Ozone	0.05	-	-
Respirable particulates	-	0.15	-
TVOC	3	-	-
Biological contaminants			
Total bacterial counts	-	-	500
Total fungal counts	-	-	1000
Ventilation performance indicator			
Carbon dioxide	C1000**	-	-

* Eight-hour time-weighted average airborne concentrations
** Ceiling limit

2.2 Particulate matter

2.2.1 Background

Particulate matter is a heterogeneous combination of solid and liquid particles suspended in the air that vary in size and composition and can be originated from chemical or biological components. It is a common proxy indicator for air pollution alongside ground-level ozone (O_3), carbon dioxide (CO_2), carbon monoxide (CO), nitrogen dioxide (NO_2), and sulphur dioxide (SO_2). The most common way to classify particulate matter is based on its dynamic diameter (size), which describes its transportability in the atmosphere and inhaling ability through a respiratory organism (WHO, 2013). Based on its size, it is divided into fine particulate matter ($PM_{2.5}$) and coarse particulate matter (PM_{10}).

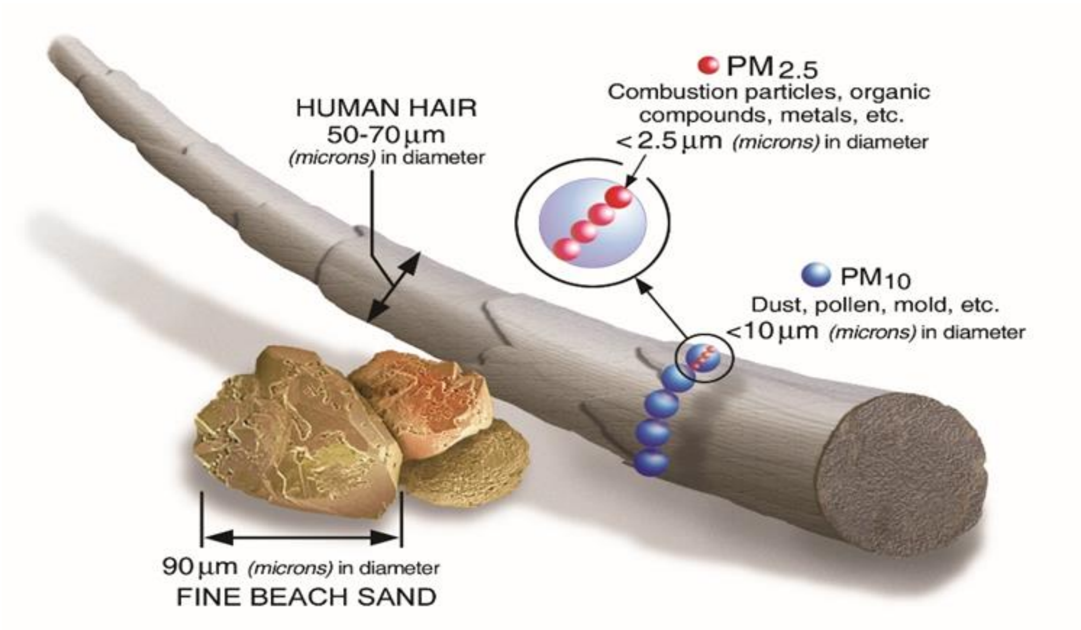

Figure 2.1: Size comparisons between particulate matter, human hair, and fine beach sand (adopted from U.S. Environmental Protection Agency [EPA], 2020)

$PM_{2.5}$ and PM_{10} differ in many ways, and Table 2.4 shows the characteristics and differences between the two types of particulate matters (Department of Environment Malaysia, 2013; K.-H. Kim *et al.*, 2015; WHO, 2013).

Table 2.4: Characteristics and differences between $PM_{2.5}$ and PM_{10}

Characteristics	**Fine particulate matter ($PM_{2.5}$)**	**Coarse particulate matter (PM_{10})**
Diameter	Less than 2.5 μm	Less than 10 μm
Components	Sulfate (SO_{2-4}); nitrate ($NO-_3$); ammonium (NH_{+4}); hydrogen ion (H+); elemental carbon (C); organic compounds; polycyclic aromatic hydrocarbons (PAH); metals (Pb, Cd, V, Ni, Cu, Zn); particle-bound water, and biogenic organics.	Resuspended dust; soil dust, street dust; coal and oil fly ash; pollen; mould spores; plant parts; and metal oxides of Si, Al, Mg, Ti, Fe, $CaCO_3$, NaCl, and sea salt.
Sources	Combustion of coal, oil, and gasoline; transformation products of NO_X, SO_2, and organics, including biogenic organics like terpenes; high-temperature processes; smelters, and steel mills	Resuspension of soil tracked onto roads and streets; suspension from disturbed soils from farming and mining; resuspension of industrial dust; construction, coal and oil combustion, and ocean spray.
Duration suspended in the air	Days to weeks	Minutes to hours
Travel distance	100 to 1000 kilometres	1 to10 kilometres
NAAQS*	35 μg/m^3 (24H) 15 μg/m^3 (Annual)	100 μg/m^3 (24H) 40 μg/m^3 (Annual)
WHO Standard	25 μg/m^3 (24H) 10 μg/m^3 (Annual)	50 μg/m^3 (24H) 20 μg/m^3 (Annual)

* National Ambient Air Quality Standard
# Fine particles with a diameter less than 0.1 μm are categorised as ultra-fine particles ($PM_{0.1}$)

2.2.2 Health impacts of particulate matter

The particulate size is directly linked to being the main cause of health problems. The smaller a particulate, the deeper it will penetrate and deposit on the respiratory tract, as illustrated in Figure 2.2. The deposition of these particulates and their components will subsequently cause respiratory illness through various mechanisms, including airway injury and inflammation; production of reactive oxygen species (ROS); genotoxic effects; cell membrane disruption; and involvement in oxidative stress and proinflammatory cytokines. (K.-H. Kim *et al.*, 2015).

For an adult, short-term and long-term exposure to particulate matter causes various cardiovascular and respiratory morbidity, such as aggravation of asthma, respiratory symptoms, and increased hospital admissions. Particulate matter is also associated with mortality from cardiovascular and respiratory diseases and lung cancer (WHO, 2013).

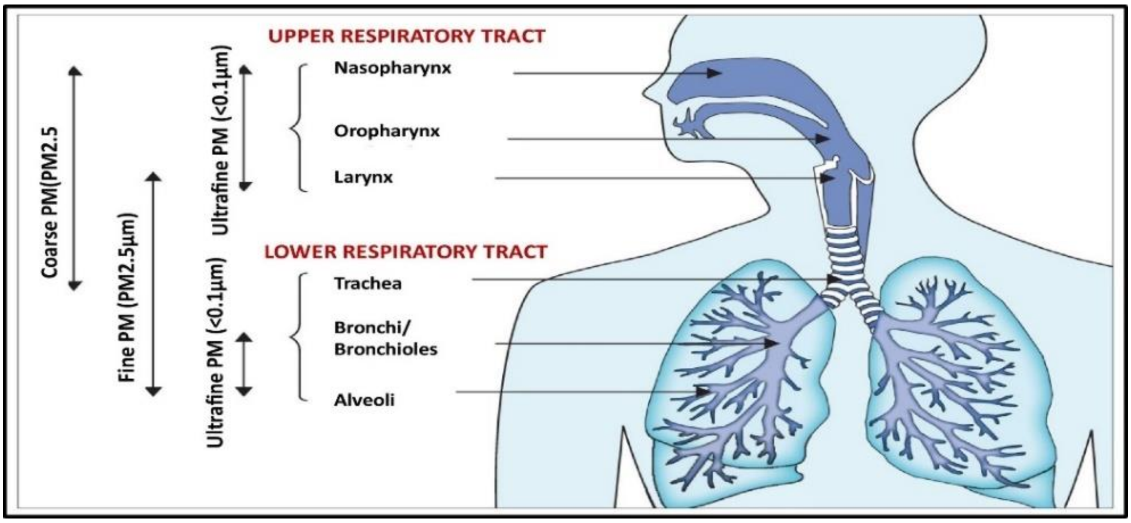

Figure 2.2: Compartmental deposition of particulate matter in different size fractions on the respiratory tract (adopted from Zoran *et al*., 2020)

2.2.3 Particulate matter in the petrol station environment

Several studies have investigated particulate matter concentrations in the petrol station environment using various measurement methods. In 2015, a study by Adebiyi *et al*. (2015) using continuous area sampling for 11 hours in four petrol stations in Nigeria revealed that the mean (SD) concentrations of PM_{10} and $PM_{2.5}$ were 100.50 (21.00) $\mu g/m^3$ and 30.75 (12.26) $\mu g/m^3$ respectively in which exceed WHO's 24-hours standard. Another study done in five petrol stations in India using fixed sampling stations of approximately 1.4 km to 2.8 km from petrol station showed that in 24 hours, the concentration ranges between 86 to 231.00 $\mu g/m^3$ for PM_{10} and 54 to 105.00 $\mu g/m^3$ for $PM_{2.5}$. The study also examined the concentration of different air pollutants, including sulphur dioxide (SO_2), oxides of nitrogen (NO_X), benzene, toluene, and xylene. All measurements, including particulate matter, exceeded the permissible limit of the National Indian Standard except for SO_2 and NO_X (Chaurasia and Tiwari, 2017).

In Malaysia, there was a personal monitoring study conducted among petrol station workers in 12 petrol stations where the result showed the mean (SD) concentration of PM_{10} among 31 pump attendants was 1.85 (0.68) $\mu g/m^3$, which was lower than the exposure limit (Alias, 2010). However, this study was conducted over a decade ago and limited to the petrol station located along highways, which may not represent the current situation.

2.3 Volatile organic compounds (VOC)

2.3.1 Background

VOC, also referred to as solvents, are organic compounds that evaporate quickly at room temperature. A VOC is an organic compound with an initial boiling point of less than or equal to 250°C measured at a standard atmospheric pressure of 101.3 kPa. The higher the volatility or the lower the boiling point, the more likely the compound will be emitted from a product or surface into the air. Classically, it can be further classified into three groups based on its volatility capability, as listed in Table 2.5 (U.S. Environmental Protection Agency [EPA], 2017).

Table 2.5: Classification of volatile organic compounds (adopted from U.S. Environmental Protection Agency [EPA], 2017)

Description	**Boiling Point Range (°C)**	**Example Compounds**
Very Volatile Organic Compounds (VVOC)	< 0 to (50-100)	Propane, butane, methyl chloride
Volatile Organic Compounds (VOC)	(50-100) to (240-260)	Formaldehyde, d-limonene, toluene, acetone, ethanol (ethyl alcohol), 2-propanol (isopropyl alcohol), hexanal
Semi-Volatile Organic Compounds (SVOC)	(240-260) to (380-400)	Pesticides (DDT, chlordane), plasticizers (phthalates), fire retardants (PCBs, PBB)
Total Volatile Organic Compounds (TVOC)	The sum of all compounds listed above	

The emission source of VOC into the environment can be divided into anthropogenic or biogenic sources. In biogenic sources, the VOC is naturally emitted from various plants, soil, and vegetation fires. Approximately 90% of VOC emitted into the environment are biogenic. However, they are emitted in low concentration and have a mechanism for natural degradation. As opposed to anthropogenic sources, they are the byproducts of human activities like the energy production industry, solvent evaporation, waste treatment and disposal, and agriculture. They are usually emitted in high concentrations, causing them to become the main concern for air pollution (Vandenbroucke, 2015). Table 2.6 shows examples of VOC and their characteristic sources.

Table 2.6: Common VOC in urban environments with their characteristic sources (adopted from Simpson & Volosciuk, 2019)

Compounds	**Characteristic Sources**
Ethane	Natural gas, biomass burning
Acetylene	Vehicle emissions, biomass burning
Methanol	Plants, VOC oxidation
Propane	Liquefied petroleum gas, natural gas
Benzene	Industrial emissions, vehicle emissions, biomass burning
Butane	Vehicle emissions, liquefied petroleum gas
Ethanol	Plants, biofuel
Pentane	Vehicle emissions, gasoline evaporation
Toluene	Solvents, vehicle emissions
Ethene	Vehicle emissions
Formaldehyde	VOC oxidation, biomass burning
Isoprene	Plants