ASSOCIATION BETWEEN PM2.5 CONCENTRATIONS AND HOSPITALIZATION CASES FOR SCHIZOPHRENIA AND MOOD DISORDERS IN HO CHI MINH CITY, VIETNAM FROM 2019 TO 2020

Miss Do Thi Hoai Thuong

A Thesis Submitted in Partial Fulfillment of the Requirements
for the Degree of Master of Public Health in Public Health
Common Course
COLLEGE OF PUBLIC HEALTH SCIENCES
Chulalongkorn University
Academic Year 2020

ความสัมพันธ์ระหว่างปริมาณฝุ่นขนาดเล็กที่มีเส้นผ่านศูนย์กลางขนาด 2.5 ไมครอน
และการเข้ารับ การรักษาในโรงพยาบาลด้วยโรคจิตเภทและโรคทางอารมณ์ ในเมืองโฮจิมินห์ซิตี้
ประเทศเวียดนาม ระหว่างปี ค.ศ. 2019-2020

น.ส.ดู ธิ ฮวย ตรุง

วิทยานิพนธ์นี้เป็นส่วนหนึ่งของการศึกษาตามหลักสูตรปริญญาสาธารณสุขศาสตรมหาบัณฑิต
สาขาวิชาสาธารณสุขศาสตร์ ไม่สังกัดภาควิชา/เทียบเท่า
วิทยาลัยวิทยาศาสตร์สาธารณสุข จุฬาลงกรณ์มหาวิทยาลัย
ปีการศึกษา 2563

Thesis Title	ASSOCIATION BETWEEN PM2.5 CONCENTRATIONS AND HOSPITALIZATION CASES FOR SCHIZOPHRENIA AND MOOD DISORDERS IN HO CHI MINH CITY, VIETNAM FROM 2019 TO 2020
By	Miss Do Thi Hoai Thuong
Field of Study	Public Health
Thesis Advisor	KRAIWUTH KALLAWICHA, Ph.D.

Accepted by the COLLEGE OF PUBLIC HEALTH SCIENCES, Chulalongkorn University in Partial Fulfillment of the Requirement for the Master of Public Health

.... Dean of the COLLEGE OF PUBLIC HEALTH SCIENCES
(Professor SATHIRAKORN PONGPANICH, Ph.D.)

THESIS COMMITTEE

.... Chairman
(Associate Professor WATTASIT SIRIWONG, Ph.D.)

.... Thesis Advisor
(KRAIWUTH KALLAWICHA, Ph.D.)

.... External Examiner
(Arthit Phosri, Ph.D.)

ดู ธิ ฮวย ตรุง : *ความสัมพันธ์ระหว่างปริมาณฝุ่นขนาดเล็กที่มีเส้นผ่านศูนย์กลางขนาด 2.5 ไมครอน และการเข้ารับการรักษาในโรงพยาบาลด้วยโรคจิตเภทและโรคทางอารมณ์ ในเมืองโฮจิมินห์ซิตี้ ประเทศเวียดนาม ระหว่างปี ค.ศ. 2019-2020.* (ASSOCIATION BETWEEN PM2.5 CONCENTRATIONS AND HOSPITALIZATION CASES FOR SCHIZOPHRENIA AND MOOD DISORDERS IN HO CHI MINH CITY, VIETNAM FROM 2019 TO 2020) อ.ที่ปรึกษาหลัก : ไกรวุฒิ กัลวิชา

จากหลักฐานการทบทวนวรรณกรรมสำหรับผลกระทบจากมลพิษของฝุ่นละอองในสิ่งแวดล้อมที่มีต่อความผิดปกติทางจิตและทางพฤติกรรมมีจำนวนจำกัด จนถึงขณะนี้ มีการศึกษาทางระบาดวิทยาเพียงเล็กน้อยที่เน้นศึกษาในด้านนี้ โดยเฉพาะอย่างยิ่งในประเทศกำลังพัฒนา จากการเปลี่ยนแปลงความเข้มข้นและแหล่งที่มาของมลพิษทางอากาศในช่วงทศวรรษที่ผ่านมาในเวียดนามทำให้เกิดมลพิษทางอากาศในระดับสูงโดยเฉพาะเรื่องฝุ่นละออง ประกอบด้วย ฝุ่นละอองขนาดเล็กไม่เกิน 2.5 ไมครอน ($PM_{2.5}$) ดังนั้น จึงเป็นสิ่งที่คุ้มค่าอย่างยิ่งในการตรวจสอบผลกระทบเฉียบพลันของมลพิษทางอากาศภายนอกต่อความผิดปกติทางจิตและทางพฤติกรรม อย่างไรก็ตาม ไม่มีการศึกษาของเวียดนามที่ศึกษาผลกระทบระยะสั้นของ $PM_{2.5}$ ต่อการรักษาตัวในโรงพยาบาลสำหรับความผิดปกติทางจิตและทางพฤติกรรม

เพื่อตรวจสอบความสัมพันธ์ระหว่าง $PM_{2.5}$ และจำนวนผู้ป่วยทั้งหมดของความผิดปกติทางจิตและทางพฤติกรรม โรคจิตเภท และโรคความผิดปกติทางอารมณ์ ตั้งแต่เดือนมิถุนายน 2562 ถึง เดือนธันวาคม 2563 ที่โรงพยาบาลจิตเวชนครโฮจิมินห์ แบบจำลองการถดถอยกึ่งปัวซองแบบอนุกรมเวลา (quasi-Poisson time series regression model) ถูกใช้เพื่อวิเคราะห์ตรวจสอบความสัมพันธ์ระหว่างการสัมผัสฝุ่นละอองขนาดเล็กไม่เกิน 2.5 ไมครอน ($PM_{2.5}$) และการเข้ารับการรักษาในโรงพยาบาลรายสำหรับความผิดปกติทางจิตจากทุกสาเหตุและความผิดปกติเฉพาะ 2 กลุ่ม ได้แก่ โรคจิตเภท (Schizophrenia) และ โรคอารมณ์ (Mood disorder) การวิเคราะห์ถดถอยคิวบิค แบบ smooth function ถูกนำมาใช้เพื่อกรองแนวโน้มในระยะยาว และการวิเคราะห์ฤดูกาลและการแบ่งชั้นถูกดำเนินการตามอายุ เพศ และฤดูกาล นอกจากนี้ เพื่อประเมินผลกระทบที่ล่าช้าเราได้ตรวจสอบความสัมพันธ์ด้วยวิธี distributed lag models เมื่อมีการจำลองเงื่อนไขความล่าช้าทีละรายการ (จาก lag0 ถึง lag7) เราเลือกแบบจำลองที่เหมาะสมที่สุดตามเกณฑ์ Q-AIC (Akaike Information Criterion)

ผู้ป่วยเข้ารับการรักษาในโรงพยาบาลด้วยความผิดปกติทางจิตและทางพฤติกรรม รวมทั้งหมด 3,513 ราย จากโรงพยาบาลสุขภาพจิตในนครโฮจิมินห์ ในปี พ.ศ. 2562-2563 จำนวนผู้ป่วยโรคจิตเภทที่เข้ารับการรักษาในโรงพยาบาลคิดเป็นเกือบสี่เท่าของความผิดปกติทางอารมณ์ (1,724 เทียบกับ 447 รายตามลำดับ) ข้อมูลจากสถานีตรวจวัดอากาศบ่งชี้ว่า ความเข้มข้นรายวันของ $PM_{2.5}$ อยู่ในช่วง 8.7 ถึง 66.0 ไมโครกรัม/ลูกบาศก์เมตร โดยมีค่าเฉลี่ยเท่ากับ 25.6 ไมโครกรัม/ลูกบาศก์เมตร ผลการศึกษาพบว่า แต่ละ 10 ไมโครกรัม/ลบ.ม. เพิ่มขึ้นใน $PM_{2.5}$ ที่ lag 7 สำหรับความผิดปกติทางจิตและพฤติกรรม และโรคจิตเภทสอดคล้องกับการเพิ่มขึ้น 1.25 ที่ช่วงความเชื่อมั่นเท่ากับ 1.03-1.52 (95%CI: 1.03 – 1.52), 1.45 ที่ช่วงความเชื่อมั่นเท่ากับ 1.12-1.89) (95%CI: 1.12-1.89) ในการเข้ารับการรักษาในโรงพยาบาลรายวันของผู้สูงอายุตามลำดับ

การศึกษาของเราแสดงให้เห็นว่าผู้สูงอายุในนครโฮจิมินห์ มีความเสี่ยงเพิ่มขึ้นจากการเข้ารักษาในโรงพยาบาลด้วยความผิดปกติทางจิตและทางพฤติกรรม อันเนื่องมาจากระดับความเข้มข้นของ $PM_{2.5}$ ที่สูงในสภาพแวดล้อมอากาศในเมือง การค้นพบนี้ได้แสดงเป็นหลักฐานในการสร้างนโยบายด้านสาธารณสุขในการป้องกันและลดผลกระทบด้านสุขภาพที่ไม่พึงประสงค์จากมลพิษทางอากาศในผู้สูงอายุ

สาขาวิชา	สาธารณสุขศาสตร์	ลายมือชื่อนิสิต	....
ปีการศึกษา	2563	ลายมือชื่อ อ.ที่ปรึกษาหลัก	....

6374010453 : MAJOR PUBLIC HEALTH
KEYWORD: Ho Chi Minh City; hospital admission; mental and behavioral disorders; PM2.5; time-series study.

Do Thi Hoai Thuong : ASSOCIATION BETWEEN PM2.5 CONCENTRATIONS AND HOSPITALIZATION CASES FOR SCHIZOPHRENIA AND MOOD DISORDERS IN HO CHI MINH CITY, VIETNAM FROM 2019 TO 2020. Advisor: KRAIWUTH KALLAWICHA, Ph.D.

The evidence for adverse effects of ambient particulate matter pollution on mental and behavioral disorders (MBDs) is limited. Until now, few epidemiological studies have focused on this field, especially in developing countries. With the changes in concentrations and sources of air pollution over the past decade in Vietnam lead to high levels of air pollutants, especially particulate matters including $PM_{2.5}$. Therefore, it is worthwhile to investigate the acute effects of outdoor air pollution on MBDs. However, no Vietnamese study has looked into the short-term effect of $PM_{2.5}$ on hospitalization for MBDs.

To examine the association between $PM_{2.5}$ and the cases for total MBDs, Schizophrenia and Mood disorder from June 2019 to December 2020 at Ho Chi Minh City Mental health hospital. A quasi-Poisson time series regression model was used to determine the association between $PM_{2.5}$ exposure and daily hospital admission for all-cause mental disorders and two specific disorders including Schizophrenia and Mood disorder. A natural cubic regression smooth function was adopted to filter out long term trends and seasonality and stratified analyses were also performed by age, gender and season. Besides, to estimate the delayed effect, we examined the association in distributed lag models when lag terms were modelled one at a time (from lag0 to lag7). We select the most optimal model based on the Q-AIC criterion (Akaike Information Criterion).

In total, 3,513 hospital admissions for MBDs were collected from HCMC Mental health hospital in 2019-2020. The number of hospital admissions of Schizophrenia was nearly four times of Mood disorder (1,724 vs 447 admissions, respectively). Data from monitoring stations suggested that the daily concentration of $PM_{2.5}$ ranged from 8.7 to 66.0 $\mu g/m^3$ with a mean of 25.6 $\mu g/m^3$. Results revealed that each 10 $\mu g/m^3$ increase in $PM_{2.5}$ at lag 7 for MBDs and Schizophrenia corresponded to an increase of 1.25 (95%CI: 1.03 – 1.52), 1.45 (95%CI: 1.12-1.89) in daily hospital admission among the elderly, respectively.

Our study demonstrated that the elderly in HCMC have an increased risk of MBDs admissions due to the high level of $PM_{2.5}$ concentration in the city's ambient air. These findings have provided evidence for building public health policies to prevent and minimize the adverse health effects of air pollution on the elderly.

Field of Study:	Public Health	Student's Signature ....
Academic Year:	2020	Advisor's Signature ....

ACKNOWLEDGEMENTS

This thesis became a reality with the kindly guidance and help of many individuals. I would like to extend my sincere appreciation and gratitude thanks to all of them.

First and foremost, I would like to express my wholehearted treasure and great gratitude to my advisor, Kraiwuth Kallawicha, Ph.D. for outstanding guidance, invaluable suggestions, kindly support and encouragement throughout the whole process of this study and MPH course as well. I am convenient in all of the time of research and thesis writing due to his motivation, patience, immense technical knowledge and enthusiasms.

I would like to express sincere gratitude and deep appreciation to Assoc. Prof. Dr. Wattasit Siriwong, PhD. Chairman of the thesis committee and Arthit Phosri, Ph.D., Mahidol University, External Examiner, for their invaluable guidance and insight comments which develop to my thesis.

I am delighted to express my special thanks to Tran Ngoc Dang, Ph.D., University of Medicine and Pharmacy at Ho Chi Minh City, for his kindly review and excellent comments on my data set during secondary data collection.

And I also sincerely acknowledge Dean, Prof. Sathirakorn Pongpanich, Ph.D. and all the teachers, lecturers and staffs of College of Public Health Sciences for all the support and kindness towards the students.

I would like to thanks my family and special thanks to my friends who walked with me throughout my MPH course for all the moral support, kindness and happiness we shared together.

Last but not least, I would like thank to the Ho Chi Minh City Mental health hospital and PAM Air Company for providing hospital admission data and air pollution data to make this study accomplished.

Do Thi Hoai Thuong

TABLE OF CONTENTS

Page

LIST OF TABLES

Page

LIST OF FIGURES

Page

Chapter I: Introduction

1.1 Background

Increasing mental disorder is a serious public health problem, which has brought about a social, economic and disease burden in all countries worldwide. Mental health problems are comprised of depression, bipolar disorder, schizophrenia, dementia, as well as developmental disorders including autism and other psychiatric disorders (WHO, 2019). According to the World Health Organization (WHO) report, unipolar depressive disorder was the third root of disease burden, constituting 4.3% of the global burden of disease. Estimates for low and middle-income countries are 3.2% and 5.1%, respectively (WHO, 2011). Globally, an estimated 264 million people are affected by depression, 50 million people are affected by dementia, 45 million people are affected by bipolar disorder and 20 million people are affected by schizophrenia (James et al., 2018). This leads to people having lived with a disability-related to mental disorders in low- and middle-income nations, making up 25.3% and 33.5%, respectively (WHO, 2011). WHO predicted that by 2030 depression will be the leading cause of the disease burden worldwide (WHO, 2011). Additionally, those who suffer mental disorders often lack educational and income-generation opportunities, restricting their economic development chances and depriving them of social networks and status within society (WHO, 2011). Consequently, mental health issues also lead individuals and families to poverty at the national level and delay economic growth. A report has predicted that over the next 20 years, the estimate of total global effects of mental illness in terms of lost economic performance is US$ 16,000 billion (World Economic Forum and the Harvard School of Public Health, 2011). Because of the significant individuals and social burden caused by mental health problems, it is imperative to identify the risk factors for modifiable mental disorders.

Previous studies have determined that there are many risk factors for mental illness such as genetic factors (Di Forti et al., 2012; Geschwind & Flint, 2015; Robinson et al., 2016), socioeconomic (Fazel, Geddes, & Kushel, 2014; Kawakami et al., 2012) and lifestyle factors such as diet (Cristy, 2017) or smoking (Edward, 2012). Recently, however, new research has indicated a relationship between the presence of mental disorders and ambient air pollution. Air pollution is the presence in the air of hazardous substances or compounds at health-threatening levels, such as particles matter (PM), ozone (O_3), nitrogen dioxides (NO_2), sulfur dioxides (SO_2), carbon monoxide, carbon monoxide (CO) (WHO, 2020). Despite the accurate elemental air pollution-induced brain pathology mechanism is not completely found, current research has shown that neuritis, oxidative stress, glial activation, and cerebrovascular damage are the key potential triggers (Block & Calderón-Garcidueñas, 2009; MohanKumar, Campbell, Block, & Veronesi, 2008). For instance, an animal experiment showed that, compared to dogs from a clean rural area, dogs living in Mexico city exposed to high-level air pollution develop major histologic lesions in the olfactory bulb and other brain regions (Oberdörster & Utell, 2002). Fonken study comparing male mice exposed to particulate matter with aerodynamic diameter less than 2.5 µm ($PM_{2.5}$) and filtered air (FA) showed that $PM_{2.5}$ mice showed more depressive reactions (Fonken et al., 2011) and impairments in spatial learning and memory comparison to mice exposed to FA (Calderón-Garcidueñas et al., 2004). Animal testing data showed that long-term exposure to adverse air pollution can also have adverse effects on the human brain.

Many epidemiological studies worldwide have also reported a lot of evidence on the relationship between environmental particulate matter contamination and mental health, notably in developing nations. In one longitudinal research, data suggested that people exposed to long-term air pollution were more likely to be diagnosed with dementia than those under low exposure (Oudin et al., 2016). Prolonged exposure to air contamination is health concern for schizophrenia (C. B. Pedersen, Raaschou-Nielsen, Hertel, & Mortensen, 2004), depressive and anxiety symptoms (Pun, Manjourides, & Suh, 2017). In addition, short time associations have also been identified between exposure to surrounding matter particles and mental illness hospitalization (Briere, Downes, & Spensley, 1983; Rotton & Frey, 1984; J. Song et al., 2018). According to a Chinese time-series study, it is indicated that daily hospital admission for mental and behavioral disorders increased 0.48% correspond to a 10 $\mu g/m^3$ increase in a 3-day average concentration (lag02) of $PM_{2.5}$ and PM_{10} (J. Song et al., 2018). Another study by Chen et al. (2018) shown that a 10 $\mu g/m^3$ increase in 2-day, moving-average concentration of inhalable particulate matter was remarkably related to increments of 1.27% [95% (CI): 0.28%, 2.26%] in hospital admissions per day for MDs (Chen et al., 2018)

In Vietnam, regarding the National Mental Hospital, the proportion of 10 frequent mental health conditions in 2014 was 14.2%, of which 2.45% belonged to depressive disorders. The rate of suicide in 2015 was 5.87 per 100.000 population (National Psychiatric Hospital No 1, 2015). Meanwhile, air pollution in Vietnam increased significantly. According to a report by Air Visual, in 2019, Vietnam ranked 15th in the world for $PM_{2.5}$ pollution with an average annual concentration of $PM_{2.5}$ up to 34.06 µg/m^3 (Air Visual, 2017). Especially in Ho Chi Minh City - a large industrial park and leading commercial center of the country with nearly 9 million people (General Statistic Office, 2019a). In 2017, up to 61% of the total days in Ho Chi Minh City had an average daily $PM_{2.5}$ concentration exceeding WHO guidelines (25µg/m^3) (Green Innovation and Development Centre, 2017). Besides, the rapid economic development attracts more people to migrate to the city. This increases people's concerns about the surrounding air quality. However, there are no studies in Vietnam that concentrate on air contamination impacts on particular mental disorders. There is a lack of research focusing on the association of $PM_{2.5}$ with the number of hospital admissions for mental illness in developing countries with tropical climates and a low capacity to cope with the influences of extreme weather events. Meanwhile, air pollution plays a crucial preventable element, which helps reduce the burden of illness related to mental disorders, so special attention should be paid to it.

Therefore, the author conducted this study to determine the association relationship between the air pollution caused by $PM_{2.5}$ and the number of hospital admissions because of mental disorders in Ho Chi Minh City. Such evidence will contribute to improve mental health management and construct suitable adoption programs for each vulnerable group. The findings of this study have important implications for public health adaptation and prevention program implementation in the protection of residents from the adverse health effects of ambient particulate matter.

1.2 Research question

Is there an association between $PM_{2.5}$ and the cases for total Mental and Behavioral Disorders (MBDs), Schizophrenia and Mood disorder from June 2019 to December 2020 at Ho Chi Minh City Mental health hospital?

1.3 Research objectives

1.3.1 General objective

To examine the association between $PM_{2.5}$ and the cases for total Mental and Behavioral Disorders (MBDs), Schizophrenia and Mood disorder from June 2019 to December 2020 at Ho Chi Minh City Mental health hospital.

1.3.2 Specific objectives

1. To describe the characteristics of the cases for MBDs at Ho Chi Minh City Mental health hospital from June 2019 to December 2020.
2. To describe the distribution of ambient $PM_{2.5}$ concentration in Ho Chi Minh City from June 2019 to December 2020.
3. To determine the association between $PM_{2.5}$ concentration and cases by sex, age and season for MBDs at Ho Chi Minh City Mental hospital from June 2019 to December 2020.

1.4 Research Hypotheses

1.4.1 Null Hypothesis

There is no association between $PM_{2.5}$ and the cases for total Mental and Behavioral Disorders (MBDs), Schizophrenia and Mood disorder at Ho Chi Minh City Mental health hospital from June 2019 to December 2020.

1.4.2 Alternative Hypothesis

There is an association between $PM_{2.5}$ and the cases for total Mental and Behavioral Disorders (MBDs), Schizophrenia and Mood disorder at Ho Chi Minh City Mental health hospital from June 2019 to December 2020.

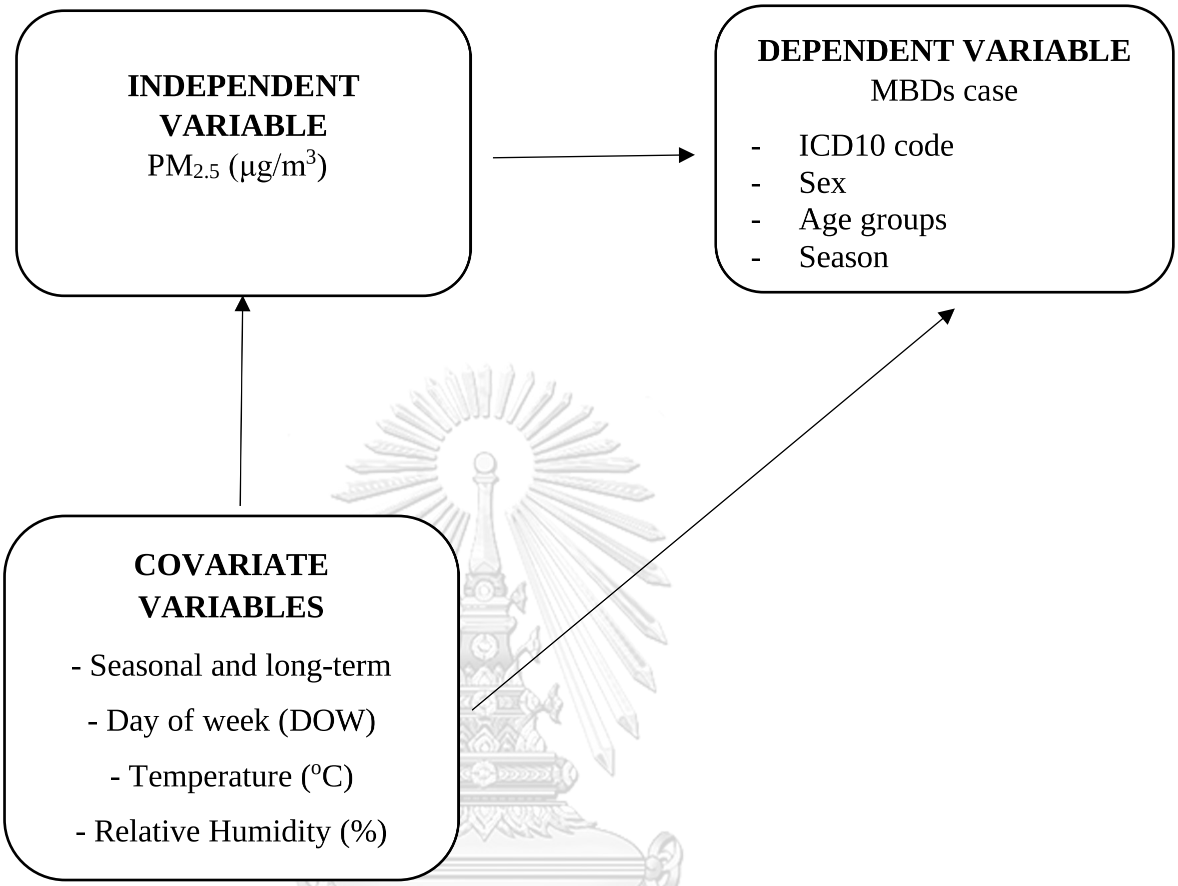
1.5 Operational definitions

Admission date	It is the date of admission with the interested diagnosis according to the medical record. The admission date considered in this study is from June 1st, 2019 to August 31st,

	2020.
Discharge date	It is the date of discharge after treatment of interested diagnosis according to the medical record.
Age	According to the birth year, the age of the patient at the admission date from the medical records of study subjects.
Sex	recording from the medical records, dichotomous variable including 2 values: Male, Female
Address	The permanent address based on the medical record and is the address in Ho Chi Minh City.
ICD10 code	ICD-10 is the 10th revision of the International Statistical Classification of Diseases and Related Health Problems (ICD), a list of medical categorization introduced by the World Health Organization (WHO). It consists of disease codes, signs and symptoms, abnormal outcomes, complaints, social contexts, and external roots of injury or illnesses.
Mental and Behavioral Disorders (MBDs)	It is diagnosed and encoded by the psychiatrist by ICD-10 codes (MBDs) in the diagnostic code group: F00-F99 (WHO, 1992).
Schizophrenia	A form of schizophrenia in which affective changes are prominent, delusions and hallucinations fleeting and fragmentary, behaviour irresponsible and unpredictable, and mannerisms common. The mood is shallow and inappropriate, thought is disorganized, and speech is incoherent and encoded by the psychiatrist as F20 in the ICD-10.
Mood disorder	It includes disorders in which the underlying disorder is a change in mood affecting depression (with or without anxiety related) or with excitement. Mood swings are often accompanied by a change in overall activity level; most other

	symptoms are secondary or easy to develop in the context of mood and activity changes. Most of these disorders tend to recur, and the onset of each can often be related to stressful situations and encoded by the psychiatrist as F30-F39 in the ICD-10.
Hospitalizations for MBDs:	A total number of hospital admissions diagnosed under the ICD-10 code (F00-F99) from June 1st, 2019 to December 31st, 2020.
$PM_{2.5}$ concentration	The average concentration of $PM_{2.5}$ per day ($\mu g/m^3$) will be measured from 31 monitoring stations from June 1st, 2019 to December 31st, 2020.
Relative Humidity (RH,%)	It is the average value of relative humidity (%) measured from 31 monitoring stations.
Temperature (°C)	It is the average value of ambient temperature (%) measured from 31 monitoring stations.

1.6 Conceptual Framework



Chapter II: Literature Review

2.1 Mental health overview

As defined by the World Health Organization (WHO): "Health is a state of complete physical, mental and well-being and not merely the absence of disease or infirmity." (WHO, 2018d). A vital meaning of this concept is that mental health (MH) has been an indispensable and essential component of health and that MH has a close connection with physicality and society (WHO, 2018d).

Since then, WHO also introduced the concept of MH: Mental health "is a state of well-being in which an individual realizes his or her abilities, can cope with the normal stresses of life, can work productively and is able to contribute to his or her community." (WHO, 2018d). MH represents a feeling, psychological and social. It affects how we operate our brain, feel and act. Besides, it helps us to deal with stress and make decisions. (U.S. Department of Health & Human Services, 2020).

Mental illness (mental disorder)

According to the World Health Organization (WHO): "Mental disorders include a wide range of problems and different symptoms. They are often characterized by some combination of unusual thoughts, feelings, behaviors and relationships with others" (WHO, 2019).

Mental and Behavioral Disorders are classified as an international illness (ICD10) in diagnostic codes: F00-F99.

F00-F09	Organic, including symptomatic, mental disorders
F10-F19	Mental and behavioral disorders due to psychoactive substance use
F20-F29	Schizophrenia, schizotypal and delusional disorders
F30-F39	Mood [affective] disorders
F40-F48	Neurotic, stress-related and somatoform disorders
F50-F59	Behavioral syndromes associated with physiological disturbances and physical factors
F60-F69	Disorders of adult personality and behavior
F70-F79	Mental retardation

F80-F89	Disorders of psychological development
F90-F98	Behavioral and emotional disorders with onset usually occurring in childhood and adolescence
F99	Mental disorder, not otherwise specified

2.1.1 Causes of mental and behavioral disorder

Although the exact root of most mental diseases is vague, it is known via prior research to have depicted that there are multiple mental illness hazards, such as genetic factors (Di Forti et al., 2012; Geschwind & Flint, 2015; Robinson et al., 2016), environmental factors such as socioeconomic (Fazel et al., 2014; Kawakami et al., 2012) and lifestyle factors namely diet (Cristy, 2017) or smoking (Edward, 2012). Recently, however, recent research has suggested a correlation between the rate of mental illnesses, in addition to air contamination in the ambiance (Briere et al., 1983; C. B. Pedersen et al., 2004; Rotton & Frey, 1984; J. Song et al., 2018).

2.1.1.1 Genetic factors

Mental illness sometimes runs in families. Genes also play a role in determining if someone has a mental illness. Experts believe that many mental illnesses are associated with abnormalities in many genes, not just one or several genes. The way these genes interact with social-environmental or lifestyle factors varies from person to person. In 2012, Di Forti et al. has shown that as compared to consumers who were T/T carriers, individuals using cannabis having the C/C genotype showed a greater than double the risk of a psychotic illness (OR= 2.18, 95% Cl 1.12-4.31). In addition, frequent consumers of cannabis bearing the C/C genotype reported a sevenfold rise in psychosis probabilities relative to T/T carriers (OR=7.23, 95% Cl 1.37-38.12) (Di Forti et al., 2012). Previous research has established that several forms of genetic susceptibility for autism spectrum disorders (ASDs) affect a continuum of behavioral and developmental characteristics that can be diagnosed with ASD or other psychiatric illnesses (Robinson et al., 2016).

2.1.1.2 Environmental factors

Infection: Several infections have been associated with brain injury and the development or deterioration of mental illness. Studies by Schaefer et al. has discussed that HCV-infected individuals are more susceptible to mental illness, which may be due to a higher incidence of HCV infection in psychiatric patients, but may also be due to a direct or indirect impact of HCV on the central nervous system (CNS) (Schaefer et al., 2012). Other research findings indicate that young people with perinatal HIV encounter emotional and behavioral issues at higher than normal rates compared to the general population, including mental disorders (Mellins & Malee, 2013).

Defects or Injury to the brain: Signs of cognitive dysfunction occur following traumatic brain injury and partly mediate symptoms of depression (Gorgoraptis et al., 2019).

Socioeconomic: Mental medical problems are one reason for the high death rate among homeless people, especially suicide (Fazel et al., 2014). Another study also reported that low individual incomes and spouse incomes (increased unemployment, decreased earnings among the employed) were associated with early-onset mental disorders (Kawakami et al., 2012).

Air pollution:

There is a growing body of literature that recognizes air pollution with a negative relationship to mental health. Individuals exposed to long-term air pollution were more likely to be diagnosed with dementia than those exposed to a low exposure (Oudin et al., 2016). Ambient air pollutants have been associated with poor mental health, especially PM and nitric oxides. Long-term exposure to $PM_{2.5}$ could lead to a rise in the risk of new-onset of depressive symptoms. Besides, the rate of nitric dioxide increased in summer exacerbated depressive conditions (Buoli et al., 2018). Furthermore, much research demonstrated the increasing mental disorders admission related to contaminants such as $PM_{2.5}$, PM_{10} (Briere et al., 1983; Rotton & Frey, 1984; J. Song et al., 2018).

2.1.1.3 Lifestyle factors

Existing research has acknowledged the remarkable point that after toxic smoke inhalation, long-term brain and psychological dysfunction result, with certain areas of the brain showing gradual deterioration after smoke inhalation after 3 to 14 years (Edward, 2012). It has previously been observed that those who smoke have a poorer state of mental health, especially among people with more serious illnesses

(Plurphanswat, Kaestner, & Rodu, 2017). In addition, other risk factors such as diet (Cristy, 2017; O'neil et al., 2014), online social networking (Igor, 2014), experiencing abortion (Ditzhuijzen, Have, Graaf, Nijnatten, & Vollebergh, 2018) or Covid-19 pandemic (Janusz, 2020) also contribute to the effect on human mental health.

2.1.2. The state of mental health

Mental health in adults

According to recent estimates, about 20% of Americans over 18 years old have a diagnosed mental disorder in a given year. Four of the top ten causes of disability, major depression, bipolar disorder, schizophrenia, and obsessive-compulsive disorder are mental illness. About 3% of the population has more than one mental illness at a time. About 5% of adults are severely affected by mental illness, which interferes with their ability to function in society. These severe and persistent mental illnesses include schizophrenia, bipolar disorder, depression, anxiety disorder, and obsessive-compulsive disorder. About 20% of doctor's appointments are related to anxiety disorders such as panic attacks. Eight million people suffer from depression each year. Two million Americans suffer from schizophrenia and 300,000 new cases are diagnosed each year (Mental Health American, 2019).

Mental health in children and adolescents

The National Mental Health Association has compiled a number of statistics on mental illness in children and adolescents. Mental health problems affect one in five children at any one time. An estimated two-thirds of young people with mental health problems do not get the help they need. Less than one-third of children under 18 years old with a serious mental health problem receive any mental health service. Up to 1 in 33 children may experience depression. Depression in adolescents can reach up to 1/8. Suicide is the third leading cause of death for children aged 15-24 and the sixth leading cause of death for children aged 5-15. Schizophrenia is rare in children under 12 years old, but it occurs in about 3 in 1,000 adolescents, between 118,700 and 186,600 adolescents with at least one mental illness. Of the 100,000 teenagers detained as adolescents, an estimated 60% have behavioral, cognitive or emotional problems (Biological & National, 2007).

2.2 Air pollution

Air pollution is the presence of toxic chemicals or compounds in the air, including substances of biological origin, that exist at levels posing a health risk. Air pollution is understood in a broader sense as the presence of chemicals or compounds that are not normally present in the air, causing deterioration of air quality or causing adverse changes to the quality of life (Environmental Pollution Centers, 2020).

Air pollution cannot be seen with the naked eye because the pollutants are smaller than human visibility. However, in some cases, such as smoke from fires, burning wood, coal, gasoline, oil, diesel can be detected with the naked eye. Not seeing air pollution does not mean it does not exist (Luong, Phung, Sly, Morawska, & Thai, 2017).

2.2.1 Causes of air pollution

❖ **Natural causes:**

- Volcanic activity disperses several toxic gases (sulfur, chlorine) and particulates (ash), occurring locally;
- Wind and air currents carry air pollutants spread over a large area;
- Wildfires generate large amounts of CO2 and other pollutants;
- The natural decay of microorganisms releases gases, especially methane;
- Process of radioactive decay;
- The increase in temperature contributes to the increase in the number of pollutants evaporating from soil and water into the air.

❖ **Causes from humans:**

- Industrial activities such as mining, mining waste treatment, electricity generation;
- Agricultural activities using plant protection chemicals that contain volatile toxic organic compounds;
- Construction and demolition, especially for old buildings that may contain hazardous substances such as PCBs, PBDEs, asbestos;
- Landfilling activities generate methane gas due to the natural decomposition of microorganisms;

Waste incineration;

- Store and use household products containing volatile organic solvents (WHO, 2018b).

2.2.2 Air pollutants

Air pollutants can be divided into two main forms according to their physical status includes gaseous and solid (particulate matter suspended in the air). There is abundant evidence that particulate matter (PM), Ozone (O_3), Nitrogen dioxide (NO_2), Sulfur dioxide (SO_2) are the main causes of air pollution.

Particulate matter (PM) is the common name for the particles in the air around us. They are distributed mainly from fuel burning. These particles come in many different sizes and shapes. According to the US Environmental Protection Agency (EPA), there are 2 main types of granules: PM_{10} and $PM_{2.5}$ (Luong et al., 2017).

PM_{10} consists of particles less than 10 μm in diameter. These particles can be inhaled deep into the lungs, some of which can be stored in the nose, mouth, or throat. Common emission sources include sea salt, pollen, fuel burning, and industrial buildings. The presence of PM_{10} in high concentrations in the air can irritate the eyes and throat. In people with heart or lung disease, symptoms include difficulty breathing, wheezing, and chest tightness (Nhung et al., 2018).

$PM_{2.5}$ consists of fine particles under 2.5 μm in diameter and tiny enough to be inhaled deeply into the lungs. $PM_{2.5}$ is the result of burning fossil fuels, organic matter. They are found in the exhaust gases of motor vehicles, power plants, and smoke from wildfires. Children, people over 65 years of age, pregnant women and people with lung or cardiovascular disease are sensitive to the effects of these particles matter. Symptoms include difficulty breathing, wheezing, and chest tightness (Luong et al., 2017).

Ozone (O_3) is a remarkably reactive gas consisting of 3 oxygen atoms. In terms of the position in the atmosphere, they have certain effects on human health. In the stratosphere, ozone is formed by the interaction of ultraviolet radiation with O_2, reducing the harmful effects of ultraviolet rays on the earth's surface. In the troposphere, ozone is generated from the photochemical reaction between volatile organic compounds (VOCs) and Nitrogen oxide (NOx). Exposure to ozone in the air can lead to respiratory symptoms, airway inflammation, and impaired lung function (Nhung et al., 2018).

Nitrogen dioxide (NO_2) is mostly colorless or brownish at room temperature and has a distinctive odor. They pollute the air through car exhaust, power plants, burning fuels, electroplating, and welding. High concentrations of NO_2 in the air trigger inflammation of the lung mucosa, reducing immunity to lung infections, causing problems such as difficulty breathing, wheezing, coughing, bronchitis (Nhung et al., 2018).

Sulfur dioxide (SO_2) is manufactured mostly from fossil fuels burning, volcanoes, and vehicles and equipment that use high sulfur fuels. High SO_2 concentrations in the air also result in the generation of other forms of sulfur oxides that combine other substances in the atmosphere to create fine particles. These particles deeply invade the lungs, causing serious problems for the respiratory system, especially in the long term at high concentrations (Erik van Nunen et al., 2017).

2.2.3 The effects of air pollution

Air pollution is a risk factor for non-communicable diseases with an estimated 7 million deaths each year (WHO, 2018c). One in three deaths from stroke, lung cancer and heart disease are related to air contamination (WHO, 2018c). Recent research have figured out the city's long-term effects on air contamination on mortality (Rob. Beelen et al., 2014) (Anoop S V Shah et al., 2013), cardiovascular disease incidence (Cesaroni et al., 2014), decreased lung function in children (Eeftens et al., 2014) (Gehring et al., 2013), childhood respiratory infections (MacIntyre et al., 2014) and low birth weight (M. Pedersen et al., 2013) confirm earlier studies based on both in and mid-city exposure to the air pollution (Brook et al., 2010) (Hoek et al., 2013). What is more, the evidence is appearing for the role of air pollution in other diseases such as diabetes (Coogan et al., 2012) (Eze et al., 2014). Ambient air pollution ranks ninth in the 2010 Global Disease Estimates Ranking (S. S. Lim et al., 2012), contributing to an estimated 3-4 million premature deaths and is estimated to reduce life expectancy by nearly 9 months in Europe (WHO, 2013b).

In Vietnam, out of the 10 diseases with the highest mortality rates in Vietnam, there exist 6 respiratory illnesses due to air contamination and air quality. In the disease structure, respiratory diseases are also one of the top 5 most affected groups.

Air pollution causes much damage to human health and life. Regarding the World Bank (WB) report, the loss of global economic due to air contamination is approximately 225 billion USD (World Bank, 2016). For Vietnam, air contamination causes an economic loss of about 10 billion dollars per year (accounting for 5-7% of GDP) (The World Bank Institute for Health Metrics and Evaluation, 2016).

2.3 $PM_{2.5}$ particulate matter

Particular matter (PM) is a large-scale air pollutant consisting of a mixture of solid and liquid particles suspended in the air. PM is commonly known for its mass concentrations of particles less than 10µm including PM_{10}, $PM_{2.5}$ and ultrafine particles less than 0.1µm (PM_1) (WHO, 2013a).

PM is a mixture with different physical properties and of course, the popular chemical composition of PM includes sulfates, nitrates, ammoniums, other inorganic ions including sodium, potassium, calcium, magnesium and chloride ions, organic and elemental carbon, crust material, metals (cadmium, copper, nickel, vanadium, zinc) and PAH. Apart from that, biological substances such as allergens and biotic compounds are detected in PM (WHO, 2013a). The pathogenicity of PM is determined by its size, composition, origin, solubility and ability to generate reactive oxygen (X. Zhang et al., 2013).

$PM_{2.5}$ is 2.5 µm in size. Although the diameter is small, the surface area is large. It can carry many different toxic substances, creep to the end of the respiratory tract, deep in the alveoli, accumulate there and diffuse, affecting other parts of the body. (X. Zhang et al., 2013)

$PM_{2.5}$ is generated from natural elements or human activities, often burning fossil fuels, from vehicle exhaust, industrial production and factories electricity, as well as from natural sources such as dust, wind and volcanic activity (United States Environmental Protection Agency, 2016).

$PM_{2.5}$ in urban areas is very complex, can be divided into primary and secondary sources (Huang et al., 2014). Primary sources are related to the direct emissions of burning fossil fuels (such as petroleum, coal), organic matter (such as wood, plants) and materials such as rubber and plastics. Motor vehicles, power plant emissions and forest fires are the main sources of these dust emissions (Environment Protection Authority Victoria, 2016). Secondary sources are generated from chemical processes that oxidize the primary substances in the atmosphere (Huang et al., 2014).

$PM_{2.5}$ predicts exposure to health effects better than PM_{10}, so $PM_{2.5}$ is often used to denote the standard content of floating particles per cubic meter of air and the higher the index the more severe (U.S Environmental Protection Agency, 2012).

Summary of air quality standards for $PM_{2.5}$:

Organization	Standard guidelines
Ministry of Natural Resources and Environment (QCVN 05:2013) (Minister of Natural Resources and Environment of The Socialist Republic of Vietnam, 2013)	25 µg/m^3 (annual average) 50 µg/m^3 (24-hour average)
EPA (U.S Environmental Protection Agency, 2012)	35 µg/m^3 (24-hour average)
WHO (WHO, 2005)	10 µg/m^3 (annual average) 25 µg/m^3 (24-hour average)

2.3.1 Effects of $PM_{2.5}$ on human health

Most air pollutants enter the body through inhalation. Depending on the size and dosage, they cause different levels of harm. $PM_{2.5}$ is an agent that easily penetrates the lungs, stimulates, erodes the alveolar wall leading to impaired lung function, increases the risk of COPD, emphysema and other respiratory diseases (C. Song et al., 2017).

A greater risk factor than PM_{10} coarse (particles in the 2.5-10µm range) is $PM_{2.5}$. Long-term exposure to $PM_{2.5}$ was correlated with a 6%-13% elevated risk of long-term cardiopulmonary mortality, with a 10 µg/m^3 $PM_{2.5}$ percent rise (Arden Pope III, Burnett, & al., 2002) (Rob Beelen et al., 2008) (Krewski et al., 2009). An increase in $PM_{2.5}$ interregional coverage above 0 day delay is associated with an increase of 25.5% (95% CI, 2.6% 54.5%) risk of hospitalization for myocardial infarction (Pan et al., 2019). To determine the relationship of $PM_{2.5}$ and $PM_{2.5-10}$ with mortality, a time-series study used the Quasi-Poisson distribution was carried out. During the study period, an increase of 10.5 µg/m^3 in $PM_{2.5}$ (lag01) was correlated with an increase in all-cause mortality of 1.18% (95% CI: 0.64-1.72), 0.34% (95% CI: 0.03-0.64) and 0.43% (90% CI: 0.02-0.95) respectively in Busan, Seoul and Incheon (T.-Y. Kim, Kim, Yi, Cheong, & Heo, 2018).

According to a study by Jairo A Morantes-Caballero in 2019, more patients were hospitalized due to acute episodes of COPD after exposure to $PM_{2.5}$ more than 48 hours before the onset of symptoms, taking antibiotics more corticosteroids

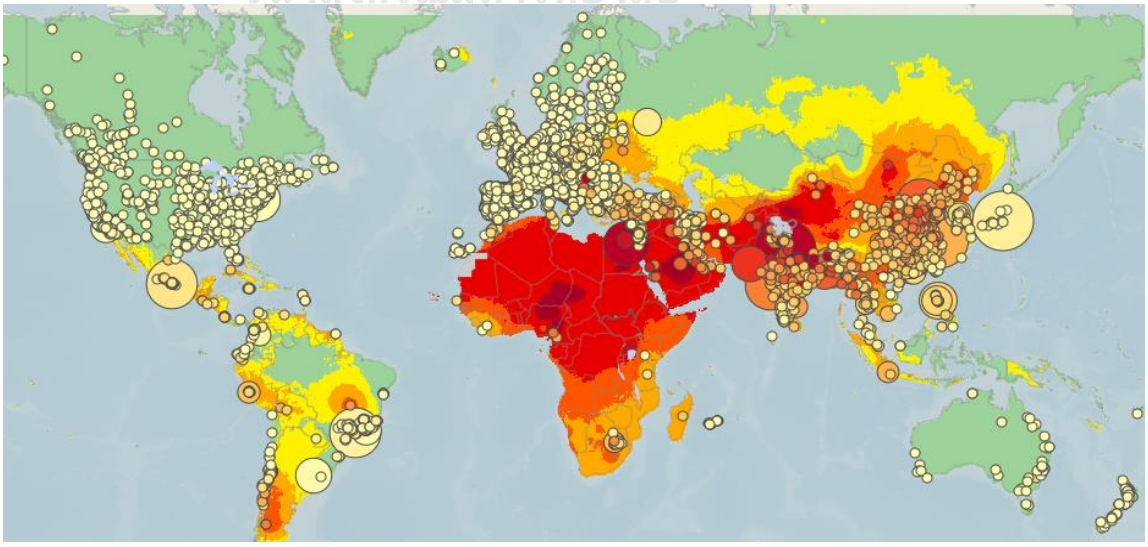
(Morantes-Caballero & Rodriguez, 2019). $PM_{2.5}$ exposure to pulmonary carcinoma is nearly twice as high each year as squamous cell carcinoma, small cell carcinoma, and other histological subtypes (p = 0.024). The increased risk for the high-risk cluster is associated with an occupational risk of air pollution more than four hours per day, five times higher for a diagnosis of lung carcinoma (OR = 5.69, 95% CI = 3.14-7.21, p <0.001) (Wahab et al., 2019).

According to research by Li. Q et al when culturing human skin keratinocytes in media containing $PM_{2.5}$. As a result, the viability of cells decreased with increased levels of surrounding $PM_{2.5}$, which might elevate eczema and other skin disease risks (Li et al., 2017). In addition, $PM_{2.5}$ also affects nerve cell death and seasonal nerve cell damage (M. Chen, Li, & Sang, 2017).

According to a study by Pallavi Pant et al. 2014 on the impact of $PM_{2.5}$ on short-term exposure in tourists to Vietnam, HCMC had $PM_{2.5}$ concentrations of 18.9 ± 9.24 µg /m³, was the highest of the 3 study cities and increased the risk of post-exposure hospitalization for tourists by 2.2% (Pant, Huynh, & Peltier, 2018).

A study conducted in Hubei (2020) has found a correlation between emissions of $PM_{2.5}$ and COVID-19 in cities both within and outside the province. COVID-19 rose by 0.24% (95% CI: 0.01 - 0.48) and 0.26% (95% CI: 0.00 - 0.51) with every 10 µg/m^3 rise in $PM_{2.5}$ and PM_{10} concentrations, respectively (Yao et al., 2020).

2.3.2 The situation of $PM_{2.5}$



Global ambient air pollution map ©WHO, 2018 (WHO, 2018a)

From 2010 to 2016, global $PM_{2.5}$ concentrations raised by 18%, from 43.2 μg/m^3 to 51.1 μg/m^3.

In heavily populated countries and regions such as India, Bangladesh, Pakistan and China, global $PM_{2.5}$ concentrations are highly affected by levels of air pollution. Since 1990, however, the incidence of $PM_{2.5}$ in other heavily populated countries (such as Russia, Indonesia, Japan, Brazil, the United States and the European Union) has declined, except the United States. This is still above the WHO Air Quality Guidelines (Health Metrics Institute, 2018). Worldwide, about 90% of the population living in cities in 2016 were exposed to particulates at concentrations exceeding WHO air quality guidelines (WHO, 2016a). Ambient air pollution of particulate matter 2.5 μm or less in diameter ($PM_{2.5}$) in national urban areas ranges on average from less than 10 to more than 100 μg/m^3 and particulate matter with a diameter of 10 μm or less (PM_{10}) with an average of less than 10 to more than 200 μg/m^3 (WHO, 2016c). National level exposure to particulate matter increases the risk of acute lower respiratory infections, chronic obstructive pulmonary disease, ischemic heart disease, and stroke and lung cancer. Average annual $PM_{2.5}$ concentrations for both rural and urban populations were estimated using a statistical model using data from a variety of sources, including terrestrial measurements and satellite data. . The average annual concentration of $PM_{2.5}$ ranges from less than 10 to more than 100 μg/m^3. In cities, exposure to $PM_{2.5}$ increases the risk of many acute and chronic respiratory and cardiovascular diseases for both children and adults. According to reports in the years 2010-2016, more than 4,000 residential areas (mainly in cities) have reported concentrations of PM_{10} and $PM_{2.5}$ exceeding WHO air quality standards (WHO, 2016b).

$PM_{2.5}$ situation in Vietnam

In 2019, according to the ranking of Air Visual, Vietnam ranked 15th in the group of the most polluted countries with an average $PM_{2.5}$ concentration of 34.06 μg/m^3, exceeding the air exposure standard of WHO is 10 μg/m^3 and the Vietnamese standard is 25 μg/m^3 (Air Visual, 2018). According to a report by the Green Innovation and Development Center (GreenID), the average $PM_{2.5}$ concentration in Ho Chi Minh City is 29.6 μg/m^3. Also in 2017, the number of days the city had $PM_{2.5}$ concentrations exceeding the WHO 24-hour average standard (25 μg/m^3) was 222 days and exceeded the 24-hour average QCVN standard of 14 days (50 μg/m^3) (Green Innovation and Development Centre, 2017).

In Vietnam, 2018 monitoring data from the US Consulate monitoring station located in Hanoi shows that the annual average $PM_{2.5}$ dust concentration is 40.6 μg/m^3, which is 1.5 times higher than National standards (25 μg/m^3) and 4 times the WHO standards for air quality (10 μg/m^3). When analyzing data by day, the number of days with high average $PM_{2.5}$ dust concentration still accounts for a large number, with 88 days out of the total number of days in the year exceeding the permitted limit in National Standards (50 μg/m^3) and compared with the stricter WHO recommendation (25 μg/m^3) this is 232 days, accounting for 64% of the total days of the year. Particulate matter concentration at the US Consulate in Ho Chi Minh City is 26.4 μg/m^3 more stable than in Ha Noi but still exceeds the national standards and WHO Recommendations (Green Innovation and Development Centre, 2018). In 2016, in HCMC. In Ho Chi Minh City, the annual average $PM_{2.5}$ dust concentration reached 29.6 μg/m^3, which exceeded the prescribed limit for $PM_{2.5}$ concentrations in the National Standards (25 μg/m^3) and 3 times higher than the limit according to WHO guidelines (10 μg/m^3). In 2017, there were only about 14 days, equivalent to 4% of the total number of days, the average $PM_{2.5}$ concentration exceeded Vietnam standard, 85 days less than Hanoi. However, there are still 222 days, equivalent to 61% of the total concentration of days of the year.

Overview of Ho Chi Minh City

Ho Chi Minh City (HCMC) is the largest city in Vietnam in terms of population and urbanization. It is also one of the most important economic, political, cultural, scientific, technical, educational and tourist centers. Ho Chi Minh City (HCMC) has an area of 2,095 km^2. In recent years, the air quality in the HCM city is getting worse day by day. As of 2019, the whole city has a population of nearly 9 million people living and working. In addition, Ho Chi Minh City is also located in the key economic region in the South, the economic center of the country, with high economic growth. Economic development with high growth rates has created a large contribution to GDP for the country. The city's GDP ratio accounts for 1/3 of the country's GDP. Thanks to favorable natural conditions, HCMC has become an important traffic hub of Vietnam and Southeast Asia, including roads, railway, waterways and airways.

Along with the process of economic and social development in recent years, the city. Ho Chi Minh City is also facing problems of pollution in general and in particular, air pollution caused by industrial activities and human activities.

The sources of air pollution in the city come mainly from three main categories as follows:

- Air pollution due to traffic activities

Through statistics show, means of transport in the city. HCM is about 9 million motorbikes and nearly 800,000 cars. Having millions of motorbikes, especially expired vehicles, homemade cars with cars and trucks in circulation, will generate a large number of toxic emissions, dust, seriously affecting the quality of the urban air environment threatens the health and life of the people.

- Air pollution due to industrial activities

Currently, HCMC has about 1,000 large-scale factories and tens of thousands of handicraft production facilities. Except for several factories located in concentrated industrial zones or located in remote areas, most production establishments, especially cottage and handicraft production establishments, are still alternating. For residential areas, the exhaust gas from production activities also contributes to air pollution and its effects on the urban population.

- Air pollution from urban activities

HCMC is entering the stage of urban construction, renovation and embellishment, so construction activities are everywhere. This has a great impact on the city's air quality from the construction works. In addition, the daily activities and services of the people also take place in residential areas such as food and drink business, garbage burning,... and create significant air pollution and noise affects the air quality in general.

2.4 Related studies

The impact of particulate air pollution on mental health is of great interest to many countries and ecological design studies are carried out to determine the implications. There are studies done to assess the effects of acute air pollution, while others are interested in daily air pollution assessment. However, the common points in these study groups assessed the level of air pollution through $PM_{2.5}$ related indicators. $PM_{2.5}$ results were significantly associated with hospitalization for mental disorders.

In Korea, a 10.1% (95% CI = 2.0 - 19.0) increase in suicidal risk was observed relative to an interregional range with a corresponding increase in $PM_{2.5}$ (1 day before the date of suicide). Researchers have utilized a time-stratified case-crossover study design to measure the relationship. Confounding variables such as national holidays, mean hours of sunlight, the temperature, the mean temperature, the dew point temperature, the mean dew point temperature, the air pressure, and the mean air pressure was controlled in the model. However, bias misclassification can occur due to the use of the death database to identify suicides. Suicide data were used across seven cities, while $PM_{2.5}$ concentrations were taken from only one city. (C. Kim et al., 2010)

Q Gao et al. (2017) performed a study with a sample size of 13,291 psychiatric hospital admissions in Beijing from January 1, 2013 to December 31, 2015. In this study, generalized additive Poisson models were used. Long-term trends and seasonality, temperature, humidity, barometric pressure, day of the week, sunny hours and holidays were controlled in the model. The results showed $PM_{2.5}$ (lag 03) there was a positive correlation with schizophrenic hospital admission (0.49% [95% CI: 0.04–0.95%]). On various lag days, PM_{10}, PM_C, $PM_{2.5}$ were significantly correlated with schizophrenia admissions. Contaminations had only been assessed by outdoor pollution, and that may not be the entire personal exposure. However, there is a strong point in this analysis. The researchers used air tracking data from 35 general stations spread in Beijing, which were more reflective of general population exposure than from a single tracking station (Gao, Xu, Guo, Fan, & Zhu, 2017).

Other studies in China evaluated hospitalization due to general mental disorders. Specifically, sequence analysis at Shijiazhuang Psychiatric Hospital, China collected 9156 daily hospitalized people for psychiatric disorders from 2014 to 2016. A time-series regression was adopted to assess the relationship between the acute effect of particulate matter ($PM_{2.5}$ and PM_{10}) on hospitalizations due to psychiatric and behavioral problems. Seasonal and long-term trends, temperature, humidity, day of the week, holidays were controlled in the model. The result reported a $10\mu g/m^3$ rise in $PM_{2.5}$ over an average of 3 days (lag02) associated with 0.48% (95%CI: 0.18-0.79%) increase rates in daily hospitalization psychiatric and behavioral disorders. The vulnerable groups are male and older people (≥45 years). In addition, outcomes showed a generally stronger correlation of $PM_{2.5}$ in the cool season with psychiatric and behavioral problems than in the warm season. Many personal characteristics, such as socioeconomic state, schooling, and comorbidities, are closely linked to mental illness but were not taken into consideration in this study. The research did not analyze the effects of particles matter on specific psychological groups (J. Song et al., 2018)

Another research by Chen Chen et al. Used a time-series analysis to investigate the relationships between six air pollutant parameters and regular hospital admissions for MDs from 2013 to 2015 in Shanghai, China. An optimization model was used after controlling for time trends, weather conditions, weekdays and holidays. There was a rise with 1.27% hospitalizations having a significant association with inhalable particulate matter, sulfur dioxide (SO_2), and carbon monoxide (10-$\mu g/m^3$ increase 2-day). The study indicated stronger correlations in warm seasons of air contaminants with MDs than in cool seasons and there is no difference in sex and age groups. The study also did not analyze the short-term associations between particle matter and specific psychological groups (Chen et al., 2018).

Author Feng Wang et al (2018) in China also paid attention to mental health, particularly depression. The researchers utilized a time stratified case-crossover design to assess the short-term effect of PM on hospitalization for depression. This approach helped control the impact of day of the week, seasonal and long-term patterns, and possible individual-level risk factors (such as sex and genetics). Outcomes indicated that $PM_{2.5}$ presented the association with the figure for depression positively. Especially, the risks of hospitalization peaked when $PM_{2.5}$ on lag day 0 (2.92; 1.37–4.50) and lag day 5 (3.65; 2.09–5.24). Older people were more vulnerable when exposing to $PM_{2.5}$ (9.23; 5.09–13.53) (F. Wang et al., 2018).

Hang Qiu et al also assess the short-term impacts of $PM_{2.5}$ on hospital admissions for MDs in Chengdu, China from 2015 to 2016 by time-series analysis. They used an overdispersed generalized additive model (GAM) in the model. Confounding factors such as trend and seasonality, mean temperature and relative humidity are also controlled. The outcome showed that $PM_{2.5}$ was substantially correlated with elevated hospitalization risks for MDs. In hospitalizations for MDs, every 10 $\mu g/m^3$ increase in $PM_{2.5}$ at lag06 corresponded to an increase of 2.89% (95%

CI: 0.75-5.08%). Dementia, schizophrenia, and depression were found a significant association with PM pollution. In this research, personal features such as smoking, marital and social status were not regulated. They only considered temperature and relative humidity as confounding factors between the association of weather conditions and air pollutants (Qiu et al., 2019).

Another study in Chengdu, China also evaluated the exposure-response effects of PM emissions on hospitalizations for MDs, a generalized additive model (GAM) was employed. PM contamination has been shown to be strongly linked to hospital admissions for general and particular MDs. At the cumulative lag03 day, every 10 $\mu g/m^3$ rise in $PM_{2.5}$ concentrations ($\leq 2.5\ \mu m$) will be responsible for 6.38% (95%CI: 4.79–7.97%) rises in regular hospital admissions for MDs, respectively. It is noted that males and individuals over 45 years had stronger associations in cool seasons (P. Zhang & Zhou, 2020).

Summary of related studies

Authors	**Location**	**Study time**	**Research Design**	**Method**	**Sample size**	**Results**	**Limitations**
Changsoo Kim et al. (C. Kim et al., 2010)	Seoul, Busan, Incheon, Daejeon, Daegu, Gwangju, and Ulsan	2004	Time-stratified case-crossover study	Two-stage hierarchical model	4,341 suicide cases	a 10.1% (95% CI=2.0–19.0) rise in suicide risk due to an interquartile range increase in particulate matter ≤ 2.5 μm (1 day prior to the day of suicide)	Bias misclassification can occur due to the use of the death database to identify suicides. Suicide data were used across seven cities, while $PM_{2.5}$ concentrations were taken from only one city.
Q. Gao et al. (Gao et al., 2017)	Beijing, China	2013 to 2015	A time-series regression study	Generalized additive Poisson model	13,291 hospital admissions	Per 10 mg/m^3 grow in PM_{10} and PMC on lag4 relationship with a 0.28% (95%CI: 0.05–0.50%) and	Contaminations had only been assessed by outdoor pollution, and that

Authors	**Location**	**Study time**	**Research Design**	**Method**	**Sample size**	**Results**	**Limitations**
						0.51% (95%CI: 0.02–0.99%) increase in all root hospitalizations, respectively. On various lag days, PM_{10}, PM_C, $PM_{2.5}$ were significantly correlated with schizophrenia admissions.	may not be the entire personal exposure.
Jie Song et al. (J. Song et al., 2018)	Shijiazhuang, China	2014 to 2016	A time-series regression study	Quasi-Poisson distribution	9156 hospital admissions	a 10 μg/m^3 rise in $PM_{2.5}$ over an average of 3 days (lag02) associated with 0.48% (95%CI: 0.18-0.79%) increases daily hospitalization rates for MBDs. The vulnerable groups are male and older people (≥45 years). Having	The research did not analyze the effects of particle matter on specific psychological groups. Individual characteristics, such as socioeconomic status, schooling,

Authors	**Location**	**Study time**	**Research Design**	**Method**	**Sample size**	**Results**	**Limitations**
						a generally stronger correlation of $PM_{2.5}$ in the cool season with psychiatric and behavioral problems than in the warm season.	and comorbid conditions, were not considered in this study.
Chen Chen et al. (Chen et al., 2018)	Shanghai, China	2013 to 2015	A time-series regression study	Quasi-Poisson distribution	39,143 hospital admissions	Increases of 1.27% [95 %(CI): 0.28%, 2.26%], 6.88% (95%CI, 2.75%, 11.00%), and 0.16% (95 %CI: 0.02%, 0.30%) were significantly correlated with a 10-μg/m^3 rise in 2-day, moving-average concentration of inhalable particulate matter, sulfur dioxide (SO_2), and carbon monoxide. In warm seasons,	The study also did not analyze the short-term associations between particles matter and specific psychological groups

Authors	Location	Study time	Research Design	Method	Sample size	Results	Limitations
						we have typically found stronger associations of air contaminants with MDs than in cool seasons. The associations between different sexes and age groups have not distinguished significantly.	
Feng Wang et al. (F. Wang et al., 2018)	26 Chinese cities		A time stratified case-crossover design	Conditional logistic regression	19,646 hospital admissions	$PM_{2.5}$ presented the association with the figure for depression positively. Especially, the risks of hospitalization peaked when $PM_{2.5}$ on lag day 0 (2.92; 1.37–4.50) and lag day 5 (3.65; 2.09–5.24). Older people were more	This study could not differentiate between emergent admissions and planned admissions, resulting in bias due to certain cases that did not affect PM exposure.

Authors	Location	Study time	Research Design	Method	Sample size	Results	Limitations
						vulnerable when exposing to $PM_{2.5}$ (9.23; 5.09–13.53)	
Hang Qiu et al (Qiu et al., 2019)	Chengdu, China	2015 to 2016	A time-series regression study	A generalized additive model (GAM)	10,947 hospital admissions	The outcome showed that $PM_{2.5}$ was substantially correlated with elevated hospitalization risks for MDs. In hospitalizations for MDs, every 10 μg/m^3 increase in $PM_{2.5}$ at lag06 corresponded to an increase of 2.89% (95% CI: 0.75-5.08%). Dementia, schizophrenia, and depression were found a significant association with PM pollution.	Personal features such as smoking, marital and social status were not regulated. Only temperature and relative humidity were considered as confounders of weather conditions.
Pei Zang	Chengdu,	2013	A time-series	A	134,292	At the cumulative lag03	This study assumed

Authors	Location	Study time	Research Design	Method	Sample size	Results	Limitations
et al (P. Zhang & Zhou, 2020)	Southwestern China	to 2017	analysis	generalized additive model (GAM)	hospital admissions	day, every 10 μg/m^3 rise in $PM_{2.5}$ concentrations (≤ 2.5 μm) will be responsible for 6.38% (95%CI: 4.79–7.97%) rises in regular hospital admissions for MDs, respectively. It is noted that males and individuals over 45 years had stronger associations in cool seasons.	that residents in Chengdu shared the same level of PM pollution. This did not consider spatial heterogeneity of PM pollution and people's time-activity patterns, which may lead to underestimation of the association between short-term exposure to PM pollution and hospital admissions of MDs

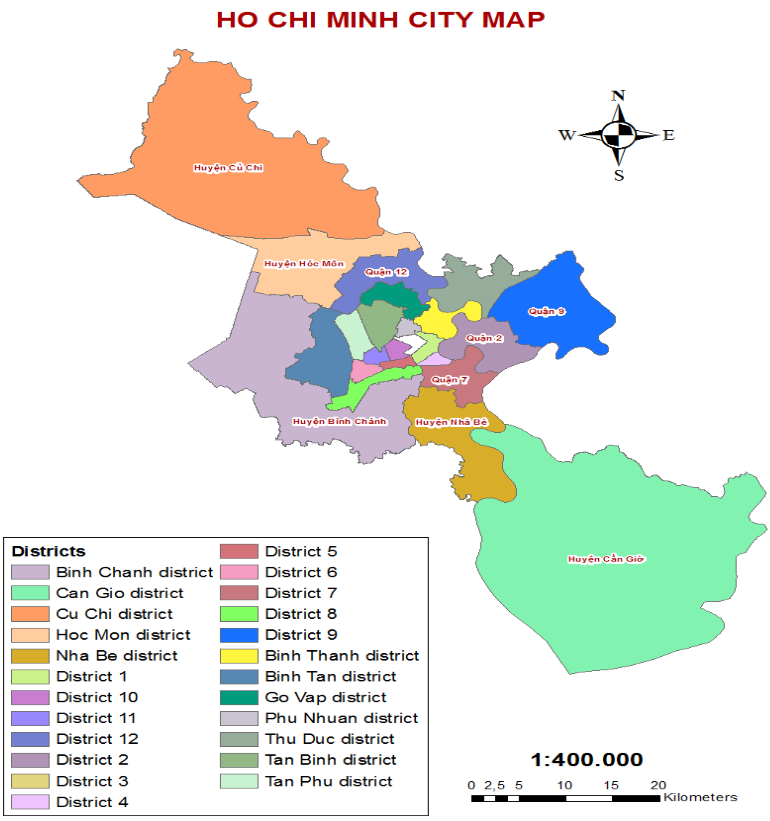
Chapter III: Methodology

3.1 Research design

The research was conducted using a time-series regression analysis. The data on hospital admission related to mental and behavioral disorders will be obtained from the Ho Chi Minh City Mental health hospital. In this study, the study period is June 2019 to December 2020 which corresponds to the air pollution data from monitoring stations that started to collect in June 2019.

3.2 Study area

This study was carried out in HCMC, the South of Vietnam, which possesses a tropical climate. The total region of the city is 2095 km^2, comprising 19 urban and 5 suburbans which have a population of 8.993.082 people in 2019 (General Statistic Office, 2019b). The city has a hot and humid climate year-round, with a high mean temperature of 28°C. The climate has two major seasons, the rainy season (May to October) and the dry season (November to April the next year).



Ho Chi Minh City Map

3.3 Study population

Hospitalized patients who were diagnosed with mental and behavioral disorders in HCMC.

3.4 Sampling technique

The hospital admission data obtained from HCMC Mental Health Hospital, including the total number of inpatient hospitalizations due to MBDs. HCMC Mental Health Hospital is one of the biggest hospitals in the Southern of Vietnam that specialized in mental illness. This hospital has two separate inpatient departments for men and women with a total of 100 beds.

Inclusion criteria

Data of patients hospitalized for mental and behavioral disorders at HCMC Mental Hospital from June 2019 to December 2020, including F00-F99.

Exclusion criteria

Patient with incomplete address information or the address not located in HCMC.

3.5 Sample and sample size

All hospitalizations for mental and behavioral issues at the HCMC Mental Health Hospital from June 1st, 2019 to December 31st, 2020.

3.6 Data collection

3.6.1 Hospital admission data

This study using secondary data from the hospital record.

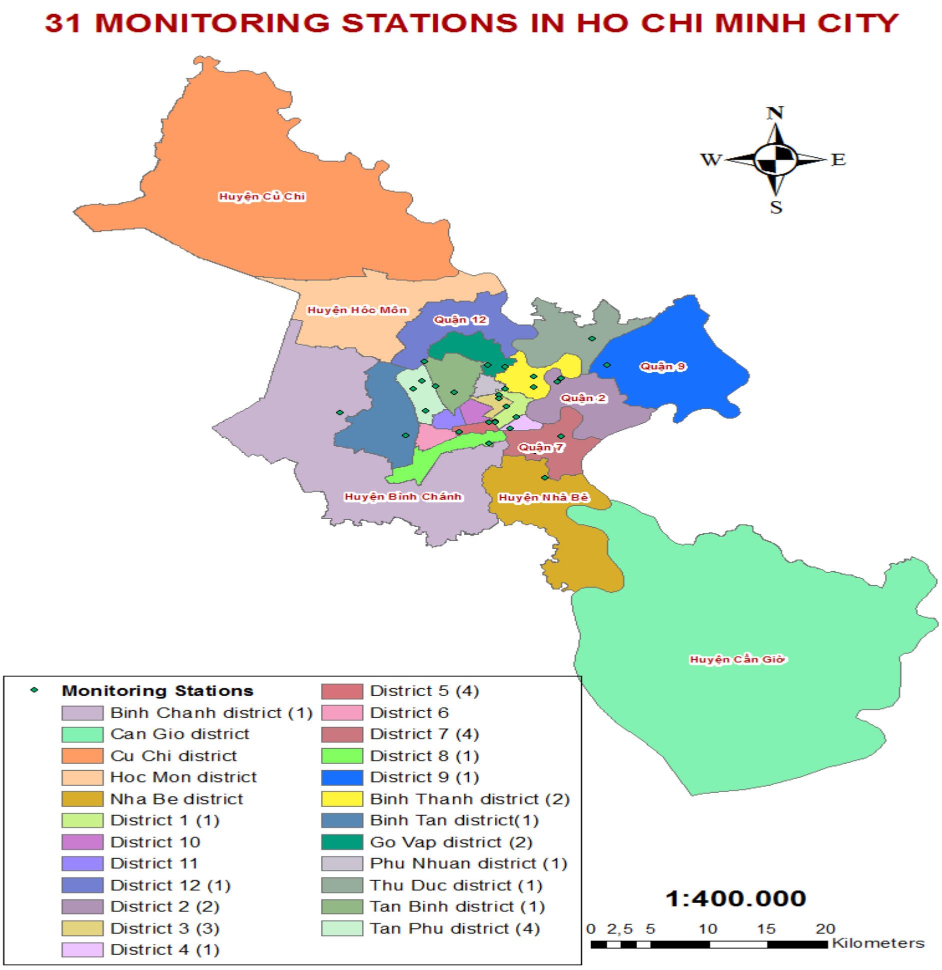
The variables related to the patient admission including: final diagnosis with ICD-10, admission date, discharge date, age, sex, permanent address of the patient from June 2019 to December 2020 extracted from the electronic medical records of the Mental Hospital in HCMC.

We obtained permission from Ho Chi Minh City Mental health hospital to use medical records in this study.

3.6.2 Air pollution data

The $PM_{2.5}$ data we collected from 31 monitoring stations (PAS-OA318) located in Ho Chi Minh City. These monitoring stations were organized and maintained by PAM Air as a D&L Technology Integration and Consultancy Joint Stock Company project, providing real-time air quality developments and air pollution warnings in

Vietnam. The average concentrations daily were then calculated from hourly values with a 50% completeness criterion. It means that if less than 12 hours of concentration data were available per day, then the average each day was assigned as 'missing'. Missing values were substituted with the average of one datum before the missing value and one datum after the missing value using the mean-before-after method (Norazian, Shukri, Azam, & Bakri, 2008).



31 monitoring stations in HCMC (PAM Air Company)

Daily average temperature and relative humidity data in the same period were extracted from the 31 monitoring stations (PAS-OA318). The stations are located on major roads and densely populated areas.

The physical sensor with code is PAS - OA 318 manufactured by PAM Air.

- Device uses Light Scattering technology to measure the concentration of $PM_{2.5}$.

- Device measures every 5 minutes for indicators: $PM_{2.5}$, temperature and humidity.

- Equipment is directly installed, operated and maintained by engineers.

- Equipment is calibrated before shipped and once every 3 months during operation.

- $PM_{2.5}$ measured concentrations will be converted to Air Quality Index (AQI) according to the US Consulate's "NowCast" hourly AQI calculation method.

Measuring range	
Temperature	0 - 65ºC
Relative humidity	0 - 100%
$PM_{2.5}$	0 - 999 µg/m^3

3.7 Data analysis

3.7.1 Descriptive Statistics

Quantitative variables ($PM_{2.5}$, temperature and humidity) report mean, standard deviation, minimum, maximum, and percentile of 25%, 50%, 75%.

Describe the distribution of variables that have changed over the study period.

Describe seasonal variation of the variables study period.

3.7.2 Statistical analysis

A quasi-Poisson time series regression model was used to determine the association between daily hospital admission for MBD_S and ambient particulate matter pollution. In which the dependent variable is the number of daily admissions due to MBDs. The independent variable is the average daily $PM_{2.5}$ concentration. We sub-analyzed the risk following the groups, including ICD10 code, sex, age and season groups.

A flexible spline function of time with 7 degrees of freedom per year was used to control seasonal and long-term trends (Bhaskaran, Gasparrini, Hajat, Smeeth, & Armstrong, 2013). At the same time, to estimate the delayed effect, we examined the association when lag terms were modelled one at a time (from lag 0 to lag 7) as shown in the equation.

We used the natural smooth functions of the mean temperature (6, *df*) and relative humidity (3, *df*) in order to control for the nonlinear confounding effects (J. Song et al., 2018). We also have integrated day of week into the model as dummy variable.

Hospital admission data for MBDs were extracted for 2 disease groups of Schizophrenia (F20) and Mood disorder (F30-F39). In addition, a sensitivity analysis was conducted to check for the model. We used a time-stratified model with a stratum for each month nested in year as an alternative seasonality and long-term trend control.

We select the most optimal model based on the Q-AIC criterion (Akaike Information Criterion). The best model is the one with the smallest Q-AIC value (ScienceDirect, 2020). The model parameters are described in detail below:

$$Yt \sim \text{Quasi-Poisson}\ (\mu t)$$

$$\text{Log}\ (E(Yt)) = \alpha + \beta{*}Zt + \text{ns}\ (\text{time}_t, df) + \text{ns}\ (\text{temp}_t, 6) + \text{ns}\ (\text{rh}_t, 3) + \text{DOW}$$

Where

α is the intercept

E(Yt) is the number of daily cases due to MBDs, obeying quasi-Poisson distribution for each day t

β represents the log-related rate of MBDs admission rate associated with a unit (per 10 $\mu g/m^3$) increase of $PM_{2.5}$

Zt: indicates the daily mean concentration of $PM_{2.5}$ at day t

ns (time_t, df) is the natural spline function for calendar time

ns (temp_t, 6); ns (rh_t, 3) are the natural spline function for temperature and humidity at day t

DOW is the categorical day of the week with a reference day of Sunday

All statistical analysis will be performed using R 4.0.5

3.8 Ethical consideration

The study was only carried out by collecting secondary data (the number of daily hospitalizations due to mental illness) and not collecting patient names, so it should ensure confidentiality for study participants.

Exemption for Ethics Review consideration for this study was approved by the Ethics Review Committee of Chulalongkorn University, as attached in Appendix.

3.9 Expect benefit of study

This study will be the first study to determine the relationship between $PM_{2.5}$ and hospitalization rates due to mental illness in Ho Chi Minh City. Study results will offer more evidence about the impacts of $PM_{2.5}$ on people's health.

Chapter IV: Results

From 4,544 cases collected from the hospital's electronic medical records, based on the inclusion and exclusion criteria, the final sample size we used to analyze for hospital admission was 3,513 cases.

4.1 Descriptive statistics

4.1.1 Characteristics of hospital admissions due to MBDs, $PM_{2.5}$ and weather condition in Ho Chi Minh City

During the study period from June 2019 to the end of 2020, the total hospital admissions for MBDs was 3,513 at HCMC mental health hospital. In which, nearly half of the hospitalized cases were diagnosed with the code F20 (Schizophrenia), accounting for 49.1%, which was more than four times that of F30-F39 (Mood disorders), (1,724 and 447, respectively). The number of MBDs admissions of males was nearly twice of females (2,253 and 1,260 admissions, respectively). There were more admissions for the younger age group ≤ 44 year old than the middle age group of 45-59 years old and the elderly age group ≥ 60 year old (2,174; 1,052 and 287, respectively).

At the same time, the higher number of hospitalizations during the wet season (May to October) accounted for 61.3%, which was 1.5 times compared to the dry season (November to April).

Table 1. Characteristics of hospitalizations for mental disorders in HCMC Mental Health Hospital, Vietnam, from June 2019 to December 2020 (n = 3,513)

Variable	Frequency (n)	Percent (%)
Total number of admissions	3,513	100
Schizophrenia (F20)	1,724	49.1
Mood disorders (F30-F39)	447	12.7
Others	1,342	38.2
Sex		
Male	2,253	64.1

Variable	Frequency (n)	Percent (%)
Female	1,260	35.9
Age groups (15-76)		
≤ 44 year old	2,174	61.9
45 - 59 years old	1,052	29.9
≥ 60 year old	287	8.2
Season*		
Dry season	1,360	38.7
Wet season	2,153	61.3

**Wet season: from May to October; Dry season: from November to April.*

The daily mean all-cause hospitalization was 6.1, ranging from 0 to 14. The daily mean of Schizophrenia (F20) was the highest, and the group of Mood disorder (F30-F39) accounted for the lowest, (mean, 3.0 and 0.8 admissions/day, respectively). The number of male patients hospitalized was higher than that of female patients (2.2 vs 1.6). In addition, hospitalized patients who less than 45 year old have the highest number of cases.

In terms of climatic conditions, the average daily temperature during the study period ranged from 24.1°C to 33.2 °C (mean = 29.6 °C). The average daily humidity ranged from 50.0% to 88.4% (mean, 68.8%).

The daily levels of $PM_{2.5}$ ranged from 8.7 to 66.0 $\mu g/m^3$ with a mean (annual average concentration) of 25.6 $\mu g/m^3$, which slightly exceeded the national standard of Vietnam (25 $\mu g/m^3$) and was nearly 2.5 times the WHO air quality guideline value for annual average $PM_{2.5}$ (10 $\mu g/m^3$) (Minister of Natural Resources and Environment of The Socialist Republic of Vietnam, 2013; WHO, 2005) . During the study period, the daily averages of $PM_{2.5}$ exceeded the Vietnamese national standard (50 $\mu g/m^3$ for 24-h average) on only 6 days (1.0% of) but exceeded the WHO guideline (25 $\mu g/m^3$ for 24-h average) on 145 days (25% of the study period).

Table 2. Summary statistics of $PM_{2.5}$ and meteorological variables in HCMC Mental Health Hospital, Vietnam, from June 2019 to December 2020

	Mean (SD)	Min	Frequency distribution			Max
			25th	50th	75th	
Hospital admissions for MBDs (total and by groups)						
All cases	6.1 (3.0)	0	4	6	8	14
Schizophrenia (F20)	3.0 (2.0)	0	2	3	4	10
Mood disorder (F30 – F39)	0.8 (0.9)	0	0	1	1	4
Sex						
Male	3.9 (2.2)	0	2	4	5	11
Female	2.2 (1.6)	0	1	2	3	8
Age groups						
≤ 44 year old	3.7 (2.1)	0	2	4	5	11
45 - 59 years old	1.8 (1.5)	0	1	2	3	9
≥ 60 year old	0.5 (0.7)	0	0	0	1	3
Meteorology						
Temperature (^{o}C)	29.6 (1.4)	24.1	28.7	29.6	30.5	33.2
Relative humidity (%)	68.8 (7.3)	50.0	63.8	68.4	73.5	88.4
$PM_{2.5}$ ($\mu g/m^3$)	25.6 (8.5)	8.7	20.8	24.8	29.9	66.0

	Number of day of $PM_{2.5}$ exceed of standard level	(n)	(%)
QCVN 05:2013*	50 $\mu g/m^3$ 24-hour (day)	6	1.0
WHO (World Health Organization, 2005)	25 $\mu g/m^3$ 24- hour (day)	145	25.0

**National Technical Regulation on Ambient Air Quality (Vietnam)*

4.1.2 Distribution of hospital admissions due to MBDs and $PM_{2.5}$ concentrations over time in 2019 – 2020

Overall, the number of hospital admissions seems to be cyclical to change every three months. The number of hospital admissions increased in the first three months of the year and then decreased in the next three months, then continues to increased in the next three months and decreased in the last three months of the year. In addition, the daily hospital admissions were lowest in April 2020 (115 cases and mean, 3.8 admissions/day). Meanwhile, the concentration of $PM_{2.5}$ increased from the middle to the end of the year and decreased in the first 6 months. There was a spike in the concentration of $PM_{2.5}$ around a few days of the end of December 2020 (from 16.8 to 66 μg/m^3) .

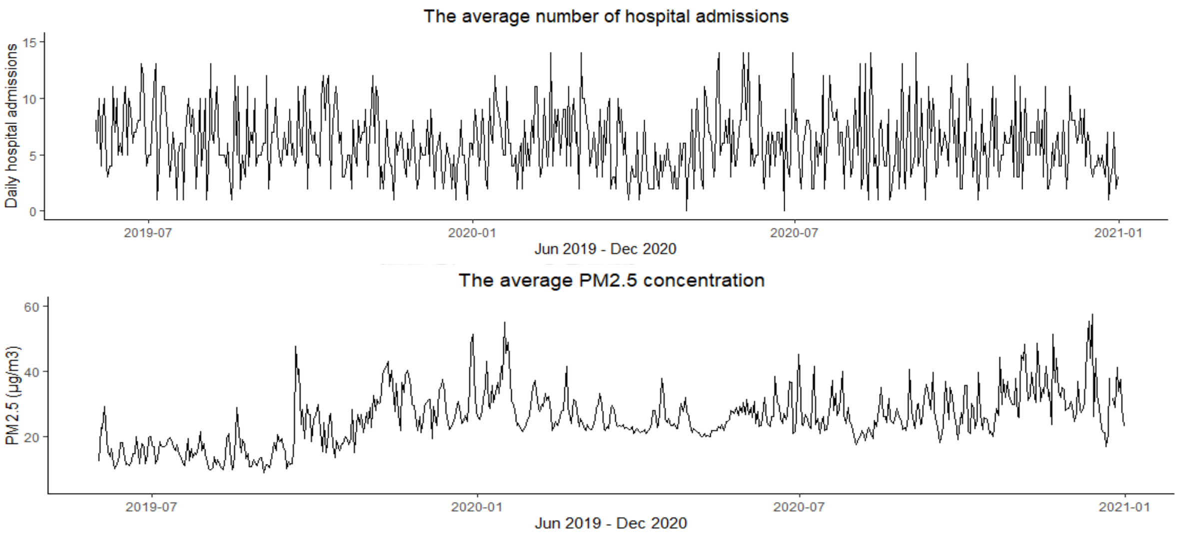


Figure 1. Distributions of daily hospital admissions for MBDs and daily mean concentration of $PM_{2.5}$ (μg/m^3) in Ho Chi Minh city during the study period (Jun 2019 – Dec 2020)

The number of hospital admissions fluctuated around an average of about 6 admissions/day throughout the months. The daily hospital admissions was decreased to the lowest in April at 3.8 admissions/day. Meanwhile, the concentration of $PM_{2.5}$ increased from the end of the year (November) to the beginning of the upcoming year (February), with the highest average concentration was 33.7 (μg/m^3) in November and the lowest average was 18.9 (μg/m^3) in August.

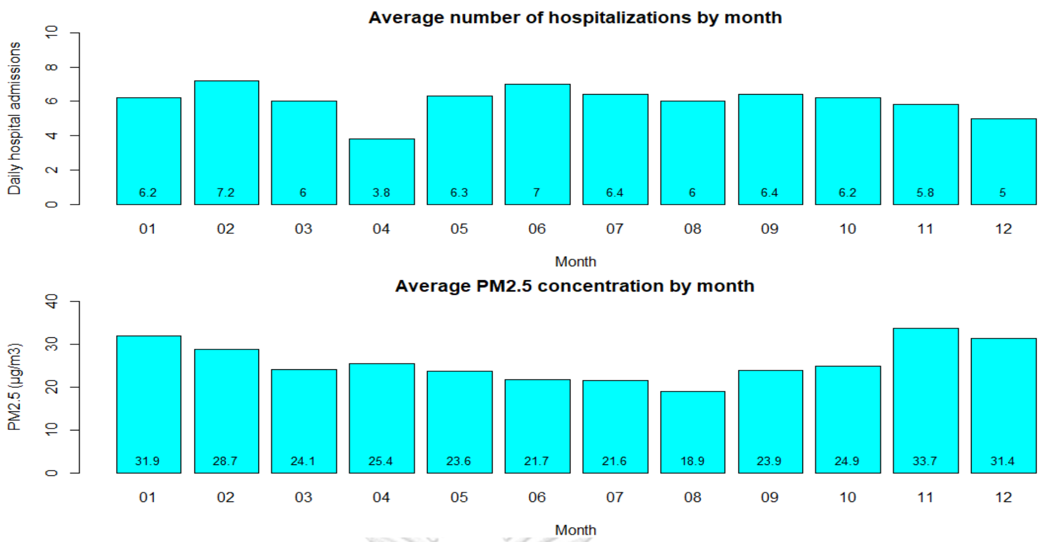


Figure 2. Daily hospital admissions and mean concentration of $PM_{2.5}$ in each month in HCMC (Jun 2019 – Dec 2020)

The average number of hospital admissions per day in the wet season was higher than in the dry season (6.4 vs 5.6 admissions/day, respectively). In addition, the seasonal distribution of $PM_{2.5}$ is different from the mean hospital admission data. In the wet season, the average daily $PM_{2.5}$ concentration was 22.3 $\mu g/m^3$ that low than the average daily concentration in the dry season with 30.0 $\mu g/m^3$. In addition, the average of hospital admissions and that of $PM_{2.5}$ between 2 seasons, were statistically significant differences *(t-test, $p < 0.01$).*

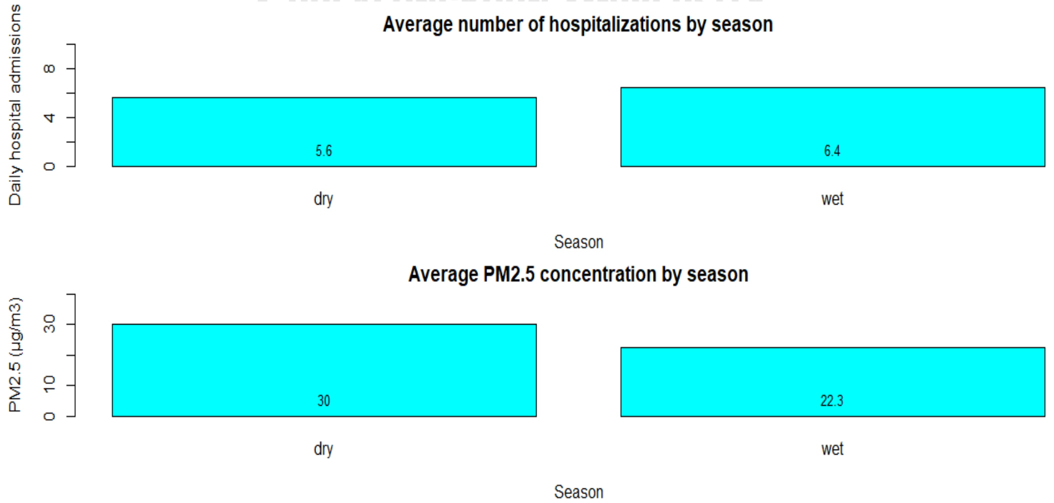


Figure 3. Daily hospital admissions and mean concentration of $PM_{2.5}$ in each season in HCMC (Jun 2019 – Dec 2020)

4.2 The correlation between MBDs hospitalization and potential predictor variables

Considering the correlation between variables with hospital admission. There was variable $PM_{2.5}$ concentration was a weak negative correlation with hospital admission. Temperature and relative humidity has a weak positive correlation, but all these results were not statistically significant with the hospitalization due to MBDs.

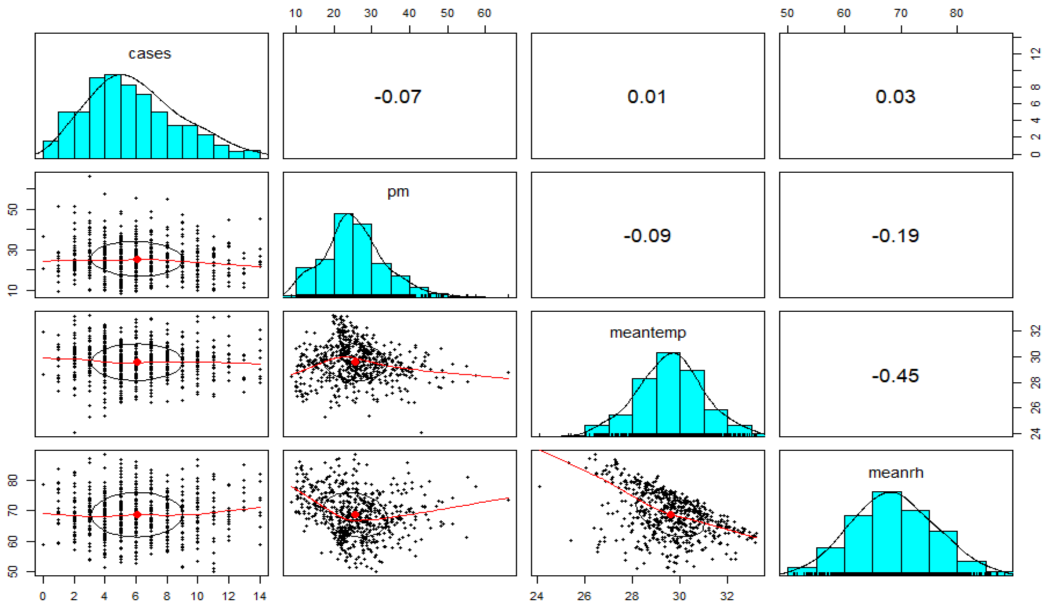


Figure 4. Spearman correlation coefficient between multiple variables

4.3 Association between $PM_{2.5}$ and hospital admissions for total MBDs, Schizophrenia and Mood disorder

Overall, the association between $PM_{2.5}$ and admission for MBDs (Total, Schizophrenia and Mood disorder) after seven days of exposure were not observed. For single lag effects, every 10 μg/m^3 of $PM_{2.5}$ increased, the risk of hospital admission for Mood disorder increased with RR = 1.05 (95%CI: 0.89-1.23) at lag 7, but this association is not statistically significant.

Table 3. Association between $PM_{2.5}$ and hospital admissions for MBDs

Lag (days)	Total MBDs	Schizophrenia	Mood disorder
Lag 0	1.00 (0.94-1.06)	1.01 (0.93-1.10)	0.99 (0.84-1.17)
Lag 1	1.00 (0.95-1.07)	1.00 (0.91-1.08)	0.97 (0.82-1.14)
Lag 2	0.98 (0.93-1.05)	1.00 (0.92-1.09)	0.93 (0.79-1.10)
Lag 3	1.00 (0.94-1.06)	0.99 (0.91-1.08)	0.93 (0.79-1.10)
Lag 4	1.01 (0.95-1.07)	0.97 (0.89-1.06)	1.02 (0.87-1.20)
Lag 5	0.98 (0.93-1.04)	0.99 (0.91-1.07)	0.94 (0.79-1.10)
Lag 6	0.98 (0.92-1.04)	0.99 (0.91-1.07)	0.94 (0.80-1.10)
Lag 7	1.01 (0.96-1.08)	1.00 (0.91-1.08)	1.05 (0.89-1.23)

4.4 Association between $PM_{2.5}$ and hospital admissions for MBDs by sex

In both models, when considering the day-to-day and the all lagged effect modeled together, the association for the male and female groups at any lag and any groups (total MBDs, Schizophrenia and Mood disorder) were not observed. However, it can be seen that the delayed effects of the female were all positive associations (from lag 0 to lag 7) in total MBDs.

Table 4. Association between $PM_{2.5}$ and hospital admissions for MBDs by sex

Single lag effects	Sex	
	Male	**Female**
Total		
Lag 0	0.97 (0.90-1.04)	1.06 (0.96-1.16)
Lag 1	0.98 (0.91-1.05)	1.05 (0.96-1.16)
Lag 2	0.97 (0.90-1.05)	1.01 (0.91-1.11)
Lag 3	0.99 (0.92-1.07)	1.00 (0.91-1.10)
Lag 4	1.01 (0.94-1.09)	1.00 (0.91-1.10)
Lag 5	0.97 (0.90-1.05)	1.00 (0.91-1.11)
Lag 6	0.96 (0.89-1.03)	1.03 (0.93-1.13)
Lag 7	1.02 (0.95-1.10)	1.01 (0.91-1.11)
Schizophrenia		
Lag 0	0.98 (0.88-1.10)	1.06 (0.94-1.20)

Single lag effects	Sex	
	Male	**Female**
Lag 1	0.95 (0.85-1.06)	1.06 (0.94-1.20)
Lag 2	1.00 (0.90-1.12)	1.01 (0.89-1.15)
Lag 3	1.04 (0.93-1.15)	0.94 (0.83-1.07)
Lag 4	1.00 (0.90-1.10)	0.94 (0.83-1.07)
Lag 5	1.02 (0.91-1.13)	0.95 (0.83-1.08)
Lag 6	0.96 (0.86-1.07)	1.03 (0.91-1.17)
Lag 7	1.03 (0.92-1.14)	0.95 (0.84-1.08)
Mood disorder		
Lag 0	0.88 (0.68-1.14)	1.06 (0.85-1.32)
Lag 1	1.05 (0.82-1.34)	0.90 (0.72-1.13)
Lag 2	1.11 (0.87-1.41)	0.79 (0.62-1.01)
Lag 3	0.92 (0.71-1.19)	0.94 (0.75-1.18)
Lag 4	1.03 (0.81-1.31)	1.02 (0.82-1.26)
Lag 5	0.77 (0.60-1.00)	1.06 (0.85-1.32)
Lag 6	0.91 (0.71-1.17)	0.96 (0.77-1.20)
Lag 7	1.04 (0.82-1.32)	1.04 (0.84-1.29)

4.5 Association between $PM_{2.5}$ and hospital admissions for MBDs by age group

No statistically significant associations were found between the $PM_{2.5}$ and ≤ 44 year old groups for total MBDs, Schizophrenia and Mood disorder from lag 0 to lag 7.

Among 45 – 59 years old group, except for lag 1, there were all negative associations between $PM_{2.5}$ and total MBDs and Schizophrenia. In which especially, the highest RR for each 10 $\mu g/m^3$ increase in $PM_{2.5}$ was 1.15 (95%CI: (0.88-1.51) at lag 3 for Mood disorder. However, these associations were not statistically significant.

In contrast, positive associations between $PM_{2.5}$ and hospital admissions for total MBDs and Schizophrenia were found for ≥ 60 year old at lag 7, RR for each 10 $\mu g/m^3$ increase in $PM_{2.5}$ were 1.25 (95%CI: 1.03-1.52) and 1.45 (95%CI: 1.12-1.89), respectively.

Table 5. Association between $PM_{2.5}$ and hospital admissions for MBDs by age group

Single lag effects	**Age group**		
	≤ 44 year old	**45 – 59 years old**	**≥ 60 year old**
Total			
Lag 0	1.00 (0.93-1.08)	0.98 (0.88-1.10)	1.03 (0.84-1.27)
Lag 1	0.99 (0.92-1.06)	1.03 (0.93-1.14)	1.06 (0.86-1.29)
Lag 2	1.00 (0.93-1.08)	0.96 (0.86-1.07)	0.93 (0.75-1.15)
Lag 3	1.01 (0.94-1.08)	0.96 (0.86-1.07)	1.04 (0.86-1.27)
Lag 4	1.01 (0.94-1.09)	0.98 (0.89-1.09)	1.04 (0.86-1.26)
Lag 5	0.97 (0.90-1.04)	0.99 (0.89-1.10)	1.06 (0.87-1.29)
Lag 6	0.97 (0.90-1.04)	0.98 (0.88-1.10)	1.11 (0.91-1.36)
Lag 7	1.02 (0.94-1.09)	0.96 (0.86-1.07)	**1.25 (1.03-1.52)***
Schizophrenia			
Lag 0	1.02 (0.92-1.14)	0.95 (0.83-1.10)	1.11 (0.85-1.45)
Lag 1	0.98 (0.88-1.10)	1.02 (0.89-1.16)	0.96 (0.72-1.28)
Lag 2	1.04 (0.93-1.16)	0.99 (0.86-1.14)	0.83 (0.62-1.12)
Lag 3	1.05 (0.94-1.17)	0.92 (0.80-1.06)	0.94 (0.73-1.23)
Lag 4	0.98 (0.87-1.09)	0.94 (0.82-1.07)	1.03 (0.80-1.33)
Lag 5	0.98 (0.87-1.09)	0.95 (0.83-1.09)	1.15 (0.88-1.50)
Lag 6	0.98 (0.87-1.10)	0.95 (0.82-1.09)	1.20 (0.92-1.57)
Lag 7	0.95 (0.85-1.07)	0.96 (0.83-1.10)	**1.45 (1.12-1.89)***
Mood disorder			
Lag 0	1.02 (0.82-1.26)	1.03 (0.76-1.39)	0.67 (0.36-1.23)
Lag 1	0.95 (0.77-1.18)	0.94 (0.71-1.25)	1.10 (0.68-1.77)
Lag 2	0.93 (0.75-1.16)	0.92 (0.68-1.23)	0.90 (0.52-1.57)
Lag 3	0.81 (0.64-1.02)	1.15 (0.88-1.51)	0.95 (0.55-1.65)
Lag 4	1.05 (0.86-1.28)	0.98 (0.74-1.31)	0.84 (0.45-1.56)
Lag 5	0.80 (0.63-1.00)	1.14 (0.88-1.47)	0.91 (0.52-1.58)
Lag 6	0.86 (0.69-1.08)	1.00 (0.76-1.33)	1.05 (0.61-1.79)
Lag 7	1.09 (0.88-1.35)	1.06 (0.82-1.38)	0.70 (0.37-1.34)

*$p < 0.05$

4.7 Association between $PM_{2.5}$ and hospital admissions for MBDs by season

Among Mood disorder, negative association was observed between $PM_{2.5}$ and hospitalization at lag 1 with RR = 0.78 (95%CI = 0.65-0.94) in the dry season. While in the wet season, significant positive association was observed in the same lag with RR = 1.23 (95%CI = 1.04-1.47).

For total MBDs admission, significant association was found at lag 7 with RR = 1.10 (95%CI: 1.02-1.18) in wet season. Similarly, the concentration of $PM_{2.5}$ positively associated with the hospitalizations for Schizophrenia at lag 7 (RR = 1.14, 95%CI: 1.00-1.29, p = 0.04), but no significant association was observed between $PM_{2.5}$ and hospitalization in dry season.

Table 6. Association between $PM_{2.5}$ and hospital admissions for MBDs by season

Single lag effects	**Season**	
	Dry	**Wet**
Total		
Lag 0	0.98 (0.92-1.05)	1.02 (0.95-1.10)
Lag 1	0.97 (0.92-1.03)	1.01 (0.94-1.10)
Lag 2	0.97 (0.91-1.04)	0.98 (0.91-1.06)
Lag 3	1.02 (0.96-1.09)	0.96 (0.89-1.04)
Lag 4	1.04 (0.98-1.10)	1.00 (0.93-1.08)
Lag 5	1.00 (0.94-1.06)	0.97 (0.90-1.05)
Lag 6	0.97 (0.91-1.03)	0.98 (0.91-1.06)
Lag 7	0.95 (0.90-1.01)	**1.10 (1.02-1.18)***
Schizophrenia		
Lag 0	1.08 (0.96-1.22)	0.97 (0.85-1.11)
Lag 1	0.96 (0.85-1.09)	0.98 (0.86-1.13)
Lag 2	1.00 (0.88-1.14)	1.01 (0.88-1.15)
Lag 3	1.06 (0.93-1.21)	0.94 (0.82-1.07)
Lag 4	1.04 (0.92-1.17)	0.92 (0.80-1.06)
Lag 5	0.99 (0.87-1.12)	0.97 (0.85-1.11)
Lag 6	0.98 (0.86-1.12)	0.99 (0.87-1.13)
Lag 7	0.92 (0.81-1.05)	**1.14 (1.00-1.29)***

Single lag effects	Season	
	Dry	Wet
Mood disorder		
Lag 0	0.93 (0.77-1.11)	1.12 (0.94-1.35)
Lag 1	**0.78 (0.65-0.94)***	**1.23 (1.04-1.47)***
Lag 2	0.85 (0.71-1.02)	1.07 (0.89-1.28)
Lag 3	1.01 (0.85-1.20)	0.92 (0.76-1.12)
Lag 4	1.10 (0.93-1.31)	1.05 (0.87-1.26)
Lag 5	1.08 (0.92-1.26)	0.83 (0.69-1.01)
Lag 6	0.96 (0.82-1.13)	0.86 (0.72-1.04)
Lag 7	0.92 (0.78-1.09)	1.19 (1.00-1.42)

*$p < 0.05$

4.8 Overall lag effect of $PM_{2.5}$ on hospital admissions for MBDs

Overall, the associations varied by ICD groups, sex age groups and season for the $PM_{2.5}$ effects were insignificant. Among sex groups, insignificant positive associations were found in female patients. In the age-specific analysis, the associations were more prominent among patients who were older than 60 years than among those who were in the younger age groups, but this association is not statistically significant.

In the wet season, although not statistically significant, our study revealed that the cumulative lag effect during this period was higher than in the dry season (RR=1.04 vs RR=0.92, respectively).

Table 7. Overall lag effect of 7 days of $PM_{2.5}$ and hospital admissions for total MBDs (Spline function model)

	Overall cumulative lag effect	
	RR	95% CI
Total	0.99	0.89 - 1.11
Schizophrenia (F20)	0.99	0.84 - 1.16
Mood disorder (F30 – F39)	0.89	0.66 - 1.21
Sex		
Male	0.95	0.83 - 1.09
Female	1.07	0.89 - 1.29
Age groups		
≤ 44	0.99	0.86 - 1.13
45 - 59 years old	0.96	0.79 - 1.17
≥ 60 year old	1.12	0.77 - 1.62
Season		
Dry	0.92	0.81 - 1.04
Wet	1.04	0.88 - 1.23

4.9 Sensitivity analysis

We performed sensitivity analyzes to check the reliability of the model. To control for seasonality and long-term trends, we have changed the functions of time is fitted as part of the regression model (Time stratified model and Flexible spline functions). Regarding temperature and relative humidity were changed the procedure to generate a basis matrix in the model by cross-basis matrices with strata defined by internal cut-offs or natural cubic spline (B-spline).

Other sensitivity analyzes conducted in this study did not show any notable changes in the results. The Q-AIC value results show that our main model is the most optimal (Q-AIC value = 2726.113).

Table 8. Q-AIC values of different models

Alternative models	Q-AIC value
Main model *(Lag terms were modelled one at a time)*	**2726.113**
Time – stratified model (Model 1)	2729.28
Spline function model and cross-basis matrices with strata defined by internal cut – offs for temperature and relative humidity (Model 2)	2845.918

Chapter V: Discussion

In recent years, epidemiological and animal toxicology studies reported several constituents of air pollution might have the adverse impacts on central nervous system. Many studies have shown that air pollution has detrimental health impacts, however, most of them have concentrated on physical disease, with only a handful studying the impact of air pollution on mental health. This research adds to our understanding of how air pollution affects our health, especially about mental health. Our study showed that the city wide daily mean concentrations of $PM_{2.5}$ were 25.6 $\mu g/m^3$. These values were exceed 24-hour mean concentrations for $PM_{2.5}$ recommended by WHO Air quality guidelines (AQGs), which is 25 $\mu g/m^3$ (WHO, 2005).

5.1 Association between $PM_{2.5}$ and hospital admissions for MBDs by sex

Contrary to expectations, this study did not find a significant association between sex and hospitalizations for mental disorders. This finding contradicts the observations of Gao et al. (2017) who found that $PM_{2.5}$ is substantially linked to female for schizophrenia admissions on lag06 (Gao et al., 2017).

Although not statistically significant, our study showed that the cumulative lag effect in females was higher than in males (RR=1.07 vs RR=0.95, respectively). Analyzing of individual characteristics to air pollutantion exposure are also useful to investigate the mechanism of effects from air pollutants. A demonstrated that nonsmokers were more sensitive to air pollution than smokers (Cakmak, Dales, & Judek, 2006). Oxidative and inflammatory effects of smoking might play rather vital roles in the health effects of air pollutants to the extent that they dominate the clinical endpoints. Besides, airway reactivity is slightly greater in females than in males (Yunginger et al., 1992). Therefore, concentration-response relations might be detected more easily in females than in males. However, according to evidence from animal and human research, males may be more susceptible to air pollution neurotoxicity than females (Costa et al., 2014; Sunyer et al., 2015). We cannot exclude the possibility that some other subtypes of MBDs, which were not examined in the current study, may be significantly associated with air pollution exposure. However, the low frequency of visits might have influenced the ability to detect the association. There were many other factors that could bring about MBDs, such as living and working pressure, individual characters, and genetic factors. Therefore, the reasons for the sex-specific observations are not yet completely clear and deserve further investigation.

5.2 Association between $PM_{2.5}$ and hospital admissions for MBDs by age group

Age is an important element that can influence mental and neurological functioning in humans. In this study, we observed that $PM_{2.5}$ had a detrimental effect on the elderly at lag 7 in single lag effects, RR for each 10 μg/m^3 increase in $PM_{2.5}$ were 1.25 (95%CI: 1.03-1.52). Our finding was generally consistent with previous studies, although not all results reported the associations of the same pollutants on the same specific subtypes of MBDs. This result is similar to many studies reported previously. A study conducted in the United States revealed that older persons living in locations with higher $PM_{2.5}$ concentrations had poorer cognitive performance (Ailshire & Crimmins, 2014). This also accords with earlier observations of Jie Song et al. (2018), which showed that the association between $PM_{2.5}$ and the group of 45 years and older is more prominent than the other groups (J. Song et al., 2018). Although considering other pollutants, a study in Seoul, Korea reported that an increase in PM_{10}, NO_2, and O_3 can increase depressive symptoms in the elderly (Y.-H. Lim et al., 2012). However, the association between ambient air pollution (PM_{10} and $PM_{2.5}$), age and cognitive function as well as depressive symptoms was differently reported in other studies (Ranft, Schikowski, Sugiri, Krutmann, & Krämer, 2009; Y. Wang et al., 2014) .

Another important finding is that the elderly with schizophrenia are susceptible to $PM_{2.5}$. RR for each 10 μg/m^3 increase in $PM_{2.5}$ was 1.45 (95%CI: (1.12-1.89) at lag 7 in single lag effects. This finding is comparable with a study in China (2017) which also found that the every 10 μg/m^3 of $PM_{2.5}$ increase was associated with a 1.00% increase in schizophrenia admissions at 0–6 cumulative lag days (Gao et al., 2017). Similarly, a study in Japan also indicated that OR associated with significantly increased $PM_{2.5}$ levels for schizophrenic patients over 65 years old (Eguchi et al., 2018). These associations were potential explained by the characteristics of ambient particulate matters. A study indicated that biological components of PM such as endotoxins, mold, and pollen were associated with neurodevelopmental disorders (e.g., schizophrenia, autism, mental retardation) and neurodegenerative diseases. These biological components may play roles in infection and affect the host neuro system (Meyer, Feldon, & Fatemi, 2009). Another possible reason was the characteristic of the elderly. Aging results in the chronic inflammatory status known as 'inflamm-aging', which is clearly associated with deterioration of immune function, called 'immunosenescence' (Bulati, Caruso, & Colonna-Romano, 2017). On the basis of Block's hypothesis that increased cytokine expression, oxidative stress, and activation of microglia affect brain function, the symptoms of schizophrenia may be exacerbated as a result of the deterioration of the function of the immune system associated with aging (Block et al., 2012). However, a report by Sarnat et al. (2001) had shown that ambient concentrations of gaseous air pollutants cannot be considered as surrogates for their respective personal exposures without site-specific evidence to support that assumption (Sarnat, Schwartz, Catalano, & Suh, 2001). Therefore, future studies should considered more potential associate factors such as residential address, household characteristics (e.g., indoor ventilation, indoor air quality), and time spent outdoor.

5.3 Association between $PM_{2.5}$ and hospital admissions for MBDs by season

In this study, we found a significant association between the number of hospital admissions for all mental illnesses at lag 7 with RR = 1.10 (95% CI: 1.02–1.18) in the wet season. Especially for disease subgroups, significant associations were found between $PM_{2.5}$ and hospitalization for schizophrenia at lag 7 (1.14, 95%CI: 1.00 - 1.29, p = 0.04). According to the admission trend, it is clear that the hospital admissions tended to be higher in the wet season (from May to October) compared to that of dry season (from November to April). Similar finding was reported by Gao et al. (2017) who also indicated that during the warm period (from May to October), PM_{10} increased 1.94% risk of schizophrenia admissions at lag 6. However, the association of MBDs and $PM_{2.5}$ in different season were still inconsistent among studies (Gao et al., 2017; J. Song et al., 2018; Tong, Li, & Zhou, 2016). This complex association might be related to PM concentrations which are influenced by meteorological conditions and consequently affect humans' health differently.

Our results revealed a notably finding that the dry season (November to April) had a negative association between $PM_{2.5}$ and total hospitalizations considered single lag effects at lag 1 RR = 0.78 (95%CI = 0.65-0.94). This association may result from the small sample size might have limited the power of the statistics. Furthermore, sociodemographic factors such as economic status, socioeconomic, lifestyle, household and neighborhood characteristics may altered the actual association (Jacobson, James, & C.Schwertman, 2009). Moreover, people may have more outdoor activities in the dry season than in the wet season. Being more active is probably less of a risk for mental health-related illnesses. In addition, these differences may be due to the complex constituents of the particulate matter, climatic conditions, and exposure patterns in different regions. Therefore, the precise seasonal patterns are yet unknown and need to be investigated further.

5.4 Limitation and Strength

5.4.1 Limitation

Our study had some limitations. Firstly, the inconsistent results regarding the association between $PM_{2.5}$ and hospitalizations for MBDs may be due to potential confounding factors that we could not control for in this study. For example, socioeconomic conditions, personal behaviors such as smoking, housing conditions with high exposure to $PM_{2.5}$. Secondly, in the present study only measured outdoor pollution, and that may not be representative of total individual exposures, since exposure to pollution may occur in other surroundings such as in workplace or at home. Furthermore, due to data on hospital admissions in some other mental and behavioral disorders the small size of the groups, we could not do a comprehensive analysis of all groups. For credible precision and power, it needs thousands of observation days with an average of tens of events per day. Another limitation was the prior scheduled hospital admission for mental and behavioral illnesses. It may influenced the number of daily admissions. However, this information could not be obtained due to the privacy and security reason. Therefore, we cannot exclude those patients who admitted due to the prior scheduled out from the daily case number.

Finally, it should be noted that using this time series association analysis was only able to demonstrated the association between exposure and the number of MBDs admission. We cannot demonstrate the causal relationship of the exposure and outcome, but these association may suggest a trigger for emergency admissions for MBDs.

5.4.2 Strength

We used $PM_{2.5}$ data as well as weather data (temperature, humidity) from PAM Air as a D&L Technology Integration and Consultancy Joint Stock Company. Data was collected from 31 monitoring stations dispersed over 17 districts in In Ho Chi Minh City, this allows for a better assessment of air pollution exposure than from a single observation station - especially for spatially heterogeneous pollutants such as $PM_{2.5}$. Moreover, To our knowledge, this is the first study in Vietnam to examine into the association between $PM_{2.5}$ and mental health hospitalizations.

5.5 Conclusion

The present study provided evidence that the daily hospital admission for MBDs and schizophrenia among the elderly in the most populous city of Vietnam were significantly associated with the concentration of $PM_{2.5}$ measured in the city. During the study period, each 10 $\mu g/m^3$ increase in $PM_{2.5}$ heightened the risk of hospital admission for MBDs and schizophrenia significantly in the elderly at lag 7 [1.25 (95%CI: 1.03-1.52), 1.45 (95%CI: 1.12-1.89)], respectively. Moreover, seasons had a significant effect on how $PM_{2.5}$ impacts mental disorders. There is a need for intervention to control the high level of ambient air pollution in the city to protect the population's health in Vietnam.

5.6 Recommendation

Our findings have provided evidence for should have guidelines to prevent and minimize the adverse health effects of air pollution on the elderly, such as placing devices to measure indoor air pollution concentrations.

Also, thorough epidemiological, mechanistic and translational studies to identify how air pollution impacts mental health with the goal of eventual intervention and prevention of mental disease are greatly needed.

Analyzing of individuals characteristics which related to air pollution exposure are also useful to investigate the mechanism of effects from air pollutants.

Appendix

Appendix: Ethical Approval

AF 01-12

The Research Ethics Review Committee for Research Involving Human Research Participants, Group I, Chulalongkorn University

Jamjuree 1 Building, 2th Floor, Phyathai Rd., Patumwan district, Bangkok 10330, Thailand,
Tel: 0-2218-3202, 0-2218-3049 E-mail: eccu@chula.ac.th

COA No. 082/2021

Certificate of Approval
Exemption for Ethics Review

Study Title No. 075.1/64 : ASSOCIATION BETWEEN PM2.5 CONCENTRATIONS AND HOSPITALIZATION CASES WITH MENTAL AND BEHAVIORAL DISORDERS IN HO CHI MINH CITY, VIETNAM FROM 2019 TO 2020

Principal Investigator : MS. DO THI HOAI THUONG

Place of Proposed Study/Institution : College of Public Health Sciences, Chulalongkorn University

This Research proposal is exempted for ethics review in compliance with the Office for Human Research Protections (OHRP Exempt Categories) 45 CFR part 46.101(b).

Certified under condition: To conduct this research project, the researcher (s) must strictly adhere to research proposal approved by the committee. If there is any amendment, it must be sent to the committee for review before carrying on the project.

Signature: P. Sa Tasanapradit
(Associate Professor Prida Tasanapradit, M.D.)
Chairman

Signature: Raveenan Mingpakanee,
(Assistant Prof. Raveenan Mingpakanee, Ph.D.)
Secretary

Date of Exemption : 7 April 2021

Remark: Final report (AF 01-15) and abstract is required for a one year (or less) research/project and report within 30 days after the completion of the research/project.

REFERENCES

TÀI LIỆU THAM KHẢO

Ailshire, J. A., & Crimmins, E. M. (2014). Fine particulate matter air pollution and cognitive function among older US adults. *American journal of epidemiology, 180*(4), 359-366.

Air Visual. (2017). The most polluted countries in the world 2019 (PM2.5). Retrieved from https://www.iqair.com/vi/world-most-polluted-countries?fbclid=IwAR0oPpksCc_Tkt7BHWnN-c1juKBUsEDeeI55dyZWHvFUZOMhTCQp7k9G4VM

Air Visual. (2018). World most polluted countries 2018 (PM2.5). Retrieved from https://www.airvisual.com/world-most-polluted-countries

Anoop S V Shah, et al. (2013). Global association of air pollution and heart failure: a systematic review and meta-analysis. *Lancet, 382*(9897), 1039-1048.

Arden Pope III, C., Burnett, R. T., & al., e. (2002). Lung Cancer, Cardiopulmonary Mortality, and Long-term Exposure to Fine Particulate Air Pollution. *JAMA, 287*(9), 1132-1141.

Beelen, R., et al. (2008). Long-Term Effects of Traffic-Related Air Pollution on Mortality in a Dutch Cohort (NLCS-AIR Study). *Environmental health perspectives, 116*, 196-202.

Beelen, R., et al. (2014). Effects of long-term exposure to air pollution on natural-cause mortality: an analysis of 22 European cohorts within the multicentre ESCAPE project. *The Lancet, 383*(9919), 785-795.

Bhaskaran, K., Gasparrini, A., Hajat, S., Smeeth, L., & Armstrong, B. (2013). Time series regression studies in environmental epidemiology. *Int J Epidemiol, 42*(4), 1187-1195. doi:10.1093/ije/dyt092

Biological, S. C. S., & National, I. o. H. (2007). Information about Mental Illness and the Brain. In *NIH Curriculum Supplement Series [Internet]*: National Institutes of Health (US).

Block, M. L., & Calderón-Garcidueñas, L. (2009). Air pollution: mechanisms of neuroinflammation and CNS disease. *Trends Neurosci, 32*(9), 506-516.

Block, M. L., et al. (2012). The outdoor air pollution and brain health workshop. *Neurotoxicology, 33*(5), 972-984.

Briere, J., Downes, A., & Spensley, J. (1983). Summer in the city: urban weather conditions and psychiatric emergency-room visits. *Journal of Abnormal Psychology, 92*(1), 77.

Brook, R. D., et al. (2010). Particulate matter air pollution and cardiovascular disease: An update to the scientific statement from the American Heart Association. *Circulation, 121*(21), 2331-2378.

Bulati, M., Caruso, C., & Colonna-Romano, G. (2017). From lymphopoiesis to plasma cells differentiation, the age-related modifications of B cell compartment are influenced by “inflamm-ageing”. *Ageing research reviews, 36*, 125-136.

Buoli, M., et al. (2018). Is there a link between air pollution and mental disorders? *Environment international, 118*, 154-168.

Cakmak, S., Dales, R. E., & Judek, S. (2006). Do gender, education, and income modify

the effect of air pollution gases on cardiac disease? *J Occup Environ Med, 48*(1), 89-94. doi:10.1097/01.jom.0000184878.11956.4b
Calderón-Garcidueñas, L., et al. (2004). Brain Inflammation and Alzheimer's-Like Pathology in Individuals Exposed to Severe Air Pollution. *Toxicologic pathology, 32*(6), 650-658.
Cesaroni, G., et al. (2014). Long term exposure to ambient air pollution and incidence of acute coronary events: prospective cohort study and meta-analysis in 11 European cohorts from the ESCAPE Project. *The BMJ, 348*, f7412.
Chen, et al. (2018). Ambient air pollution and daily hospital admissions for mental disorders in Shanghai, China. *Science of the Total Environment, 613-614*, 324-330.
Chen, M., Li, B., & Sang, N. (2017). Particulate matter (PM2.5) exposure season-dependently induces neuronal apoptosis and synaptic injuries. *Jounal of Enviromental Sciences, 54*, 336-345.
Coogan, P., et al. (2012). Air pollution and incidence of hypertension and diabetes mellitus in black women living in Los Angeles. *Circulation, 125*(6), 767-772.
Costa, L. G., et al. (2014). Neurotoxicants are in the air: convergence of human, animal, and in vitro studies on the effects of air pollution on the brain. *BioMed research international, 2014*.
Cristy, P. (2017). Lifestyle modulators of neuroplasticity: how physical activity, mental engagement, and diet promote cognitive health during aging. *Neural plasticity*.
Di Forti, M., et al. (2012). Confirmation that the AKT1 (rs2494732) genotype influences the risk of psychosis in cannabis users. *Biological psychiatry, 72*(10), 811-816.
Ditzhuijzen, J. v., Have, M. T., Graaf, R. d., Nijnatten, C. H. C. J. v., & Vollebergh, W. A. M. (2018). Abortion and the risk of mental disorders. *Tijdschrift voor psychiatrie, 60*(8), 527-535.
Edward, T. (2012). Progressive neuropsychiatric and brain abnormalities after smoke inhalation. *Case Reports, 2012*, bcr0220125945.
Eeftens, M., et al. (2014). Elemental composition of particulate matter and the association with lung function. *Epidemiology, 25*(5), 648-657.
Eguchi, R., et al. (2018). The relationship between fine particulate matter (PM 2.5) and schizophrenia severity. *International archives of occupational and environmental health, 91*(5), 613-622.
Environment Protection Authority Victoria. (2016). Air Pollution. Retrieved from https://www.epa.vic.gov.au/your-environment/air/air-pollution
Environmental Pollution Centers. (2020). What Is Air Pollution? Retrieved from https://www.environmentalpollutioncenters.org/air/
Erik van Nunen, et al. (2017). Land Use Regression Models for Ultrafine Particles in Six European Areas. *Environmental Science & Technology, 51*(6), 3336-3345.
Eze, I. C., et al. (2014). Long-term air pollution exposure and diabetes in a population-based Swiss cohort. *Environment international, 70*, 95-105.
Fazel, S., Geddes, J. R., & Kushel, M. (2014). The health of homeless people in high-income countries: descriptive epidemiology, health consequences, and clinical and policy recommendations. *The Lancet, 384*(9953), 1529-1540.
Fonken, L. K., et al. (2011). Air pollution impairs cognition, provokes depressive-like behaviors and alters hippocampal cytokine expression and morphology.

Molecular Psychiatry, 16(10), 987-995. doi:10.1038/mp.2011.76
Gao, Q., Xu, Q., Guo, X., Fan, H., & Zhu, H. (2017). Particulate matter air pollution associated with hospital admissions for mental disorders: A time-series study in Beijing, China. *European Psychiatry, 44*, 68-75. doi:10.1016/j.eurpsy.2017.02.492
Gehring, U., et al. (2013). Air pollution exposure and lung function in children: the ESCAPE project. *Environmental health perspectives, 121*(11-12), 1357-1364.
General Statistic Office. (2019a). *Infographic Population, labour and employment in 2020*. Retrieved from
General Statistic Office. (2019b). *The Viet Nam Population and Housing Census*. Retrieved from
Geschwind, D. H., & Flint, J. (2015). Genetics and genomics of psychiatric disease. *Science, 349*(6255), 1489-1494.
Gorgoraptis, N., et al. (2019). Cognitive impairment and health-related quality of life following traumatic brain injury. *NeuroRehabilitation, 44*(3), 321-331.
Green Innovation and Development Centre. (2017). *Air quality report* Retrieved from Ha Noi: http://en.greenidvietnam.org.vn/allDocument/
Green Innovation and Development Centre. (2018). *Air quality report* Retrieved from Ha Noi: http://en.greenidvietnam.org.vn/allDocument/
Health Metrics Institute. (2018). *Evaluation's Global Burden of Disease Project*. Retrieved from The Health Effects Institute:
Hoek, G., et al. (2013). Long-term air pollution exposure and cardio- respiratory mortality: a review. *Environmental Health, 12*(1), 43.
Huang, X., et al. (2014). Source apportionment and secondary organic aerosol estimation of PM2.5 in an urban atmosphere in China. *Science China Earth Sciences, 57*(6), 1352–1362.
Igor, P. (2014). Online social networking and mental health. *Cyberpsychology, Behavior and Social Networking, 17*(10), 652-657.
Jacobson, T., James, J., & C.Schwertman, N. (2009). An example of using linear regression of seasonal weather patterns to enhance undergraduate learning. *Journal of Statistics Education, 17*(2).
James, S. L., et al. (2018). Global, regional, and national incidence, prevalence, and years lived with disability for 354 diseases and injuries for 195 countries and territories, 1990–2017: a systematic analysis for the Global Burden of Disease Study 2017. *The Lancet, 392*(10159), 1789-1858.
Janusz, H. (2020). Impact of COVID-19 pandemic on mental health. *Psychiatria Polska, 54*(2), 187-198.
Kawakami, N., et al. (2012). Early-life mental disorders and adult household income in the World Mental Health Surveys. *Biological psychiatry, 72*(3), 228-237.
Kim, C., et al. (2010). Ambient particulate matter as a risk factor for suicide. *Am J Psychiatry, 167*(9), 1100-1107. doi:10.1176/appi.ajp.2010.09050706
Kim, T.-Y., Kim, H., Yi, S.-M., Cheong, J.-P., & Heo, J. (2018). Short-term Effects of Ambient PM2.5 and PM2.5-10 on Mortality in Major Cities of Korea. *Aerosol and Air Quality Research, 18*.
Krewski, D., et al. (2009). Extended follow-up and spatial analysis of the American Cancer Society study linking particulate air pollution and mortality. *Health Effects Institute*(140), 115-136.

Li, Q., et al. (2017). Effects of Ambient Fine Particles PM2.5 on Human HaCaT Cells. *Journery of Enviromental Research and Public Health, 14*(1), 72.

Lim, S. S., et al. (2012). A comparative risk assessment of burden of disease and injury attributable to 67 Risk factors and risk factor clusters in 21 regions, 1990-2010: a systematic analysis for the Global Burden of Disease Study 2010. *Lancet, 380*(9859), 2224-2260.

Lim, Y.-H., et al. (2012). Air pollution and symptoms of depression in elderly adults. *Environmental health perspectives, 120*(7), 1023-1028.

Luong, L. M., Phung, D., Sly, P. D., Morawska, L., & Thai, P. K. (2017). The association between particulate air pollution and respiratory admissions among young children in Hanoi, Vietnam. *Science of the Total Environment, 578*, 249-255.

MacIntyre, E. A., et al. (2014). Air pollution and respiratory infections during early childhood: an analysis of 10 European birth cohorts within the ESCAPE Project. *Environmental health perspectives, 122*(1), 107-113.

Mellins, C. A., & Malee, K. M. (2013). Understanding the mental health of youth living with perinatal HIV infection: lessons learned and current challenges. *Journal of the International AIDS Society, 16*(1), 18593.

Mental Health American. (2019). Quick Facts And Statistics About Mental Health. Retrieved from https://www.mhanational.org/mentalhealthfacts

Meyer, U., Feldon, J., & Fatemi, S. H. (2009). In-vivo rodent models for the experimental investigation of prenatal immune activation effects in neurodevelopmental brain disorders. *Neuroscience & Biobehavioral Reviews, 33*(7), 1061-1079.

Minister of Natural Resources and Environment of The Socialist Republic of Vietnam. (2013). *National technical regulation on ambient air quality QCVN 05: 2009/BTNMT*. Retrieved from Government Document:

MohanKumar, S. M., Campbell, A., Block, M., & Veronesi, B. (2008). Particulate matter, oxidative stress and neurotoxicity. *Neurotoxicology, 29*(3), 479-488.

Morantes-Caballero, J. A., & Rodriguez, H. A. F. (2019). Effects of air pollution on acute exacerbation of chronic obstructive pulmonary disease: a descriptive retrospective study (pol-AECOPD). *Dovepress, 2019*(14), 1549—1557.

National Psychiatric Hospital No 1. (2015). National epidemiology mental disorder Survey by National Psychiatric Hospital No 1. National Psychiatric Hospital No 1 – Unpublished report submitted to WHO in Vietnam. Retrieved from https://www.who.int/vietnam/health-topics/mental-health#:~:text=In%20Viet%20Nam%2C%20according%20to,5.87%20per%20100%20000%20population.

Nhung, N. T. T., et al. (2018). Acute effects of ambient air pollution on lower respiratory infections in Hanoi children: An eight-year time series study. *Environment international, 110*, 139-148.

Norazian, M. N., Shukri, Y. A., Azam, R. N., & Bakri, A. M. M., Al (2008). Estimation of missing values in air pollution data using single imputation techniques. *ScienceAsia, 34*(3), 341.

O'neil, A., et al. (2014). Relationship between diet and mental health in children and adolescents: a systematic review. *American journal of public health, 104*(10), e31-e42.

Oberdörster, G., & Utell, M. J. (2002). Ultrafine particles in the urban air: to the respiratory tract--and beyond? *Environmental health perspectives, 110*(8), A440-A441.

Oudin, A., et al. (2016). Traffic-related air pollution and dementia incidence in northern Sweden: a longitudinal study. *Environmental health perspectives, 124*(3), 306-312.

Pan, H.-Y., et al. (2019). Short-Term Effects of Ambient Air Pollution on ST-Elevation Myocardial Infarction Events: Are There Potentially Susceptible Groups. *International journal of environmental research and public health, 16*(19), 3760.

Pant, P., Huynh, W., & Peltier, R. E. (2018). Exposure to air pollutants in Vietnam: Assessing potential risk for tourists. *Journal of Environmental Sciences, 73*, 147-154.

Pedersen, C. B., Raaschou-Nielsen, O., Hertel, O., & Mortensen, P. B. (2004). Air pollution from traffic and schizophrenia risk. *Schizophrenia research, 66*(1), 83-85.

Pedersen, M., et al. (2013). Ambient air pollution and low birthweight: a European cohort study (ESCAPE). *The Lancet Respiratory Medicine, 1*(9), 695-704.

Plurphanswat, N., Kaestner, R., & Rodu, B. (2017). The effect of smoking on mental health. *American journal of health behavior, 41*(4), 471-483.

Pun, V. C., Manjourides, J., & Suh, H. (2017). Association of ambient air pollution with depressive and anxiety symptoms in older adults: results from the NSHAP study. *Environmental health perspectives, 125*(3), 342-348.

Qiu, H., et al. (2019). Attributable risk of hospital admissions for overall and specific mental disorders due to particulate matter pollution: a time-series study in Chengdu, China. *Environmental research, 170*, 230-237.

Ranft, U., Schikowski, T., Sugiri, D., Krutmann, J., & Krämer, U. (2009). Long-term exposure to traffic-related particulate matter impairs cognitive function in the elderly. *Environmental research, 109*(8), 1004-1011.

Robinson, E. B., et al. (2016). Genetic risk for autism spectrum disorders and neuropsychiatric variation in the general population. *Nature genetics, 48*(5), 552-555.

Rotton, J., & Frey, J. (1984). Psychological costs of air pollution: Atmospheric conditions, seasonal trends, and psychiatric emergencies. *Population and Environment, 7*(1), 3-16.

Sarnat, J. A., Schwartz, J., Catalano, P. J., & Suh, H. H. (2001). Gaseous pollutants in particulate matter epidemiology: confounders or surrogates? *Environmental health perspectives, 109*(10), 1053-1061.

Schaefer, M., et al. (2012). Hepatitis C infection, antiviral treatment and mental health: a European expert consensus statement. *Journal of hepatology, 57*(6), 1379-1390.

ScienceDirect. (2020). Akaike Information Criterion. Retrieved from https://www.sciencedirect.com/topics/medicine-and-dentistry/akaike-information-criterion?fbclid=IwAR0uQdPYgKYAkIEnO_2VwVIUQVEMBEgXT99ON4JMDWsd7A6GCXBWOr29ksw

Song, C., et al. (2017). Health burden attributable to ambient PM2.5 in China. *Environmental Pollution, 223*, 575-586.

Song, J., et al. (2018). Acute effects of ambient particulate matter pollution on hospital admissions for mental and behavioral disorders: a time-series study in Shijiazhuang, China. *Science of the Total Environment, 636*, 205-211.
Sunyer, J., et al. (2015). Association between traffic-related air pollution in schools and cognitive development in primary school children: a prospective cohort study. *PLoS Med, 12*(3), e1001792.
The World Bank Institute for Health Metrics and Evaluation. (2016). *The Cost of Air Pollution: Strengthening the Economic Case for Action*. Retrieved from Washington:
Tong, L., Li, K., & Zhou, Q. (2016). Season, sex and age as modifiers in the association of psychosis morbidity with air pollutants: a rising problem in a Chinese metropolis. *Science of the Total Environment, 541*, 928-933.
U.S Environmental Protection Agency. (2012). *Revised Air Quality Standards For Particle Pollution And Updates To The Air Quality Index (AQI)*. Retrieved from
U.S. Department of Health & Human Services. (2020). What Is Mental Health? Retrieved from https://www.mentalhealth.gov/basics/what-is-mental-health
United States Environmental Protection Agency. (2016). *Fine Particle (PM2.5) Designations*. Retrieved from
Wahab, S. A., et al. (2019). Cluster Analysis Evaluating PM2.5, Occupation Risk and Mode of Transportation as Surrogates for Air-pollution and the Impact on Lung Cancer Diagnosis and 1-Year Mortality. *Asian Pacific Journal of Cancer Prevention, 20*(7), 1959-1196.
Wang, F., et al. (2018). Ambient concentrations of particulate matter and hospitalization for depression in 26 Chinese cities: A case-crossover study. *Environment international, 114*, 115-122. doi:https://doi.org/10.1016/j.envint.2018.02.012
Wang, Y., et al. (2014). Ambient air pollution and depressive symptoms in older adults: results from the MOBILIZE Boston study. *Environmental health perspectives, 122*(6), 553-558.
WHO. (1992). *The ICD-10 classification of mental and behavioural disorders: clinical descriptions and diagnostic guidelines*.
WHO. (2005). *WHO Air quality guidelines for particulate matter, ozone, nitrogen dioxide and sulfur dioxide: global update 2005 :summary of risk assessment*.
WHO. (2011). *Global burden of mental disorders and the need for a comprehensive, coordinated response from health and social sectors at the country level* Retrieved from https://apps.who.int/gb/ebwha/pdf_files/EB130/B130_9-en.pdf
WHO. (2013a). *Health effects of particulate matter*. Retrieved from
WHO. (2013b). *Review of evidence on health aspects of air pollution–REVIHAAP project: final technical report*. Retrieved from Bonn:
WHO. (2016a). *Concentrations of fine particulate matter (PM2.5)*. Retrieved from
WHO. (2016b). Exposure to ambient air pollution.
WHO. (2016c). *Global Health Observatory (GHO) data*. Retrieved from
WHO. (2018a). Global ambient air pollution. Retrieved from https://www.who.int/gho/phe/outdoor_air_pollution/en/#:~:text=Worldwide%2C%20ambient%20air%20pollution%20is,26%25%20of%20respiratory%20infection%20deaths.
WHO. (2018b). Global ambient air pollution. Retrieved from https://www.who.int/gho/phe/outdoor_air_pollution/en/#:~:text=Worldwide%2C

%20ambient%20air%20pollution%20is,26%25%20of%20respiratory%20infection%20deaths

WHO. (2018c). How air pollution is destroying our health. Retrieved from https://www.who.int/air-pollution/news-and-events/how-air-pollution-is-destroying-our-health

WHO. (2018d). Mental health: strengthening our response. Retrieved from https://www.who.int/en/news-room/fact-sheets/detail/mental-health-strengthening-our-response

WHO. (2019). Mental health : Mental disorders. Retrieved from https://www.who.int/mental_health/management/en/

WHO. (2020). Types of pollutants. Retrieved from https://www.who.int/teams/environment-climate-change-and-health/air-quality-and-health/ambient-air-pollution/pollutants/types-of-pollutants

World Bank. (2016). Air pollution deaths cost global economy US$225 billion. Retrieved from https://www.worldbank.org/en/news/press-release/2016/09/08/air-pollution-deaths-cost-global-economy-225-billion

World Economic Forum and the Harvard School of Public Health. (2011). *The Global Economic Burden of Non-communicable Diseases*. Retrieved from

Yao, Y., et al. (2020). Association of particulate matter pollution and case fatality rate of COVID-19 in 49 Chinese cities. *Science of the Total Environment, 741*, 140396.

Yunginger, J. W., et al. (1992). A community-based study of the epidemiology of asthma. Incidence rates, 1964-1983. *Am Rev Respir Dis, 146*(4), 888-894. doi:10.1164/ajrccm/146.4.888

Zhang, P., & Zhou, X. (2020). Health and economic impacts of particulate matter pollution on hospital admissions for mental disorders in Chengdu, Southwestern China. *Science of the Total Environment, 733*, 139114.

Zhang, X., et al. (2013). Factors contributing to haze and fog in China. *Chinese Science Bulletin, 58*(13), 1178-1187.

Ailshire, J. A., & Crimmins, E. M. (2014). Fine particulate matter air pollution and cognitive function among older US adults. *American journal of epidemiology, 180*(4), 359-366.

Air Visual. (2017). The most polluted countries in the world 2019 (PM2.5). Retrieved from https://www.iqair.com/vi/world-most-polluted-countries?fbclid=IwAR0oPpksCc_Tkt7BHWnN-c1juKBUsEDeeI55dyZWHvFUZOMhTCQp7k9G4VM

Air Visual. (2018). World most polluted countries 2018 (PM2.5). Retrieved from https://www.airvisual.com/world-most-polluted-countries

Anoop S V Shah, et al. (2013). Global association of air pollution and heart failure: a systematic review and meta-analysis. *Lancet, 382*(9897), 1039-1048.

Arden Pope III, C., Burnett, R. T., & al., e. (2002). Lung Cancer, Cardiopulmonary Mortality, and Long-term Exposure to Fine Particulate Air Pollution. *JAMA, 287*(9), 1132-1141.

Beelen, R., et al. (2008). Long-Term Effects of Traffic-Related Air Pollution on Mortality in a Dutch Cohort (NLCS-AIR Study). *Environmental health perspectives, 116*, 196-202.

Beelen, R., et al. (2014). Effects of long-term exposure to air pollution on natural-cause mortality: an analysis of 22 European cohorts within the multicentre ESCAPE project. *The Lancet, 383*(9919), 785-795.

Bhaskaran, K., Gasparrini, A., Hajat, S., Smeeth, L., & Armstrong, B. (2013). Time series regression studies in environmental epidemiology. *Int J Epidemiol, 42*(4), 1187-1195. doi:10.1093/ije/dyt092

Biological, S. C. S., & National, I. o. H. (2007). Information about Mental Illness and the Brain. In *NIH Curriculum Supplement Series [Internet]*: National Institutes of Health (US).

Block, M. L., & Calderón-Garcidueñas, L. (2009). Air pollution: mechanisms of neuroinflammation and CNS disease. *Trends Neurosci, 32*(9), 506-516.

Block, M. L., et al. (2012). The outdoor air pollution and brain health workshop. *Neurotoxicology, 33*(5), 972-984.

Briere, J., Downes, A., & Spensley, J. (1983). Summer in the city: urban weather conditions and psychiatric emergency-room visits. *Journal of Abnormal Psychology, 92*(1), 77.

Brook, R. D., et al. (2010). Particulate matter air pollution and cardiovascular disease: An update to the scientific statement from the American Heart Association. *Circulation, 121*(21), 2331-2378.

Bulati, M., Caruso, C., & Colonna-Romano, G. (2017). From lymphopoiesis to plasma cells differentiation, the age-related modifications of B cell compartment are influenced by “inflamm-ageing”. *Ageing research reviews, 36*, 125-136.

Buoli, M., et al. (2018). Is there a link between air pollution and mental disorders? *Environment international, 118*, 154-168.

Cakmak, S., Dales, R. E., & Judek, S. (2006). Do gender, education, and income modify the effect of air pollution gases on cardiac disease? *J Occup Environ Med, 48*(1), 89-94. doi:10.1097/01.jom.0000184878.11956.4b

Calderón-Garcidueñas, L., et al. (2004). Brain Inflammation and Alzheimer's-Like Pathology in Individuals Exposed to Severe Air Pollution. *Toxicologic pathology, 32*(6), 650-658.

Cesaroni, G., et al. (2014). Long term exposure to ambient air pollution and incidence of acute coronary events: prospective cohort study and meta-analysis in 11 European cohorts from the ESCAPE Project. *The BMJ, 348*, f7412.

Chen, et al. (2018). Ambient air pollution and daily hospital admissions for mental disorders in Shanghai, China. *Science of the Total Environment, 613-614*, 324-330.

Chen, M., Li, B., & Sang, N. (2017). Particulate matter (PM2.5) exposure season-dependently induces neuronal apoptosis and synaptic injuries. *Jounal of Enviromental Sciences, 54*, 336-345.

Coogan, P., et al. (2012). Air pollution and incidence of hypertension and diabetes mellitus in black women living in Los Angeles. *Circulation, 125*(6), 767-772.

Costa, L. G., et al. (2014). Neurotoxicants are in the air: convergence of human, animal, and in vitro studies on the effects of air pollution on the brain. *BioMed research international, 2014*.

Cristy, P. (2017). Lifestyle modulators of neuroplasticity: how physical activity, mental engagement, and diet promote cognitive health during aging. *Neural plasticity*.

Di Forti, M., et al. (2012). Confirmation that the AKT1 (rs2494732) genotype influences the risk of psychosis in cannabis users. *Biological psychiatry, 72*(10), 811-816.

Ditzhuijzen, J. v., Have, M. T., Graaf, R. d., Nijnatten, C. H. C. J. v., & Vollebergh, W. A. M. (2018). Abortion and the risk of mental disorders. *Tijdschrift voor psychiatrie, 60*(8), 527-535.

Edward, T. (2012). Progressive neuropsychiatric and brain abnormalities after smoke inhalation. *Case Reports, 2012*, bcr0220125945.

Eeftens, M., et al. (2014). Elemental composition of particulate matter and the association with lung function. *Epidemiology, 25*(5), 648-657.

Eguchi, R., et al. (2018). The relationship between fine particulate matter (PM 2.5) and schizophrenia severity. *International archives of occupational and environmental health, 91*(5), 613-622.

Environment Protection Authority Victoria. (2016). Air Pollution. Retrieved from https://www.epa.vic.gov.au/your-environment/air/air-pollution

Environmental Pollution Centers. (2020). What Is Air Pollution? Retrieved from https://www.environmentalpollutioncenters.org/air/

Erik van Nunen, et al. (2017). Land Use Regression Models for Ultrafine Particles in Six European Areas. *Environmental Science & Technology, 51*(6), 3336-3345.

Eze, I. C., et al. (2014). Long-term air pollution exposure and diabetes in a population-based Swiss cohort. *Environment international, 70*, 95-105.

Fazel, S., Geddes, J. R., & Kushel, M. (2014). The health of homeless people in high-income countries: descriptive epidemiology, health consequences, and clinical and policy recommendations. *The Lancet, 384*(9953), 1529-1540.

Fonken, L. K., et al. (2011). Air pollution impairs cognition, provokes depressive-like behaviors and alters hippocampal cytokine expression and morphology. *Molecular Psychiatry, 16*(10), 987-995. doi:10.1038/mp.2011.76

Gao, Q., Xu, Q., Guo, X., Fan, H., & Zhu, H. (2017). Particulate matter air pollution associated with hospital admissions for mental disorders: A time-series study in Beijing, China. *European Psychiatry, 44*, 68-75. doi:10.1016/j.eurpsy.2017.02.492

Gehring, U., et al. (2013). Air pollution exposure and lung function in children: the ESCAPE project. *Environmental health perspectives, 121*(11-12), 1357-1364.

General Statistic Office. (2019a). *Infographic Population, labour and employment in 2020*. Retrieved from

General Statistic Office. (2019b). *The Viet Nam Population and Housing Census*. Retrieved from

Geschwind, D. H., & Flint, J. (2015). Genetics and genomics of psychiatric disease. *Science, 349*(6255), 1489-1494.

Gorgoraptis, N., et al. (2019). Cognitive impairment and health-related quality of life following traumatic brain injury. *NeuroRehabilitation, 44*(3), 321-331.

Green Innovation and Development Centre. (2017). *Air quality report* Retrieved from Ha Noi: http://en.greenidvietnam.org.vn/allDocument/

Green Innovation and Development Centre. (2018). *Air quality report* Retrieved from Ha Noi: http://en.greenidvietnam.org.vn/allDocument/

Health Metrics Institute. (2018). *Evaluation's Global Burden of Disease Project*. Retrieved from The Health Effects Institute:

Hoek, G., et al. (2013). Long-term air pollution exposure and cardio- respiratory mortality: a review. *Environmental Health, 12*(1), 43.

Huang, X., et al. (2014). Source apportionment and secondary organic aerosol estimation of PM2.5 in an urban atmosphere in China. *Science China Earth Sciences, 57*(6), 1352–1362.

Igor, P. (2014). Online social networking and mental health. *Cyberpsychology, Behavior and Social Networking, 17*(10), 652-657.

Jacobson, T., James, J., & C.Schwertman, N. (2009). An example of using linear regression of seasonal weather patterns to enhance undergraduate learning. *Journal of Statistics Education, 17*(2).

James, S. L., et al. (2018). Global, regional, and national incidence, prevalence, and years lived with disability for 354 diseases and injuries for 195 countries and territories, 1990–2017: a systematic analysis for the Global Burden of Disease Study 2017. *The Lancet, 392*(10159), 1789-1858.

Janusz, H. (2020). Impact of COVID-19 pandemic on mental health. *Psychiatria Polska, 54*(2), 187-198.

Kawakami, N., et al. (2012). Early-life mental disorders and adult household income in the World Mental Health Surveys. *Biological psychiatry, 72*(3), 228-237.

Kim, C., et al. (2010). Ambient particulate matter as a risk factor for suicide. *Am J Psychiatry, 167*(9), 1100-1107. doi:10.1176/appi.ajp.2010.09050706

Kim, T.-Y., Kim, H., Yi, S.-M., Cheong, J.-P., & Heo, J. (2018). Short-term Effects of Ambient PM2.5 and PM2.5-10 on Mortality in Major Cities of Korea. *Aerosol and Air Quality Research, 18*.

Krewski, D., et al. (2009). Extended follow-up and spatial analysis of the American Cancer Society study linking particulate air pollution and mortality. *Health Effects Institute*(140), 115-136.

Li, Q., et al. (2017). Effects of Ambient Fine Particles PM2.5 on Human HaCaT Cells. *Journery of Enviromental Research and Public Health, 14*(1), 72.

Lim, S. S., et al. (2012). A comparative risk assessment of burden of disease and injury attributable to 67 Risk factors and risk factor clusters in 21 regions, 1990-2010: a systematic analysis for the Global Burden of Disease Study 2010. *Lancet*, *380*(9859), 2224-2260.

Lim, Y.-H., et al. (2012). Air pollution and symptoms of depression in elderly adults. *Environmental health perspectives, 120*(7), 1023-1028.

Luong, L. M., Phung, D., Sly, P. D., Morawska, L., & Thai, P. K. (2017). The association between particulate air pollution and respiratory admissions among young children in Hanoi, Vietnam. *Science of the Total Environment, 578,* 249-255.

MacIntyre, E. A., et al. (2014). Air pollution and respiratory infections during early childhood: an analysis of 10 European birth cohorts within the ESCAPE Project. *Environmental health perspectives, 122*(1), 107-113.

Mellins, C. A., & Malee, K. M. (2013). Understanding the mental health of youth living with perinatal HIV infection: lessons learned and current challenges. *Journal of the International AIDS Society, 16*(1), 18593.

Mental Health American. (2019). Quick Facts And Statistics About Mental Health. Retrieved from https://www.mhanational.org/mentalhealthfacts

Meyer, U., Feldon, J., & Fatemi, S. H. (2009). In-vivo rodent models for the experimental investigation of prenatal immune activation effects in neurodevelopmental brain disorders. *Neuroscience & Biobehavioral Reviews, 33*(7), 1061-1079.

Minister of Natural Resources and Environment of The Socialist Republic of Vietnam. (2013). *National technical regulation on ambient air quality QCVN 05: 2009/BTNMT*. Retrieved from Government Document:

MohanKumar, S. M., Campbell, A., Block, M., & Veronesi, B. (2008). Particulate matter, oxidative stress and neurotoxicity. *Neurotoxicology, 29*(3), 479-488.

Morantes-Caballero, J. A., & Rodriguez, H. A. F. (2019). Effects of air pollution on acute exacerbation of chronic obstructive pulmonary disease: a descriptive retrospective study (pol-AECOPD). *Dovepress, 2019*(14), 1549—1557.

National Psychiatric Hospital No 1. (2015). National epidemiology mental disorder Survey by National Psychiatric Hospital No 1. National Psychiatric Hospital No 1 – Unpublished report submitted to WHO in Vietnam. Retrieved from https://www.who.int/vietnam/health-topics/mental-health#:~:text=In%20Viet%20Nam%2C%20according%20to,5.87%20per%20100%20000%20population.

Nhung, N. T. T., et al. (2018). Acute effects of ambient air pollution on lower respiratory infections in Hanoi children: An eight-year time series study. *Environment international, 110*, 139-148.

Norazian, M. N., Shukri, Y. A., Azam, R. N., & Bakri, A. M. M., Al (2008). Estimation of missing values in air pollution data using single imputation techniques. *ScienceAsia, 34*(3), 341.

O'neil, A., et al. (2014). Relationship between diet and mental health in children and adolescents: a systematic review. *American journal of public health, 104*(10), e31-e42.

Oberdörster, G., & Utell, M. J. (2002). Ultrafine particles in the urban air: to the respiratory tract--and beyond? *Environmental health perspectives, 110*(8), A440-A441.

Oudin, A., et al. (2016). Traffic-related air pollution and dementia incidence in northern Sweden: a longitudinal study. *Environmental health perspectives, 124*(3), 306-312.

Pan, H.-Y., et al. (2019). Short-Term Effects of Ambient Air Pollution on ST-Elevation Myocardial Infarction Events: Are There Potentially Susceptible Groups. *International journal of environmental research and public health, 16*(19), 3760.

Pant, P., Huynh, W., & Peltier, R. E. (2018). Exposure to air pollutants in Vietnam: Assessing potential risk for tourists. *Journal of Environmental Sciences, 73*, 147-154.

Pedersen, C. B., Raaschou-Nielsen, O., Hertel, O., & Mortensen, P. B. (2004). Air pollution from traffic and schizophrenia risk. *Schizophrenia research, 66*(1), 83-85.

Pedersen, M., et al. (2013). Ambient air pollution and low birthweight: a European cohort study (ESCAPE). *The Lancet Respiratory Medicine, 1*(9), 695-704.

Plurphanswat, N., Kaestner, R., & Rodu, B. (2017). The effect of smoking on mental health. *American journal of health behavior, 41*(4), 471-483.

Pun, V. C., Manjourides, J., & Suh, H. (2017). Association of ambient air pollution with depressive and anxiety symptoms in older adults: results from the NSHAP study. *Environmental health perspectives, 125*(3), 342-348.

Qiu, H., et al. (2019). Attributable risk of hospital admissions for overall and specific mental disorders due to particulate matter pollution: a time-series study in Chengdu, China. *Environmental research, 170*, 230-237.

Ranft, U., Schikowski, T., Sugiri, D., Krutmann, J., & Krämer, U. (2009). Long-term exposure to traffic-related particulate matter impairs cognitive function in the elderly. *Environmental research, 109*(8), 1004-1011.

Robinson, E. B., et al. (2016). Genetic risk for autism spectrum disorders and neuropsychiatric variation in the general population. *Nature genetics, 48*(5), 552-555.

Rotton, J., & Frey, J. (1984). Psychological costs of air pollution: Atmospheric conditions, seasonal trends, and psychiatric emergencies. *Population and Environment, 7*(1), 3-16.

Sarnat, J. A., Schwartz, J., Catalano, P. J., & Suh, H. H. (2001). Gaseous pollutants in particulate matter epidemiology: confounders or surrogates? *Environmental health perspectives, 109*(10), 1053-1061.

Schaefer, M., et al. (2012). Hepatitis C infection, antiviral treatment and mental health: a European expert consensus statement. *Journal of hepatology, 57*(6), 1379-1390.

ScienceDirect. (2020). Akaike Information Criterion. Retrieved from https://www.sciencedirect.com/topics/medicine-and-dentistry/akaike-information-criterion?fbclid=IwAR0uQdPYgKYAkIEnO_2VwVIUQVEMBEgXT99ON4JMDWsd7A6GCXBWOr29ksw

Song, C., et al. (2017). Health burden attributable to ambient PM2.5 in China. *Environmental Pollution, 223*, 575-586.

Song, J., et al. (2018). Acute effects of ambient particulate matter pollution on hospital admissions for mental and behavioral disorders: a time-series study in Shijiazhuang, China. *Science of the Total Environment, 636*, 205-211.

Sunyer, J., et al. (2015). Association between traffic-related air pollution in schools and cognitive development in primary school children: a prospective cohort study. *PLoS Med*, *12*(3), e1001792.

The World Bank Institute for Health Metrics and Evaluation. (2016). *The Cost of Air Pollution: Strengthening the Economic Case for Action*. Retrieved from Washington:

Tong, L., Li, K., & Zhou, Q. (2016). Season, sex and age as modifiers in the association of psychosis morbidity with air pollutants: a rising problem in a Chinese metropolis. *Science of the Total Environment, 541*, 928-933.

U.S Environmental Protection Agency. (2012). *Revised Air Quality Standards For Particle Pollution And Updates To The Air Quality Index (AQI)*. Retrieved from

U.S. Department of Health & Human Services. (2020). What Is Mental Health? Retrieved from https://www.mentalhealth.gov/basics/what-is-mental-health

United States Environmental Protection Agency. (2016). *Fine Particle (PM2.5) Designations*. Retrieved from

Wahab, S. A., et al. (2019). Cluster Analysis Evaluating PM2.5, Occupation Risk and Mode of Transportation as Surrogates for Air-pollution and the Impact on Lung Cancer Diagnosis and 1-Year Mortality. *Asian Pacific Journal of Cancer Prevention, 20*(7), 1959-1196.

Wang, F., et al. (2018). Ambient concentrations of particulate matter and hospitalization for depression in 26 Chinese cities: A case-crossover study. *Environment international, 114*, 115-122. doi:https://doi.org/10.1016/j.envint.2018.02.012

Wang, Y., et al. (2014). Ambient air pollution and depressive symptoms in older adults: results from the MOBILIZE Boston study. *Environmental health perspectives, 122*(6), 553-558.

WHO. (1992). *The ICD-10 classification of mental and behavioural disorders: clinical descriptions and diagnostic guidelines*.

WHO. (2005). *WHO Air quality guidelines for particulate matter, ozone, nitrogen dioxide and sulfur dioxide: global update 2005 :summary of risk assessment*.

WHO. (2011). *Global burden of mental disorders and the need for a comprehensive, coordinated response from health and social sectors at the country level* Retrieved from https://apps.who.int/gb/ebwha/pdf_files/EB130/B130_9-en.pdf

WHO. (2013a). *Health effects of particulate matter*. Retrieved from

WHO. (2013b). *Review of evidence on health aspects of air pollution–REVIHAAP project: final technical report*. Retrieved from Bonn:

WHO. (2016a). *Concentrations of fine particulate matter (PM2.5)*. Retrieved from

WHO. (2016b). Exposure to ambient air pollution.

WHO. (2016c). *Global Health Observatory (GHO) data*. Retrieved from

WHO. (2018a). Global ambient air pollution. Retrieved from https://www.who.int/gho/phe/outdoor_air_pollution/en/#:~:text=Worldwide%2C%20ambient%20air%20pollution%20is,26%25%20of%20respiratory%20infection%20deaths.

WHO. (2018b). Global ambient air pollution. Retrieved from https://www.who.int/gho/phe/outdoor_air_pollution/en/#:~:text=Worldwide%2C%20ambient%20air%20pollution%20is,26%25%20of%20respiratory%20infection%20deaths

WHO. (2018c). How air pollution is destroying our health. Retrieved from https://www.who.int/air-pollution/news-and-events/how-air-pollution-is-destroying-our-health

WHO. (2018d). Mental health: strengthening our response. Retrieved from https://www.who.int/en/news-room/fact-sheets/detail/mental-health-strengthening-our-response

WHO. (2019). Mental health : Mental disorders. Retrieved from https://www.who.int/mental_health/management/en/

WHO. (2020). Types of pollutants. Retrieved from https://www.who.int/teams/environment-climate-change-and-health/air-quality-and-health/ambient-air-pollution/pollutants/types-of-pollutants

World Bank. (2016). Air pollution deaths cost global economy US$225 billion. Retrieved from https://www.worldbank.org/en/news/press-release/2016/09/08/air-pollution-deaths-cost-global-economy-225-billion

World Economic Forum and the Harvard School of Public Health. (2011). *The Global Economic Burden of Non-communicable Diseases*. Retrieved from

Yao, Y., et al. (2020). Association of particulate matter pollution and case fatality rate of COVID-19 in 49 Chinese cities. *Science of the Total Environment, 741*, 140396.

Yunginger, J. W., et al. (1992). A community-based study of the epidemiology of asthma. Incidence rates, 1964-1983. *Am Rev Respir Dis, 146*(4), 888-894. doi:10.1164/ajrccm/146.4.888

Zhang, P., & Zhou, X. (2020). Health and economic impacts of particulate matter pollution on hospital admissions for mental disorders in Chengdu, Southwestern China. *Science of the Total Environment, 733*, 139114.

Zhang, X., et al. (2013). Factors contributing to haze and fog in China. *Chinese Science Bulletin, 58*(13), 1178-1187.

VITA

NAME	DO THI HOAI THUONG
DATE OF BIRTH	25 February 1993
PLACE OF BIRTH	Dong Nai, Vietnam
INSTITUTIONS ATTENDED	- University of Medicine and Pharmacy at Ho Chi Minh City - College of Public Health Sciences, Chulalongkorn University
HOME ADDRESS	Long Giao commune, Cam My district, Dong Nai province, Vietnam.