PROJECTING BURDEN OF NON-COMMUNICABLE DISEASES (NCD) ATTRIBUTABLE TO AIR POLLUTION IN THE NORTHEAST AND NORTHWEST OF PENINSULAR MALAYSIA UNDER CLIMATE CHANGE SCENARIO

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DECLARATION

I hereby declare that the work in this thesis is my own except for quotations and summaries which have been duly acknowledged.

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ABSTRAK

Pencemaran udara menyebabkan lebih daripada 7 juta kematian setiap tahun yang merangsang penyakit kardiovaskular (CVD), penyakit respiratori (RD) dan kencing manis (DM). Objektif kajian adalah untuk mengunjurkan Bebanan Penyakit Tidak Berjangkit (BoD NCD) yang diatributkan kepada pencemaran udara di Kelantan dan Kedah di bawah senario SSP5-8.5. Kajian ini melibatkan data harian i) kematian dan kemasukan hospital (HA) penyakit CVD, RD, DM (2005-2021), ii) data pencemaran udara (PM_{10}, $PM_{2.5}$, SO_2, NO_2, CO, O_3) dan data meteorologi (suhu, kelembapan relatif) (2005-2021), iii) data pencemaran udara daripada WRF-CMAQ (validasi : 2014) dan unjuran (SSP5-8.5) untuk kedua-dua lokasi. Analisis deskriptif bertujuan mengenal pasti tren temporal, manakala korelasi Spearman bertujuan menentukan perkaitan antara pencemaran udara dan NCD. DLNM digunakan untuk menentukan anggaran perkaitan pendedahan-respons kumulatif jangka pendek, diikuti dengan analisis sensitiviti untuk menilai keteguhan model. Pengiraan BoD dijalankan untuk YLL, YLD dan DALY mengikut jenis penyakit bagi data garis dasar dan unjuran. Unjuran BoD menunjukkan anggaran bebanan yang dikaitkan dengan kesan kumulatif jangka pendek terhadap pendedahan kepada pencemaran udara. Perbezaan antara bebanan NCD pada tahun unjuran dan tahun garis dasar telah dikira. Antara tahun 2005 hingga 2021, kematian dan HA penyakit CVD, RD dan DM, menunjukkan peningkatan di Kelantan dan Kedah. Kematian CVD meningkat secara mendadak selepas 2018 di Kelantan (131.5) dan Kedah (154.1). Kematian RD meningkat secara mendatar pada tahun 2013 (79.6) di Kelantan dan menghampiri 100 di Kedah (2018). Kematian DM pulak meningkat secara beransur di Kelantan (15.6, 2021) dan 18.1 di Kedah (2020). Kemasukan ke hospital (HA) bagi penyakit CVD meningkat secara konsisten, RD mencapai tahap tertinggi pada 2019 (1652.8) di Kelantan dan 1667.7 (Kedah). Bagi DM HA menunjukkan pelbagai tahap, tinggi di permulaan tahun di Kelantan dan tahap tertinggi di Kedah pada tahun 2009 (46.2). DALY yang paling tinggi adalah CVD, diikuti oleh DM dan RD, yang disumbangkan oleh YLL. Kesemua bahan pencemar berada di bawah paras ambang, walaupun PM_{10} dan $PM_{2.5}$ kadangkala meningkat melebihi paras yang ditetapkan oleh WHO. Pencemaran udara menunjukkan perkaitan negatif yang signifikan dengan NCD di Kelantan dan Kedah ($p<0.05$). Paras suhu di Kedah menunjukkan perkaitan yang positif dengan kematian RD ($r=0.047$, $p<0.05$). $PM_{2.5}$ menunjukkan perkaitan pendedahan-respons kumulatif yang konsisten dengan semua NCD di kedua-dua negeri, dan dipilih untuk mengunjurkan risiko bebanan penyakit. Dalam senario pemanasan global SSP5-8.5, $PM_{2.5}$ yang dikaitkan dengan kematian CVD di Kelantan meningkat sebanyak 368.71 (95% CI: -129 hingga 854 kematian) pada tahun unjuran. $PM_{2.5}$ yang atribut dengan kematian RD menurun sehingga 122 (95% CI: -307 hingga 451 kematian). Sebaliknya, $PM_{2.5}$ yang atribut kepada HA RD meningkat sebanyak 9,200 (95% CI: 4,351-13,786). $PM_{2.5}$ yang atribut kepada HA DM di Kelantan meningkat secara sederhana dengan kenaikan sebanyak 15 (95% CI: -134 hingga 124). Di Kedah, pada garis dasar, $PM_{2.5}$ yang atribut kepada NCD menunjukkan tiada anggaran, menyebabkkan tiada perbexaan antara garis dasar-unjuran, Kesimpulannya, di bawah pemanasan global senario SSP5.85, pencemaran udara terutamanya $PM_{2.5}$, menyebabkan bebanan penyakit NCD di Kelantan dan Kedah.

ABSTRACT

Air pollution silently claims over 7 million lives annually by triggering cardiovascular (CVD), respiratory diseases (RD) and diabetes mellitus (DM). This study aims to project BoD of NCDs attributable to air pollution in Kelantan and Kedah under SSP5-8.5 scenario. This study involves daily data on mortality and hospital admissions (HA) for CVD, RD, and DM (2005-2021); air pollution (PM_{10}, $PM_{2.5}$, SO_2, NO_2, CO, O_3) and meteorological variables (temperature, relative humidity) (2005-2021); and WRF-CMAQ air pollution output (validation: 2014) and projections (SSP5-8.5) for each state. Descriptive analysis was performed to examine temporal trends, while Spearman correlation assessed relationships between air pollution and health outcomes. The distributed lag non-linear model (DLNM) was used to estimate short-term cumulative exposure-response relationships, followed by sensitivity analyses to evaluate model robustness. WRF-CMAQ outputs were validated against observed DOE monitoring data, and health prediction models were validated using both observed and simulated air pollution data for 2014. Future NCD outcomes were projected using negative binomial regression. The best-performing baseline health models were integrated with bias-corrected WRF-CMAQ air pollution projections to estimate attributable fractions and the projected BoD, including years of life lost (YLL), years lived with disability (YLD), and disability-adjusted life years (DALYs). Differences between projected and baseline $PM_{2.5}$-attributable BoD were subsequently quantified. Between 2005 and 2021, mortality from CVD, RD, and DM, and from HA, increased in Kelantan and Kedah. CVD mortality rose sharply after 2018 in Kelantan (131.5) and Kedah (154.1). RD mortality steadily increased in 2013 (79.6) in Kelantan and nearly 100 in Kedah (2018). DM mortality gradually rose to 15.6 in Kelantan (2021) and 18.1 in Kedah (2020). CVD HA increased consistently; RD HA peaked in 2019 (1652.8) in Kelantan and 1667.7 (Kedah), while DM HA varied over time, higher early on in Kelantan and peaking in Kedah in 2009(46.2). DALYs were highest for CVD, then DM and RD, mostly driven by YLL. All pollutants remained below thresholds, though PM_{10} and $PM_{2.5}$ occasionally exceeded WHO AQG limits. Air pollution showed a significant negative association with NCD outcomes in Kelantan and Kedah ($p < 0.05$). Temperature in Kedah showed a positive association with RD mortality ($r = 0.047$, $p < 0.05$). Among all pollutants, $PM_{2.5}$ demonstrated the most consistent cumulative exposure–response relationships across NCD in both states and was therefore selected for future BoD projection. Under the global warming SSP5-8.5 scenario, $PM_{2.5}$-attributable CVD mortality in Kelantan increased by 368.71 deaths (95% CI: −129 to 854 deaths). $PM_{2.5}$-attributable RD mortality decreased by 122.02 deaths (95% CI: −307 to 451 deaths). In contrast, $PM_{2.5}$-attributable RD HA increased substantially with an absolute increase of 9,200.29 admissions (95% CI: 4,351–13,786). $PM_{2.5}$-attributable DM HA in Kelantan increased modestly with an absolute increase of 14.89 admissions (95% CI: −134 to 124). In Kedah, baseline $PM_{2.5}$-attributable NCD outcome estimates were unavailable, precluding calculation of absolute baseline–projection differences. In conclusion, under the SSP5-8.5 scenario, $PM_{2.5}$ continues to impose a measurable and evolving burden of NCDs in Kelantan and Kedah.

Keywords: non-communicable disease, air pollution, climate change scenario

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LIST OF ABBREVIATIONS

ARIMA	Autoregressive Integrated Moving Average
BOD	Burden of Diseases
CAQM	Continuous air quality monitoring stations
CCVI	Climate Change Vulnerability Index
CFA	Comparative Risk Assessment
CMIP	Coupled Model Intercomparison Project
CO	Carbon monoxide
CRF	Concentration–response function
CVD	Cardiovascular disease
DALY	Disability Adjusted Life Years
DLNM	Distributed lag non-linear model
DM	Diabetes mellitus
DOE	Department of Environment
DOSM	Department of Statistics Malaysia
DOW	Day of the week
ERF	Exposure-response function
GHG	Greenhouse gases
GLM	Generalised Linear Model
HA	Hospital admissions
ICD-10	International Classification of Diseases, Tenth Revision
IPCC	Intergovernmental Panel on Climate Change
KRB	Kelantan River Basin
MAAQS	Malaysia Ambient Air Quality Standard
MADA	Muda Irrigation scheme area
MAR	Missing at Random
MCAR	Missing Completely at Random
MICE	Multiple Imputation Chained Equations

MOH	Ministry of Health Malaysia
MRD	Muda River Basin
NBR	Negative binomial regression
NCD	Non-communicable diseases
NEM	Northeast monsoon
NO_2	Nitrogen dioxide
NOAA	National Oceanic and Atmospheric Administration
O_3	Ozone
PACF	Partial autocorrelation function
PAF	Population attributable fraction
PM_{10}	Particulate matter with a diameter of 10μm
$PM_{2.5}$	Particulate matter with a diameter of 2.5μm
Q-AIC	Akaike's Information Criterion for quasi-Poisson
RCP	Representative Concentration Pathways
RD	Respiratory disease
RR	Relative risk
SLR	Sea level rise
SO_2	Sulphur dioxide
SSP-RCP	Shared Socioeconomic Pathways – Representative Concentration Pathways
US EPA	United States Environmental Protection Agency
WHO	World Health Organisations
WRF-CMAQ	Weather Research and Forecasting -Community Multiscale Air Quality
YLD	Years Lived with Disability
YLL	Year Live Lost

CHAPTER 1

INTRODUCTION

1.1 INTRODUCTION

Climate change has become one of the defining challenges of this century, with impacts that extend far beyond the environment into human health, security, and development. A key aspect of climate change is global warming, which refers to the consistent increase in Earth's surface temperature primarily driven by human activities like burning fossil fuels, deforestation, and industrial emissions(Chen et al. 2020).

The Intergovernmental Panel on Climate Change (IPCC) projected that, if greenhouse gas emissions continue on their current trajectory, global warming is expected to reach 1.5 °C above pre-industrial levels sometime between 2030 and 2052 (IPCC 2018). The 1.5 °C threshold is a critical marker for human health and well-being. Exceeding this level would lead to more frequent and intense heatwaves, droughts, floods, and storms, which in turn would affect food production, water availability, and disease patterns (Dosio et al. 2018).

At the same time, rising temperatures worsen air quality by intensifying pollutant formation and prolonging the persistence of harmful compounds in the atmosphere (Kalisa et al. 2018). Air pollution is currently accountable for 4.2 million premature fatalities annually across the globe, primarily attributable to cardiovascular and respiratory illnesses (World Health Organisation-WHO 2022). As warming intensifies, this health burden is expected to rise.

Malaysia is particularly vulnerable to local urban and industrial emissions and also exposed to transboundary haze episodes that worsen air quality (Ismail et al. 2017)

Kelantan and Kedah represent states that are vulnerable to the global warming impact. Yet, little is known about how global warming at 1.5 °C will interact with air pollution to shape the future burden of disease (BoD) of non-communicable diseases (NCD) in these populations. This study aims to fill that gap by integrating health data with advanced climate and air quality modelling to generate local evidence to inform policy and adaptation strategies.

1.2 STUDY BACKGROUND

1.2.1 Global Warming and Climate Change

The terms "global warming" and "climate change" are frequently used interchangeably. Global warming specifically refers to the rise in Earth's average surface temperature, while climate change encompasses a broader range of alterations in climate patterns, including shifts in rainfall, rising sea levels, and more extreme weather (Stefkovics & Zenovitz 2023).

Natural processes such as volcanic eruptions, solar variability, and ocean circulation have always influenced climate, but since the mid-twentieth century, the main contribution of global warming has been human activity (Stocker et al. 2013). The burning of fossil fuels, along with industrialisation, urban growth, and deforestation, has greatly elevated greenhouse gases such as carbon dioxide, methane, and nitrous oxide in the atmosphere (Fakana 2020).

The Paris Agreement of 2015 was a milestone, as nations committed to keeping global warming below 2°C and working towards limiting it to 1.5°C (United Nations Framework Convention on Climate Change-UNFCCC 2015). The IPCC has since demonstrated that exceeding this 1.5 °C threshold will elevate the risks to health and wellbeing (IPCC 2018). Even small increments of warming are associated with a rise in heat-related deaths, food insecurity, vector-borne diseases, and cardiorespiratory illnesses (Campbell-Lendrum & Prüss-Ustün 2018).

Importantly, global warming also alters atmospheric chemistry. Higher temperatures accelerate the photochemical reactions that generate ground-level ozone, while stagnant weather during heatwaves prevents the dispersion of particulate matter (Schulte et al. 2016).These interactions highlight the direct ways in which global warming undermines human health.

1.2.2 Global Warming and Air Pollution Interplay

Air pollution and global warming are closely linked. Air pollutants such as black carbon and methane contribute to global warming by trapping heat in the atmosphere (Kumar 2021). Additionally, global warming alters meteorological conditions, intensifying air pollution episodes. The World Health Organization identifies six major air pollutants that threaten human health and ecosystems: particulate matter (PM_{10} and $PM_{2.5}$), ozone (O_3), carbon monoxide (CO), nitrogen dioxide (NO_2) and sulfur dioxide (SO_2) (Hoffmann et al. 2021).

Exposure to this air pollution has been associated with stroke, ischemic heart disease, chronic obstructive pulmonary disease (COPD), lung cancer, and diabetes (Huang et al. 2019; Pinichka et al. 2015; Vos et al. 2020; Zhao et al. 2019). Across the world, ambient air pollution causes millions of early deaths each year (WHO 2022). Global warming worsens these risks. During heatwaves, O_3 concentrations rise, and fine particles accumulate, compounding respiratory and cardiovascular strain (Du et al. 2021). In Malaysia, this interplay is evident during the annual haze season, when biomass burning in neighboring countries interacts with local emissions to produce severe air pollution episodes (Ismail et al. 2017a).

1.2.3 Non-communicable Diseases (NCDs) and Burden of Disease (BOD)

Non-communicable diseases (NCDs) now surpass infectious diseases as the leading global cause of death, representing nearly 70% of all deaths (WHO 2012). The 2019 Global Burden of Disease (GBD) study reports that NCDs result in 17 million premature deaths each year among those under 70, mainly in low- and middle-income countries (GBD 2019 Collaborators, 2020). By 2030, NCDs are projected to account for 77% of the worldwide disease burden (Shu & Jin 2023).

In Malaysia, the rise of NCDs is a serious concern, with cardiovascular disease (CVD), respiratory disease (RD), and diabetes mellitus (DM) already causing significant premature mortality (Ministry of Health Malaysia (MOH) 2021). The BoD framework offers a way to quantify these impacts. The most common measure, the Disability-Adjusted Life Year (DALY), combines years of life lost (YLL) due to early death with years lived with disability (YLD) (Murray 2022). Another measure, the Population Attributable Fraction (PAF) was used to estimate the proportion of disease or death that could be avoided if exposure to a risk factor, such as air pollution, were removed (Mansournia & Altman 2018).

These indicators have been used worldwide to measure the health burden attributable to air pollution. For example, studies in Asia and Europe have estimated thousands of DALYs lost each year due to exposure to $PM_{2.5}$ and O_3 (Alam et al. 2019; Rovira et al. 2020).While such assessments are prevalent elsewhere, there is a notable gap in similar comprehensive evaluations in Malaysia, particularly those that integrate climate change scenarios to project future risks.

1.2.4 Modelling Approaches in Air Pollution and Health

Understanding and projecting the health impact of air pollution requires robust models. Traditional approaches include Land Use Regression (LUR) models, spatial–temporal models, and machine learning tools such as Artificial Neural Networks (ANNs), all of which provide localised estimates of pollutant concentrations (Abdul Shakor et al. 2020). More specialised tools such as AIRQ+ and DIMAQ2 have also been developed to estimate health outcomes attributable to air pollution (Forastiere et al. 2020; Vos 2020).

State-of-the-art methods now use coupled models that simulate interactions between meteorology and air quality. The Weather Research and Forecasting (WRF) model captures weather processes, while the Community Multiscale Air Quality (CMAQ) model predicts pollutant concentrations and deposition (Im et al. 2010). Together, WRF-CMAQ can simulate how climate and air quality interact, making it particularly powerful for projecting health outcomes under future climate scenarios.

Internationally, WRF-CMAQ has been widely used, especially in China, to estimate deaths attributable to $PM_{2.5}$ and O_3 under various emission scenarios (Liu et al. 2021; Wang et al. 2021). Applications in Europe have shown that emission-reduction strategies can generate significant health co-benefits. However, such modelling studies are still limited in Malaysia, leaving a significant evidence gap in understanding future air pollution–related health risks.

1.2.5 Future climate Scenarios: CMIP6 and SSP-RCP Frameworks

Projections of the impact of global warming rely on scenario frameworks. The Coupled Model Intercomparison Project Phase 6 (CMIP6) is the latest international effort that brings together climate models to project future changes. Compared to its predecessor CMIP5, CMIP6 offers finer resolution and integrates socioeconomic pathways (Eyring et al. 2016). These projections combine Representative Concentration Pathways (RCPs), which describe future greenhouse gas concentrations, with Shared Socioeconomic Pathways (SSPs), which outline potential trajectories of global development (Vicedo-Cabrera et al. 2019).

The five main SSP–RCP scenarios range from strong mitigation consistent with the Paris Agreement (SSP1-1.9 and SSP1-2.6) to fossil fuel-intensive, high-emission futures (SSP5-8.5) (Rivera & Arnould 2020). Studies show that health burdens vary significantly across these scenarios. For example, deaths linked to $PM_{2.5}$ exposure decline under SSP1-2.6 but rise sharply under SSP3-7.0, reflecting both emission levels and demographic changes such as ageing populations (Xu et al. 2023).

Despite their global use, CMIP6 SSP–RCP scenarios have rarely been applied in Malaysia to estimate future health risks. This study, therefore, fills a gap by combining CMIP6 scenarios with WRF-CMAQ outputs and health data to project the future burden of NCDs attributable to air pollution under a SSP5-8.5 climate change scenario.

1.3 RESEARCH PROBLEM

While the health risks of air pollution have been widely studied globally, evidence in Malaysia remains limited and is mainly concentrated in the Klang Valley (Abd Rahim et al. 2024; Basit et al., 2018; Ibrahim et al. 2022; Wan Mahiyuddin et al. 2013). Kelantan and Kedah, two northern states in Peninsular Malaysia, continue to experience a substantial burden of non-communicable diseases (NCDs) while being exposed to both local and transboundary air pollution. Despite these concerns, there is still a lack of studies in Malaysia that project the future burden of disease (BoD) attributable to air pollution under future climate scenario.

The combined effects of global warming, air pollution, and NCDs have become a major public health concern worldwide (Siiba et al. 2024). At the 1.5 °C global warming threshold, worsening air quality and chronic disease burden are expected to intensify. However, evidence-based planning for climate-resilient health strategies in Malaysia remains limited due to the lack of integrated studies that combine climate projections, air quality modelling, and health burden assessment. Advanced modelling systems such as Weather Research and Forecasting–Community Multiscale Air Quality (WRF-CMAQ) and climate projection frameworks such as CMIP6 Shared Socioeconomic Pathway–Representative Concentration Pathway (SSP–RCP) have been widely applied in China, Europe, and the United States, but remain underutilised in Southeast Asia. Therefore, this study addresses an important research gap by integrating future climate scenario (SSP5–8.5), air quality modelling, and local health data in Malaysia.

The first research problem relates to the trend and comprehensiveness of the BoD assessment in Malaysia. The Burden of Disease and Injury Study conducted by the Ministry of Health (MOH) Malaysia was last published in 2020 (National Institute of Health, 2020). The report presented the national burden of diseases in Malaysia covering the period from 2015 to 2017. Diseases were categorized into three major groups: Group I (communicable diseases, maternal, perinatal, and nutritional conditions), Group II (non-communicable diseases), and Group III (injuries). The main indicators used in the assessment were Disability-Adjusted Life Years (DALY), Years of Life Lost (YLL), and Years Lived with Disability (YLD), which were mainly reported according to gender and age groups.

However, several limitations remain. First, the available national report only covered a three-year period, which is relatively short for providing insight into long-term trends in BoD in Malaysia. Second, the findings were presented mainly at the national level without detailed analyses by state or district, thereby limiting the understanding of local disease patterns and regional disparities. Third, the reports mainly focused on the overall burden of diseases without specifically examining the contribution of environmental risk factors, such as air pollution, to NCD burden. Existing Malaysian studies also primarily estimated DALY, YLL, and YLD separately, without integrating future climate and air pollution projections into BoD assessments (Alam et al. 2019; Chan et al. 2022; Huang et al. 2019b;Khaw et al. 2023).

In addition, the BoD assessment in this study relied primarily on mortality and hospital admission (HA) data due to their availability and accessibility from the MOH. Although diagnosed or newly diagnosed cases may provide a more comprehensive assessment of disease occurrence, such data were not consistently available across healthcare facilities. Many government hospitals and clinics in Malaysia still rely on paper-based or hybrid medical record systems, making it logistically difficult and time-consuming to extract data on newly diagnosed cases. Compared with diagnosis records, hospital admission data are more systematically documented and digitally accessible.

Therefore, HA data were used as a proxy for morbidity and YLD estimation in this study. Nevertheless, this may limit the comprehensiveness of the outcome assessment, as mild or undiagnosed cases not requiring hospitalization may not have been captured. Furthermore, limited funding allocation and the restricted timeframe of the research also constrained the feasibility of collecting nationwide newly diagnosed case data.

Another research problem relates to air quality modelling. Over time, air quality modelling has evolved progressively from estimating pollutant concentrations to integrating health-related outcomes such as mortality and NCD incidence. Previous studies have demonstrated the effectiveness of linking air quality models with NCD mortality and incidence assessments (Pinichka et al. 2017; Mazzeo et al. 2022; Wang et al., 2022).

Among these models, WRF-CMAQ is considered state-of-the-art because it integrates meteorological processes, atmospheric chemistry, and air pollutant transport simultaneously, enabling more reliable simulation and projection of air pollution exposure under future climate conditions. Despite these advancements, the application of WRF-CMAQ in Malaysia and Southeast Asia remains limited, particularly in studies linking air quality projections with future NCD burden assessment.

The third research problem concerns long-term projection of the BoD attributable to air pollution under future climate scenarios. General Circulation Models (GCMs) are the primary tools used for climate projections, and the ensemble of GCM simulations is coordinated through the Coupled Model Intercomparison Project (CMIP). CMIP6 provides updated near-term and long-term climate projections based on Shared Socioeconomic Pathways (SSPs). In this study, the SSP5–8.5 scenario was selected to represent a high-fossil-fuel-emission pathway associated with substantial warming and worsening air quality.

Globally, many studies have used climate modelling to project future health impacts. Previous studies in China and the United Kingdom estimated health burden under Representative Concentration Pathway (RCP) scenarios (Huang et al. 2019a). However, studies projecting the BoD of NCDs attributable to air pollution under SSP–RCP scenarios remain limited (Ingole et al. 2022; Liu et al. 2025). Existing studies also mainly focused on mortality outcomes, with limited emphasis on comprehensive BoD indicators such as DALY, YLL, and YLD. Therefore, there remains a critical need for localised long-term projections integrating climate scenarios, air quality modelling, and BoD assessment to support climate-resilient public health planning in Malaysia.

1.4 RESEARCH QUESTION

i. What is the annual trend for the BoD (mortality, hospital admission and DALY) of NCDs (CVD, RD and DM) in Kelantan and Kedah from 2005-2021?
ii. What is the trend of air pollution in Kelantan and Kedah from 2005-2021?

iii. What is the projection for the BoD of NCDs attributable to air pollution in Kelantan and Kedah under SSP5-8.5 scenario?

1.4 RESEARCH JUSTIFICATION

Malaysia is not exempt from the impacts of global warming and deteriorating air quality. Recent regional climate downscaling studies projected that the average surface temperature in Malaysia could increase by 3°C to 5°C by the end of the 21st century under different emission scenarios (Tangang et al. 2012). Changes in climate and meteorological conditions are expected to influence ambient air quality, particularly through changes in temperature, precipitation, atmospheric circulation, and transboundary pollution (Hong et al. 2019; Sahani et al. 2022).

At the same time, NCDs continue to impose a public health burden in Malaysia. The National Health and Morbidity Survey 2023 (Institute of Public Health-IPH 2024) reported that 2.5% of Malaysian adults are living with four major NCD risk factors, namely diabetes, hypertension, high cholesterol, and obesity, which contribute significantly to cardiovascular diseases and stroke. Existing national datasets mainly focus on specific sectors separately, such as health surveillance, climate projections, and air pollution monitoring, while integrated analyses combining climate, air quality, and health burden data remain limited in Malaysia.

Several local studies have demonstrated the adverse health effects of air pollution exposure in Malaysia. However, these studies were mostly conducted in the Klang Valley and focused primarily on short-term associations between air pollution and mortality or hospital admissions (Ibrahim et al. 2022; Tajudin et al. 2019; Wan Mahiyuddin et al. 2013). For example, Wan Mahiyuddin et al. (2013) reported significant associations between PM_{10}, SO_2, CO, NO_2, and O_3 with respiratory mortality in the Klang Valley. Tajudin et al. (2019) showed that exposure to SO_2, NO_2, and O_3 contributed to cardiovascular and respiratory hospital admissions, while Ibrahim et al. (2022) identified significant associations between $PM_{2.5}$ and SO_2 exposure with respiratory hospital admissions among children in Sarawak. These findings indicate that air pollution poses an important health risk in Malaysia; however, the available studies remain geographically limited, predominantly focused on urban areas such as Kuala Lumpur and Klang Valley, and mainly rely on historical short-term air quality data.

Furthermore, previous Malaysian studies mainly assessed mortality counts, morbidity, or isolated burden of disease (BoD) indicators without comprehensive long-term projections. For instance, Kwan et al. (2017) evaluated the reduction of $PM_{2.5}$ exposure in Kuala Lumpur and estimated its benefits in preventing premature deaths and Disability-Adjusted Life Years (DALYs), but the study did not include future climate projections or NCD-specific modelling. Similarly, Kwan et al. (2023) projected DALYs for respiratory diseases, cardiovascular diseases, and lung cancer under low-carbon mobility scenarios, yet the study lacked integration with climate-air quality modelling frameworks and future SSP-RCP climate scenarios.

In addition, there remains a substantial geographical and methodological gap in the Malaysian literature. Existing studies are concentrated mainly in the Klang Valley, whereas limited evidence is available for northern Peninsular Malaysia, particularly Kelantan and Kedah, despite these states being exposed to both local and transboundary air pollution sources (Ismail et al., 2017b). Sulphur dioxide (SO_2), nitrogen dioxide (NO_2), and ozone (O_3) have been identified as major pollutants contributing to air quality deterioration in the northern region driven by emissions from transportation and industrial activities. However, no previous study has comprehensively projected the future burden of disease attributable to air pollution in these regions under climate change scenarios.

Another important research gap concerns the application of advanced air quality modelling approaches in Malaysia. Air quality modelling in Malaysia has evolved progressively from pollutant concentration estimation to prediction-based approaches that incorporate meteorological influences (Ku Yusof et al. 2020). Various modelling techniques such as inverse distance weighted (IDW), geostatistical methods, and ordinary least squares-based geographic information systems (OLS-based GIS) have been utilised to estimate pollutant distributions (Jumaah et al. 2019). More recently, studies have highlighted the importance of meteorological variables such as temperature, humidity, wind speed, and wind direction in influencing air pollution concentrations (Abdullah et al. 2020; Ng & Awang 2018).

Despite these developments, the application of coupled climate-air quality models such as Weather Research and Forecasting–Community Multiscale Air Quality (WRF-CMAQ), which is considered state-of-the-art in air quality modelling, remains limited in Malaysia compared to countries such as China, Europe, and the United States (Birago Adomako et al. n.d.; Briant et al. 2017; Hur et al. 2021; Im et al. 2010; Tan et al., 2017).

Globally, advanced modelling frameworks that integrate climate projections, air quality simulations, and health burden assessments have increasingly been used to estimate future health impacts under climate change scenarios. Nevertheless, studies integrating CMIP6 climate projections, SSP-RCP scenarios, coupled air quality modelling, and burden of disease estimation remain scarce, particularly in Southeast Asia. In Malaysia, no study has comprehensively integrated downscaled climate projections, WRF-CMAQ air-quality modelling, and BoD assessment to project the future NCD burden attributable to air pollution under SSP5–8.5 scenarios, particularly for Kelantan and Kedah.

The Burden of Disease and Injury Study conducted by the Ministry of Health (MOH) Malaysia also highlights important gaps in the current evidence. The latest national BoD report, published in 2020, covered only the period from 2015 to 2017 and focused on broad national-level estimates of DALY, Years of Life Lost (YLL), and Years Lived with Disability (YLD) by gender and age groups (National Institute of Health (NIH) 2020).

Although NCDs consistently contributed the highest number of DALYs in Malaysia, the report was limited by its short observation period, the absence of state- and district-level analyses, and the lack of environmental risk factor assessments or future projections related to air pollution exposure. Consequently, there remains insufficient evidence to understand long-term trends and future climate-related health risks at the local level.

In summary, four major knowledge gaps remain in the Malaysian literature. First, existing studies have largely focused on short-term associations between air pollution and health outcomes, with limited translation into burden of disease metrics such as YLL, YLD, and DALY. Second, evidence from Kelantan and Kedah remains scarce despite the increasing burden of NCDs and exposure to regional air pollution. Third, previous Malaysian studies have not integrated climate projections, air quality modelling, and health burden assessment within a unified analytical framework. Fourth, few studies have projected future burden of disease attributable to air pollution under CMIP6 SSP5–8.5 climate scenarios at the state level. Addressing these gaps is essential for improving understanding of future climate-related health risks and supporting evidence-based environmental and public health policy in Malaysia.

1.5 OBJECTIVE

1.5.1 General Objective

To determine the BoD of NCDs attributable to air pollution in Kelantan and Kedah under a 1.5℃ global warming (SSP5- 8.5).

1.5.2 Specific Objectives

i. To determine the annual trend for the BoD (mortality, HA and DALY) of NCDs (CVD, RD and DM) in Kelantan and Kedah from 2005-2021.
ii. To determine the trend of air pollution in Kelantan and Kedah from 2005-2021
iii. To develop a health prediction model for BoD of NCDs in relationship with air pollution and meteorological variables in Kelantan and Kedah under SSP5-8.5 scenario
    - to determine the correlation between air pollution and meteorological variables in Kelantan and Kedah from 2005 to 2021.
    - to determine the correlation of NCD mortality with air pollution in Kelantan and Kedah from 2005-2021
    - to determine the correlation of NCD HA with air pollution in Kelantan and Kedah from 2005-2021

iv. To project the BoD of NCDs attributable to air pollution in Kelantan and Kedah under SSP5-8.5 scenario

1.6 HYPOTHESIS

There is a significant association between air pollution and meteorological variables in Kelantan and Kedah from 2005-2021.

There is a significant association between NCD mortality and air pollution in Kelantan and Kedah from 2005-2021.

There is a significant association between NCD hospital admissions and air pollution in Kelantan and Kedah from 2005-2021.

1.7 CONCLUSION

Air pollution is one of the biggest challenges of our time. It doesn't just drive climate change, but it also puts our health at risk, leading to more illness and premature deaths for people everywhere. Adverse health impacts of air pollution have been reported in many studies using various measures, including DALYs. Future air pollution levels and related BoD can be influenced by several factors, including air pollutant emissions (both natural and anthropogenic), climate variability and demographic changes. Projection models will help estimate risk and impact across scenarios. This will assist policymakers in structuring a comprehensive mitigation plan.

REFERENCES

Abd Majid, N., Razman, M. R., Zakaria, S. Z. S., Ahmed, M. F., & Zulkafli, S. A. 2021. Flood disaster in Malaysia: approach review, causes and application of geographic information system (GIS) for Mapping of flood risk area. *Eco. Env. Cons* 27 :S1–S8.

Abd Rahim, N. N., Zaki, R. A., Yahya, A., & Wan Mahiyuddin, W. R. 2025. Acute Effects of Nitrogen Dioxide Exposure and Risk of Cardiorespiratory Hospital Admissions in Peninsular Malaysia: A Time-series Study. *Malaysian Journal of Medicine and Health Sciences* 21(2):100–108. https://doi.org/10.47836/mjmhs.21.2.14

Abdul Shakor, A. S., Pahrol, M. A., & Mazeli, M. I. 2020. Effects of population weighting on PM_{10} concentration estimation. *Journal of Environmental and Public Health* 1:1561823.

Abdullah, S., Napi, N. N. L. M., Ahmed, A. N., Mansor, W. N. W., Mansor, A. A., Ismail, M., Abdullah, A. M., & Ramly, Z. T. A. 2020. Development of multiple linear regression for particulate matter (PM_{10}) forecasting during episodic transboundary haze event in Malaysia. *Atmosphere* 11(3) https://doi.org/10.3390/atmos11030289.

Afandi, G. E., Bolden-Tiller, O., Mortley, D., Asare-Baah, L., Miller, R., Ibrahim, S., ... & Rangari, V.2025. Air Quality Assessment and Source Speciation of $PM_{2.5}$ in Florida's Everglades Agricultural Area. *Earth Systems and Environment* 1-23.

Ahmad, N. A., Ismail, N. W., Ahmad Sidique, S. F., & Mazlan, N. S. 2021. Air pollution effects on adult mortality rate in developing countries. *Environmental Science and Pollution Research* 28: 8709–8721.

Akyol, S., Erdogan, S., Idiz, N., Celik, S., Kaya, M., Ucar, F., Dane, S., & Akyol, O. 2014. The role of reactive oxygen species and oxidative stress in carbon monoxide toxicity: an in-depth analysis. *Redox Report* 19(5): 180–189.

Al Ahad, M. A., Demšar, U., Sullivan, F., & Kulu, H.2024. Long term exposure to ambient air pollution and hospital admission burden in Scotland: 16 year prospective population cohort study. *BMJ Open* 14(12):e084032.

Alahmad, B., Khraishah, H., Althalji, K., Borchert, W., Al-Mulla, F., & Koutrakis, P. 2023. Connections Between Air Pollution, Climate Change, and Cardiovascular Health. *Canadian Journal of Cardiology* 39(9):1182–1190. https://doi.org/10.1016/j.cjca.2023.03.025

Alam, S., Lang, J. J., Drucker, A. M., Gotay, C., Kozloff, N., Mate, K., Patten, S. B., Orpana, H. M., Afshin, A., & Cahill, L. E. 2019. Assessment of the burden of diseases and injuries attributable to risk factors in Canada from 1990 to 2016: an analysis of the Global Burden of Disease Study. *Canadian Medical Association Open Access Journal* 7(1):E140–E148.

Alinaghian, S. A., Hamidzadeh, S., Badrizadeh, A., Khazaei, Z., Souri, A., Momenabadi, V., & Goodarzi, E. 2025. Burden of type 2 diabetes and its relationship with human development index in Asian countries: Global Burden of Disease Study in 2019. *BMC Public Health* 25(1):402.

Allan, R. P., Hawkins, E., Bellouin, N., & Collins, B.2021. IPCC, 2021: summary for Policymakers.

Amlaev, K. R., & Abdullah, A. 2025. Towards Strategies For The Medical Prevention of Non-Communicable Diseases. Problems of Social Hygiene. *Public Health and History of Medicine* 33(4): 628-632.

Anzorov, V. A., Moryakina, S. V, & Kulova, L. 2024. Environmental Impact on Cardiovascular Health: The Role of Environmental Pollution. *BIO Web of Conferences* 140:4001.

Apte, J. S., Messier, K. P., Gani, S., Brauer, M., Kirchstetter, T. W., Lunden, M. M., ... & Hamburg, S. P. 2017. High-resolution air pollution mapping with Google street view cars: exploiting big data. *Environmental Science & Technology, 51(12),* 6999-7008.

Areal, A. T. 2024. Relative humidity, temperature, and air pollution: the effect of multiple exposures on respiratory health in German adolescents.

Armstrong, B., Gasparrini, A., & Hajat, S. 2014. Estimating mortality displacement during and after heat waves. *American Journal of Epidemiology* 179(12):1405–1406.

ASEAN. 2021. ASEAN Agreement on Transboundary Haze. https://asean.org/wp-content/uploads/2021/01/ASEANAgreementonTrans [30 April 2026]

Awang, N. A., & Hamid, M. R. A. 2013. Sea level rise in Malaysia. Sea Level Rise Adaptation Measures. *Hydrolink* 2: 47–49.

Bagheri, M., Ibrahim, Z. Z., Wolf, I. D., Akhir, M. F., Talaat, W. I. A. W., & Oryani, B. 2023. Sea-level projections using a NARX-NN model of tide gauge data for the coastal city of Kuala Terengganu in Malaysia. *Environmental Science and Pollution Research*, *30*(34):81839-81857.

Balti, E. V, Echouffo-Tcheugui, J. B., Yako, Y. Y., & Kengne, A. P.2014. Air pollution and risk of type 2 diabetes mellitus: a systematic review and meta-analysis. *Diabetes Research and Clinical Practice* 106(2):161–172.

Barrow, A., Oyareme, V., & Kuye, R. A. 2026. Air pollution, health system capacity, and non-communicable disease mortality in West Africa: a mediation analysis of the environmental health-healthcare financing nexus. *Discover Public Health*, 23(1): 660.

Batz, V., Liedtke, V. B., Lameski, P., Trajkovik, V., Hußlein, S., Hansen, C., & Herzog, M. A.2025. Enhancing Public Awareness of Air Quality: Evaluating Communication Strategies and Design Prototypes Using a Design-Based Implementation Research Approach. In International Conference on Human-Computer Interaction (pp. 3-25). Cham: Springer Nature Switzerland.

Bernstein, A. S., & Rice, M. B. 2013. Lungs in a warming world: climate change and respiratory health. *Chest* 143(5): 1455–1459.

Bin Luhaim, Z., Tan, M. L., Tangang, F., Zulkafli, Z., Chun, K. P., Yusop, Z., & Yaseen, Z. M. 2021. Drought variability and characteristics in the Muda River basin of malaysia from 1985 to 2019. *Atmosphere* 12(9): 1–19. https://doi.org/10.3390/atmos12091210

Breitner-Busch, S., Mücke, H. G., Schneider, A., & Hertig, E. 2023. Corrigendum: Impact of climate change on non-communicable diseases due to increased ambient air pollution. *Journal of Health Monitoring* (8). https://doi.org/10.25646/11655

Brook, R. D., Franklin, B., Cascio, W., Hong, Y., Howard, G., Lipsett, M., Luepker, R., Mittleman, M., Samet, J., & Smith Jr, S. C. 2004. Air pollution and cardiovascular disease: a statement for healthcare professionals from the Expert Panel on Population and Prevention Science of the American Heart Association. Circulation, 109(21): 2655–2671.

Brook, R. D., Xu, X., Bard, R. L., Dvonch, J. T., Morishita, M., Kaciroti, N., Sun, Q., Harkema, J., & Rajagopalan, S. 2013. Reduced metabolic insulin sensitivity following sub-acute exposures to low levels of ambient fine particulate matter air pollution. Science of the Total Environment 448:66–71.

Budreviciute, A., Damiati, S., Sabir, D. K., Onder, K., Schuller-Goetzburg, P., Plakys, G., ... & Kodzius, R. 2020. Management and prevention strategies for non-communicable diseases (NCDs) and their risk factors. *Frontiers in Public Health* 8:574111.

Burkart, K., Causey, K., Cohen, A. J., Wozniak, S. S., Salvi, D. D., Abbafati, C., Adekanmbi, V., Adsuar, J. C., Ahmadi, K., & Alahdab, F. 2022. Estimates, trends, and drivers of the global burden of type 2 diabetes attributable to PM2·5 air pollution, 1990–2019: an analysis of data from the Global Burden of Disease Study 2019. *The Lancet Planetary Health* 6(7): e586–e600.

Buslima, F. S., Omar, R. C., Jamaluddin, T. A., & Taha, H. 2018. Flood and flash flood geo-hazards in Malaysia. *Int. J. Eng. Technol 7*(4):760-764.

Cambra-López, M., & Torres, A. G. 2008. An approach to source apportionment of dust in animal houses: the case of rabbit rearing facilities.

Campbell-Lendrum, D., & Prüss-Ustün, A. 2018. Climate change, air pollution and noncommunicable diseases. *Bulletin of the World Health Organization* 97(2): 160.

Chatzidiakou, L., Archer, R., Beale, V., Bland, S., Carter, H., Castro-Faccetti, C., & Burridge, H. C. 2023. Schools' air quality monitoring for health and education: Methods and protocols of the SAMHE initiative and project. *Developments in the Built Environment* 16: 100266.

Chaudhary, F., Ahmed, Z., Fraix, M. P., & Agrawal, D. K. 2024. Air Pollution and the Pathogenesis of Cardiovascular Disease. *In Advances in Biochemistry in Health and Disease* 30:33–166. https://doi.org/10.1007/978-3-031-62806-1_4

Chen, C., You, Y., Du, Y., Zhou, W., Jiang, D., Cao, K., Yang, M., Wu, X., Chen, M., & Qi, J. 2024. Global epidemiological trends in the incidence and deaths of acute respiratory infections from 1990 to 2021. *Heliyon* 10(16).

Chen, K., Fiore, A. M., Chen, R., Jiang, L., Jones, B., Schneider, A., Peters, A., Bi, J., Kan, H., & Kinney, P. L. 2018. Future ozone-related acute excess mortality under climate and population change scenarios in China: A modelling study. *PLoS Medicine* 15(7):1–23. https://doi.org/10.1371/journal.pmed.1002598

Chen, L., Gao, Y., Ma, M., Wang, L., Wang, Q., Guan, S., ... & Gao, H. 2023. Striking impacts of biomass burning on PM2. 5 concentrations in Northeast China through the emission inventory improvement. *Environmental Pollution* 318: 120835.

Chen, L., Mak, C. M., Hang, J., & Dai, Y. 2024. Influence of elevated walkways on outdoor thermal comfort in hot-humid climates based on on-site measurement and CFD modelling. *Sustainable Cities and Society* 100:105048.

Chen, S., Xiao, Y., Zhou, M., Zhou, C., Yu, M., Huang, B., Xu, Y., Liu, T., Hu, J., Xu, X., Lin, L., Hu, R., Hou, Z., Li, J., Jin, D., Qin, M., Zhao, Q., Gong, W., Yin, P., Ma, W. 2020. Comparison of life loss per death attributable to ambient temperature among various development regions: A nationwide study in 364 locations in China. *Environmental Health: A Global Access Science Source* 19(1). https://doi.org/10.1186/s12940-020-00653-3

Chlebnikovas, A., Paliulis, D., Bradulienė, J., & Januševičius, T. 2023. Short-term field research on air pollution within the boundaries of the large city in the Baltic region. *Environmental Science and Pollution Research*, 30(34): 81950-81965.

Costa, A. F., Hoek, G., Brunekreef, B., & de Leon, A. C. M. P. 2016. Air pollution and deaths among elderly residents of Sao Paulo, Brazil: an analysis of mortality displacement. *Environmental Health Perspectives* 125(3):349.

D'Amato, G., Cecchi, L., D'Amato, M., & Annesi-Maesano, I. 2014. Climate change and respiratory diseases. *European Respiratory Society*.

Dabass, A., Talbott, E. O., Venkat, A., Rager, J., Marsh, G. M., Sharma, R. K., & Holguin, F. 2016. Association of exposure to particulate matter ($PM_{2.5}$) air pollution and biomarkers of cardiovascular disease risk in adult NHANES participants (2001–2008). *International Journal of Hygiene and Environmental Health* 219(3):301–310.

Daiber, A., Steven, S., Weber, A., Shuvaev, V. V, Muzykantov, V. R., Laher, I., Li, H., Lamas, S., & Münzel, T. 2017. Targeting vascular (endothelial) dysfunction. *British Journal of Pharmacology* 174(12):1591–1619.

Darling, R., Hansen, K., Aguilera, R., Basu, R., Benmarhnia, T., & Letellier, N. 2023. The burden of wildfire smoke on respiratory health in California at the zip code level: uncovering the disproportionate impacts of differential fine particle composition. *GeoHealth 7*(10):e2023GH000884

Das, U., & Kar, N. 2026. Morbidity knocks the door of the economy: understanding the economic strain on middle-aged and older adults in Bankura district, West Bengal. *International Review of Sociology* 1-17.

Davis, R. E., McGregor, G. R., & Enfield, K. B. 2016. Humidity: A review and primer on atmospheric moisture and human health. *Environmental Research* 144:106–116.

Davis, W. T., Fu, Joshua, S., & Godish T. 2021. Chapter 7: Air Quality and Emissions Assessment (6th ed.). CRC.

Demetriou, E., & Hadjistassou, C. 2022. Lowering mortality risks in urban areas by containing atmospheric pollution. *Environmental Research* 211:113096.

Dhimal, M., Chirico, F., Bista, B., Sharma, S., Chalise, B., Dhimal, M. L., Ilesanmi, O. S., Trucillo, P., & Sofia, D. 2021. Impact of air pollution on global burden of disease in 2019. *Processes* 9(10):1–9. https://doi.org/10.3390/pr9101719

Dias, D., & Tchepel, O. 2018. Spatial and temporal dynamics in air pollution exposure assessment. *International journal of environmental research and public health,* 15(3):558.

Donahue, N. M. 2018. Air pollution and air quality. In Green chemistry (pp. 151–176). Elsevier.

Dondi, A., Carbone, C., Manieri, E., Zama, D., Del Bono, C., Betti, L., & Lanari, M. 2023. Outdoor air pollution and childhood respiratory disease: the role of oxidative stress. *International Journal of Molecular Sciences* 24(5): 4345.

DOSH. 2021. Guideline for the protection of Employees against the effect of Haze at the workplace. https://www.doe.gov.my/wp-content/uploads/2021/10/Guidelines-for-the-Protection-of-Employees-Against-the-Effects-of-Haze-at-Workplaces.pdf [5 Mei 2026]

Dosio, A., Mentaschi, L., Fischer, E. M., & Wyser, K. 2018. Extreme heat waves under 1.5° C and 2°C global warming. *Environmental Research Letters* 13(5):054006.

Du, J., Yang, J., Wang, L., Wu, X., Cao, W., & Sun, S. 2021. A comparative study of the disease burden attributable to $PM_{2.5}$ in China, Japan and South Korea from 1990 to 2017. *Ecotoxicology and Environmental Safety* 209. https://doi.org/10.1016/j.ecoenv.2020.111856

Durmaz, E., Raimoglu, D., İncesu, G., Raimoglu, U., Güney, S., Yalman, H., Miroğlu, M., Ozal, A., Aygün, A. A., & Acar, B. 2025. Underlying Mechanisms of Second-Generation Drug Eluting Stent Thrombosis: An Optical Coherence Tomography Study. Catheterisation and Cardiovascular Interventions.

Ebi, K. L., Bi, P., Bowen, K., Brauer, M., Chua, P. L. C., Colón-González, F. J., Dimitrova, A., Gasparrini, A., Gouveia, N., Hajat, S., Hamilton, I., Harper, S., Hasegawa, T., Hashizume, M., Heaviside, C., Honda, Y., Green, C., Jack, C., Kim, H., … Hess, J. J. 2025. Priority climate and health modelling needs. *The Lancet. Planetary Health* 9(9):101297. https://doi.org/10.1016/j.lanplh.2025.101297

Edwards, D. A., Edwards, A., Li, D., Wang, L., Chung, K. F., Bhatta, D., Bilstein, A., Hanes, J., Edirisinghe, I., & Freeman, B. B. 2025. Global warming risks dehydrating and inflaming human airways. *Communications Earth & Environment* 6(1):193.

El Kheir, D. Y. M., Al-Ibrahim, M. A., Alhaddad, M. I., Alsafwani, H. J., Alkhater, M. N., Alameer, M. H., & Almousa, M. H. 2026. An account of the healthcare-seeking behavior of the public in response to a healthcare emergency (coronavirus disease 2019): The Saudi community experience. *Journal of Family and Community Medicine* 33(1): 20-2

Elling, D., Surkan, P. J., Enayati, S., & El-Khatib, Z. 2018. Sex differences and risk factors for diabetes mellitus-an international study from 193 countries. *Globalization and Health* 14:1–7.

Emberson, L. D., Pleijel, H., Ainsworth, E. A., Van den Berg, M., Ren, W., Osborne, S., Mills, G., Pandey, D., Dentener, F., & Büker, P. 2018. Ozone effects on crops and consideration in crop models. *European Journal of Agronomy* 100:19–34.

Eyring, V., Bony, S., Meehl, G. A., Senior, C. A., Stevens, B., Stouffer, R. J., & Taylor, K. E. 2016. Overview of the Coupled Model Intercomparison Project Phase 6 (CMIP6) experimental design and organization. *Geoscientific Model Development* 9(5):1937–1958. https://doi.org/10.5194/gmd-9-1937-2016

Fakana, S. T. 2020. Causes of Climate Change: Review Article.

Farley, K. L., Owen, D., Fitch, A., Fletcher, D., Scheffler, J., & Jones, L. 2025. A tale of two cities: contrasting equity of greenspace benefits in relation to $PM_{2.5}$ exposure. *BMC Public Health 25*(1):3449.

Feleke, B. E., Morton, J., Magliano, D., & Shaw, J. E. 2023. Trends of hospitalisation for cardiovascular diseases among people with diabetes in Australia. *Diabetes Research and Clinical Practice* 205:110973.

Fenech, S., Doherty, R. M., O'connor, F. M., Heaviside, C., Macintyre, H. L., Vardoulakis, S., Agnew, P., & Neal, L. S. 2021. Future air pollution-related health burdens associated with RCP emission changes in the UK. *Science of The Total Environment* 773:145635.

Ferrari, A. J., Santomauro, D. F., Aali, A., Abate, Y. H., Abbafati, C., Abbastabar, H., Abd ElHafeez, S., Abdelmasseh, M., Abd-Elsalam, S., Abdollahi, A., Abdullahi, A., Abegaz, K. H., Abeldaño Zuñiga, R. A., Aboagye, R. G., Abolhassani, H., Abreu, L. G., Abualruz, H., Abu-Gharbieh, E., Abu-Rmeileh, N. M., … Murray, C. J. L. 2024. Global incidence, prevalence, years lived with disability (YLDs), disability-adjusted life-years (DALYs), and healthy life expectancy (HALE) for 371 diseases and injuries in 204 countries and territories and 811 subnational locations, 1990–2021: a systematic analysis for the Global Burden of Disease Study 2021. *The Lancet* 403(10440):2133–2161.

https://doi.org/10.1016/S0140-6736(24)00757-8
Fetrat, S., & Mohammadi, A. A. 2025. Investigating the Effects of Air Pollution on Human Health. *Salamat Academic & Research Journal* 2(3):43–50. https://doi.org/10.61438/sarj.v2i3.190
Firdaus, R. B. R., Leong Tan, M., Rahmat, S. R., & Senevi Gunaratne, M. 2020. Paddy, rice and food security in Malaysia: A review of climate change impacts. *Cogent Social Sciences* 6(1):1818373.
Forastiere, L., Carugno, M., & Baccini, M. 2020. Assessing short-term impact of PM 10 on mortality using a semiparametric generalised propensity score approach. *Environmental Health* 19:1–13.
Fu, H., Liu, X., Li, W., Zu, Y., Zhou, F., Shou, Q., & Ding, Z. 2020. $PM_{2.5}$ exposure induces inflammatory response in macrophages via the TLR4/COX-2/NF-κB pathway. *Inflammation* 43(5): 1948–1958.
Fulazzaky, M. A., Syafiuddin, A., Muda, K., Martin, A. Y., Yusop, Z., & Ab Ghani, N. H. (2023). A review of the management of water resources in Malaysia facing climate change. *Environmental Science and Pollution Research* 30(58):121865-121880.
Gasparrini, A., Armstrong, B., & Kenward, M. G. 2010. Distributed lag non‐linear models. *Statistics in medicine*, 29(21):2224-2234. https://doi.org/10.1002/sim.3940
Georgoulias, A. K., Lelieveld, J., Klingmüller, K., Akritidis, D., Pozzer, A., Alexandri, G., Bilal, M., Cheng, Y., Su, H., & Zanis, P. 2025. Avoided mortality by particulate air pollution control measures in China. *Science of The Total Environment* 1002:180566.
Georgoulias, A. K., Lelieveld, J., Klingmüller, K., Akritidis, D., Pozzer, A., Alexandri, G., ... & Zanis, P. 2025. Avoided mortality by particulate air pollution control measures in China. *Science of The Total Environment* 1002:180566.
Ghorani-Azam, A., Riahi-Zanjani, B., & Balali-Mood, M. 2016. Effects of air pollution on human health and practical measures for prevention in Iran. *Journal of Research in Medical Sciences* 21(1): 65.
Goh, E. Von, Azam-Ali, S., McCullough, F., & Roy Mitra, S.2020. The nutrition transition in Malaysia; key drivers and recommendations for improved health outcomes. *BMC Nutrition* 6(1):32.
Grigorieva, E., & Lukyanets, A. 2021. Combined effect of hot weather and outdoor air pollution on respiratory health: Literature review. *Atmosphere* 12(6). https://doi.org/10.3390/atmos12060790
Gu, Y., Yan, F., Xu, J., Qu, Y., Gao, W., He, F., & Liao, H. 2020. A measurement and model study on ozone characteristics in marine air at a remote island station and its interaction with urban ozone air quality in Shanghai, China. *Atmospheric Chemistry and Physics* 20(22):14361–14375.
Guo, C., Sun, X., Diao, W., Shen, N., & He, B. 2020. Correlation of clinical symptoms and sputum inflammatory markers with air pollutants in stable COPD patients in Beijing area. *International journal of chronic obstructive pulmonary disease* 1507-1517.
Hajat, S., & Kosatky, T. 2010. Heat-related mortality: a review and exploration of heterogeneity. *Journal of Epidemiology & Community Health* 64(9):753–760.
Halim, N. D. A., Latif, M. T., Mohamed, A. F., Maulud, K. N. A., Idrus, S., Azhari, A., Othman, M., & Sofwan, N. M. 2020. Spatial assessment of land use impact on air quality in mega urban regions, Malaysia. *Sustainable Cities and Society* 63.

https://doi.org/10.1016/j.scs.2020.102436.

Hasani, W. S. R., Musa, K. I., Cheng, K. Y., & Dass, S. C. 2024. Exploring the trend of age-standardized mortality rates from cardiovascular disease in Malaysia: a joinpoint analysis (2010–2021). *BMC Public Health* 24(1):2519.

Hasegawa, K., Tsukahara, T., & Nomiyama, T. 2023. Short-term associations of low-level fine particulate matter (PM2. 5) with cardiorespiratory hospitalizations in 139 Japanese cities. *Ecotoxicology and Environmental Safety* 258:114961.

Hastings, B. J. 2025. Guidance for successful healthcare transformation: A systematic review of change management practices and outcomes. *Australian Journal of Management* 50(3):985-1005.

Hertig, E., Hunger, I., Kaspar-Ott, I., Matzarakis, A., Niemann, H., Schulte-Droesch, L., & Voss, M. 2023. Climate change and public health in Germany–An introduction to the German status report on climate change and health 2023. *Journal of Health Monitoring* 8(Suppl 3):6.

Hoffmann, B., Boogaard, H., de Nazelle, A., Andersen, Z. J., Abramson, M., Brauer, M., Brunekreef, B., Forastiere, F., Huang, W., Kan, H., Kaufman, J. D., Katsouyanni, K., Krzyzanowski, M., Kuenzli, N., Laden, F., Nieuwenhuijsen, M., Mustapha, A., Powell, P., Rice, M., … Thurston, G. 2021. WHO Air Quality Guidelines 2021–Aiming for Healthier Air for all: A Joint Statement by Medical, Public Health, Scientific Societies and Patient Representative Organisations. *International Journal of Public Health* 66. https://doi.org/10.3389/ijph.2021.1604465

Hong, C., Zhang, Q., Zhang, Y., Davis, S. J., Tong, D., Zheng, Y., Liu, Z., Guan, D., He, K., & Schellnhuber, H. J. 2019. Impacts of climate change on future air quality and human health in China. Proceedings of the *National Academy of Sciences of the United States of America* 116(35):17193–17200. https://doi.org/10.1073/pnas.1812881116.

Hou, Z., Wang, Y., Chen, Z., Sun, S., Xie, N., Chen, Y., Wang, L., Lin, F., & Zhao, G. 2024. Exposure to air pollution and the risk of type II diabetes mellitus: a time-series study. *Frontiers in Endocrinology*, 1–13. https://doi.org/10.3389/fendo.2024.1482063

Huang, J., Zeng, Q., Pan, X., Guo, X., & Li, G. 2019. Projections of the effects of global warming on the disease burden of ischemic heart disease in the elderly in Tianjin, China. *BMC Public Health* 19:1–9.

Huang, L., Zhu, Y., Zhai, H., Xue, S., Zhu, T., Shao, Y., Liu, Z., Emery, C., Yarwood, G., Wang, Y., Fu, J., Zhang, K., & Li, L. 2021. Recommendations on benchmarks for numerical air quality model applications in China - Part 1: $PM_{2.5}$ and chemical species. *Atmospheric Chemistry and Physics* 21(4):2725–2743. https://doi.org/10.5194/acp-21-2725-2021

Huertas, J. I., Martinez, D. S., & Prato, D. F. 2021. Numerical approximation to the effects of the atmospheric stability conditions on the dispersion of pollutants over flat areas. *Scientific Reports* 11(1):11566.

Ibrahim, M. F., Hod, R., Ahmad Tajudin, M. A. B., Wan Mahiyuddin, W. R., Mohammed Nawi, A., & Sahani, M. 2022. Children's exposure to air pollution in a natural gas industrial area and their risk of hospital admission for respiratory diseases. *Environmental Research* 210. https://doi.org/10. 1016/j.envres. 2022.112966.

Ingole, V., Dimitrova, A., Sampedro, J., Sacoor, C., Acacio, S., Juvekar, S., Roy, S., Moraga, P., Basagaña, X., Ballester, J., Antó, J. M., & Tonne, C. 2022. Local mortality impacts due to future air pollution under climate change scenarios. *Science of the Total Environment* 823. https://doi.org/10.1016/j.scitotenv.2022.153832

Institute of Health Metrics and Evaluation (IHME). 2019. Global Burden of Disease GBD . https://www.healthdata.org/research-analysis/gbd

IPCC.2018. Special Report. Global warming of 1.5°C. https://www.ipcc.ch/site/assets/uploads/sites/2/2019/06/SR15_Full_Report_High_Res.pdf

IPH, I. for P. H., NIH, N. I. of H., & Malaysia, M. of H. 2019. National Health and Morbidity Survey (NHMS) 2019: NCDs - Non-Communicable Diseases: Risk Factors and other Health Problems. In Institute for Public Health, National Institutes of Health (NIH), Ministry of Health Malaysia (Vol.1). http://www.iku.gov.my/nhms-2019

Isenaj, Z. S., Moshammer, H., Berisha, M., & Weitensfelder, L. 2025. Effect of an educational intervention on pupil's knowledge, attitudes, perceptions, and behavior on air pollution in public schools in Pristina. *European Journal of Investigation in Health, Psychology and Education* 15(5): 69.

Ismail, A. S., Abdullah, A. M., & Samah, M. A. A. 2017. Environmetric study on air quality pattern for assessment in northern region of peninsular Malaysia. *Journal of Environmental Science and Technology* 10(4): 186–196. https://doi.org/10.3923/jest.2017.186.196.

Jafri, I. A. M., Noor, N. M., Rahim, N. A. A. A., Ul-Saufie, A. Z., Hassan, Z., & Deak, G. 2023. Spatial and Temporal Analysis of Particulate Matter (PM_{10}) in Urban-Industrial Environment during Episodic Haze Events in Malaysia. *EnvironmentAsia 16*(1)

Jakubowska, A. 2023. The burden of air pollution: a perspective on global health inequalities. *Pollutants* 3(3): 419–436.

Jalili, V., Afgan, E., Gu, Q., Clements, D., Blankenberg, D., Goecks, J., ... & Nekrutenko, A. 2020. The Galaxy platform for accessible, reproducible and collaborative biomedical analyses: 2020 update. *Nucleic acids research* 48(W1): W395-W402.

Jeong, N. J., Park, E., & Del Pobil, A. P. 2021. Effects of behavioral risk factors and social-environmental factors on non-communicable diseases in South Korea: a national survey approach. *International journal of environmental research and public health* 18(2):612.

Jiang, Y., Huang, J., Li, G., Wang, W., Wang, K., Wang, J., Wei, C., Li, Y., Deng, F., Baccarelli, A. A., Guo, X., & Wu, S. 2023. Ozone pollution and hospital admissions for cardiovascular events. *European Heart Journal* 44(18):1622–1632. https://doi.org/10.1093/eurheartj/ehad091

Jiang, Y., Wang, S., Xing, J., Zhao, B., Li, S., Chang, X., Zhang, S., & Dong, Z. 2022. Ambient fine particulate matter and ozone pollution in China: Synergy in anthropogenic emissions and atmospheric processes. *Environmental Research Letters* 17(12):123001.

Joshi, M. K., Rai, A., Kulkarni, A., & Kucharski, F. 2020. Assessing Changes in Characteristics of Hot Extremes Over India in a Warming Environment and their Driving Mechanisms. *Scientific Reports* 10(1):2631. https://doi.org/10.1038/s41598-020-59427-z

Jumaah, H. J., Ameen, M. H., Kalantar, B., Rizeei, H. M., & Jumaah, S. J. 2019. Air quality index prediction using IDW geostatistical technique and OLS-based GIS technique in Kuala Lumpur, Malaysia. *Geomatics, Natural Hazards and Risk* 10(1):2185–2199. https://doi.org/10.1080/19475705.2019.1683084.

Jung, J., Choi, A., & Yoon, S. 2022. Transboundary air pollution and health: evidence from East Asia. *Environment and Development Economics* 27(2):120–144.

Kairan, O., Zainudin, N. N., Mohd Hanafiah, N. H., Mohd Jafri, N. E. A., Suhami, F. F., & Mustapha, M. F. 2021. Temporal analysis of air pollutants in the most affected monsoon region. *Indonesian Journal of Electrical Engineering and Computer Science* 23(1):229–236. https://doi.org/10.11591/ijeecs.v23.i1.pp229-236

Karim, N., Hod, R., Wahab, M. I. A., & Ahmad, N.2024. Projecting non-communicable diseases attributable to air pollution in the climate change era: a systematic review. *BMJ Open* 14(5):1–2. https://doi.org/10.1136/bmjopen-2023-079826

Karter, A. J., Nundy, S., Parker, M. M., Moffet, H. H., & Huang, E. S. 2014. Incidence of Remission in Adults With Type 2 Diabetes: The Diabetes & Aging Study. *Diabetes Care* 37(12):3188–3195. https://doi.org/10.2337/dc14-0874

Kelishadi, R., & Poursafa, P. 2010. Air pollution and non-respiratory health hazards for children. *Archives of Medical Science* 6(4):483–495.

Keshavarz, A., Tan, M. L., Modarres, R., Gohari, A., & Yaseen, Z. M. 2026. Wavelet analysis of multi-scale drought variability and climate teleconnections in Penang, Malaysia. *Acta Geophysica* 74(4):191.

Khan, N., Shahid, S., Ahmed, K., & Yaseen, Z. M. 2025. Modeling spatial PM2. 5 risk dynamics and projecting disease burden in Pakistan. *Environmental Pollution* 373:126060.

Khaw, W. F., & Yong, H. Y. 2024. Top ten causes of death in Malaysia for the years 2013 and 2019. *The Lancet Regional Health - Western Pacific* 45:101066. https://doi.org/10.1016/j.lanwpc.2024.101066

Khaw, W.F., Chan, Y. M., Nasaruddin, N. H., Alias, N., Tan, L., & Ganapathy, S. S.2023. Malaysian burden of disease: years of life lost due to premature deaths. *BMC Public Health* 23(1):1383.

Khoo, C. M., & Tai, E. S. 2014. Trends in the incidence and mortality of coronary heart disease in Asian Pacific region. *Journal of atherosclerosis and thrombosis* 21(Supplement1):S2-S8.

Kissler, S. M., & Grad, Y. H. 2022. Anticipating racial/ethnic mortality displacement from COVID-19. *American Journal of Epidemiology* 191(8):1519–1520.

Kocot, K., & Zejda, J. E. 2022. The relationship between ambient air pollution and life expectancy–an ecological fallacy revisted. *Przegląd Epidemiologiczny-Epidemiological Review* 76(1):58-66.

Krismanuel, H. 2025. Air Pollution and Cardiovascular Health : Mechanisms , Vulnerabilities , and Genetic Factors. 1491–1508.

Krug, A., Fenner, D., Mücke, H.-G., & Scherer, D. 2020. The contribution of air temperature and ozone to mortality rates during hot weather episodes in eight German cities during the years 2000 and 2017. *Natural Hazards and Earth System Sciences* 20(11):3083–3097.

Ku Yusof, K. M. K., Ismail, S. S., Azid, A., Sani, M. S. A., Isa, N. M., & Mohamat Zawawi, M. Z. 2020. Variability on particulate matter and meteorology dataset during the hazy period in eastern region of Peninsular Malaysia. *Data in Brief* 29. https://doi.org/10.1016/j.dib.2020.105210.

Kumar, P.2021. Climate change and cities: challenges ahead. *In Frontiers in Sustainable Cities* 3:645613

Kwan, S. C., Tainio, M., Woodcock, J., Sutan, R., & Hashim, J. H. 2017. The carbon savings and health co-benefits from the introduction of mass rapid transit system in Greater Kuala Lumpur, Malaysia. *Journal of Transport and Health* 6:187–200. https://doi.org/10.1016/j.jth.2017.06.006.

Kyu, H. H., Abate, D., Abate, K. H., Abay, S. M., Abbafati, C., Abbasi, N., Abbastabar, H., Abd-Allah, F., Abdela, J., & Abdelalim, A. 2018. Global, regional, and national disability-adjusted life-years (DALYs) for 359 diseases and injuries and healthy life expectancy (HALE) for 195 countries and territories, 1990–2017: a systematic analysis for the Global Burden of Disease Study 2017. *The Lancet* 392(10159): 1859–1922.

Lai, N., Song, W., Wang, M., Zhao, L., Zhou, J., Cai, X., ... & Li, A. 2024. Qualitative and quantitative analyses of meteorological impacts on fine particle pollution in winters of cold region in China. *Processes* 12(12):2713.

Leary, P. J., Kaufman, J. D., Barr, R. G., Bluemke, D. A., Curl, C. L., Hough, C. L., Lima, J. A., Szpiro, A. A., Van Hee, V. C., & Kawut, S. M. 2014. Traffic-related air pollution and the right ventricle. The multi-ethnic study of atherosclerosis. *American Journal of Respiratory and Critical Care Medicine* 189(9):1093–1100.

Ling Hoon Leh, O., Musthafa, S. N. A. M., & Mohamed, N. 2014. Air Quality and Land Use in Urban Region of Petaling Jaya, Shah Alam and Klang, Malaysia. *EnvironmentAsia* 7(1).

Liu, B., Jin, Y., Xu, D., Wang, Y., & Li, C. 2021. A data calibration method for micro air quality detectors based on a LASSO regression and NARX neural network combined model. *Scientific Reports* 11(1). https://doi.org/10.1038/s41598-021-00804-7

Liu, C., Cai, J., Chen, R., Sera, F., Guo, Y., Tong, S., & Kan, H.2022. Coarse particulate air pollution and daily mortality: a global study in 205 cities. *American journal of respiratory and critical care medicine* 206(8):999-1007.

Liu, S., Yang, H., Li, M., Guo, Y., Zhang, Z., Liu, W., Wu, S., Liu, T., Li, S., Zhang, J., Wang, Y., Li, L., & Shi, P. 2025. Estimates, temporal evolution, and drivers of the global burden of cardiovascular disease attributable to particulate matter air pollution, 1990–2021: A systematic analysis from the global burden of disease study 2021. *Ecotoxicology and Environmental Safety* 302:118584. https://doi.org/10.1016/j.ecoenv.2025.118584

Lo, W.-C., Shie, R.-H., Chan, C.-C., & Lin, H.-H. 2017. Burden of disease attributable to ambient fine particulate matter exposure in Taiwan. *Journal of the Formosan Medical Association* 116(1):32–40.

Lu, X., Chen, S., Wang, C., Lin, D., He, F., Lin, X., Wu, H., Liang, P., Yan, L., Ren, M., & Chen, C.2025. Stronger associations of abdominal obesity-related triglyceride-glucose indices with type 2 diabetes compared to general obesity-related indices in community-dwelling Chinese adults: a cross-sectional study. *Frontiers in Endocrinology* 1–12. https://doi.org/10.3389/fendo.2025.1526849

Luyendyk, J. P., Schoenecker, J. G., & Flick, M. J. 2019. The multifaceted role of fibrinogen in tissue injury and inflammation. *Blood, The Journal of the American Society of Hematology* 133(6): 511–520.

Ma'amor, A., Noor, N. M., Jafri, I. A. M., Addiena, N. A., Ul, A. Z., Saufie, N. A. A., Boboc, M., & Deak, G. 2023. Spatial and temporal variation of particulate matter (PM_{10} and $PM_{2.5}$) and its health effects during the haze event in Malaysia. *Journal of Atmospheric Science Research| Volume* 6(04).

Mabahwi, N. A., Leh, O. L. H., & Omar, D. 2015. Urban air quality and human health effects in Selangor, Malaysia. *Procedia-Social and Behavioral Sciences* 170:282–291.

Maji, K. J., & Namdeo, A. 2021. Continuous increases of surface ozone and associated premature mortality growth in China during 2015–2019. *Environmental Pollution* 269. https://doi.org/10.1016/j.envpol.2020.116183

Manisalidis, I., Stavropoulou, E., Stavropoulos, A., & Bezirtzoglou, E. 2020. Environmental and Health Impacts of Air Pollution: A Review. *In Frontiers in Public Health* 8. https://doi.org/10.3389/fpubh.2020.00014

Mansournia, M. A., & Altman, D. G. 2018. Population attributable fraction. *BMJ* 360.

Mei, W. F. 2014. Development of A Climate Change Vulnerability Index for Peninsular Malaysia. University of Malaya (Malaysia).

Michikawa, T., Nishiwaki, Y., Asakura, K., Okamura, T., Takebayashi, T., Hasegawa, S., Milojevic, A., Minami, M., Taguri, M., Takeuchi, A., Ueda, K., Sairenchi, T., Yamagishi, K., Iso, H., Irie, F., & Nitta, H. 2025. All-Cause and Cause-Specific Mortality Associated with Long-Term Exposure to Fine Particulate Matter in Japan: The Ibaraki Prefectural Health Study. *Journal of Atherosclerosis and Thrombosis* 32(8):982–993. https://doi.org/10.5551/jat.65424

Miezaka, P., Bertins, M., Grinfelde, I., & Pilecka-Ulcugaceva, J. 2025. Air Quality in Jelgava: Impacts of Industrial Operations. *Research For Rural Development*, *40*:238.

Ministry of Health Malaysia. 2026. Usage of personal protection during haze. https://www.moh.gov.my/en/core/health-information/jerebu/artikel-dan-panduan-pengguna-berkaitan-jerebu/usage-of-personal-protection-duringss-haze [20 Mei 2026]

Mirabelli, M. C., Flanders, W. D., Vaidyanathan, A., Beavers, D. P., & Gower, W. A. 2023. Ambient air quality and fatal asthma exacerbations among children in North Carolina. *Epidemiology* 34(6):888-891.

Mohd Zulkifli, S. W. H., Samsudin, H. B., & Majid, N. 2024. Association between PM 10 and respiratory diseases admission in Peninsular Malaysia during haze. *Scientific Reports* 14(1): 21030.

Monoson, A., Schott, E., Ard, K., Kilburg-Basnyat, B., Tighe, R. M., Pannu, S., & Gowdy, K. M.2023. Air pollution and respiratory infections: the past, present, and future. *Toxicological Sciences* 192(1): 3–14.

Monteiro, T. F. G. 2019. Exposure to ambient air and physical exercise. Universidade do Porto (Portugal).

Morawska, L., & Buonanno, G. 2021. The physics of particle formation and deposition during breathing. *Nature Reviews Physics* 3(5):300–301. https://doi.org/10.1038/s42254-021-00307-4

Münzel, T., Gori, T., Al-Kindi, S., Deanfield, J., Lelieveld, J., Daiber, A., & Rajagopalan, S. 2018. Effects of gaseous and solid constituents of air pollution on endothelial function. *European Heart Journal* 39(38): 3543–3550.

Murray, C. J. L. 2022. The global burden of disease study at 30 years. *Nature Medicine* 28(10):2019–2026.

Murray, C. J. L., Aravkin, A. Y., Zheng, P., Abbafati, C., Abbas, K. M., Abbasi-Kangevari, M., Abd-Allah, F., Abdelalim, A., Abdollahi, M., & Abdollahpour, I. 2020. Global burden of 87 risk factors in 204 countries and territories, 1990–2019: a systematic analysis for the Global Burden of Disease Study 2019. *The*

Lancet 396(10258): 1223–1249.
Nagashima, T., & Kawano, N. 2023. Impacts of Climate Change on Tropospheric Ozone. In *Handbook of Air Quality and Climate Change* 1245-1253. Singapore: Springer Nature Singapore.
National Institute of Health, M. of H. M. 2020. Malaysian Burden of Disease and Injury Study.
NEHAP. 2026. Climate Change and Health in Malaysia: Implication and Challenge TWG10. https://nehapmalaysia.moh.gov.my/ [30 April 2026]
Nengsih, T. A., Wardhana, I., & M. Nazori Madjid, M. N. 2025. Addressing Missing Data in Environmental Technologies: Economic and Environmental Optimizing Air Quality Monitoring with Random Forest and MissForest. *Jurnal Riset Teknologi Pencegahan Pencemaran Industri* 16(1):23–31. https://doi.org/10.21771/jrtppi.2025.v16.no1.p23-31
Ng, K. Y., & Awang, N. 2018. Multiple linear regression and regression with time series error models in forecasting PM_{10} concentrations in Peninsular Malaysia. *Environmental Monitoring and Assessment* 190(2). https://doi.org/10.1007/s10661-017-6419-z.
Nissan, H., Goddard, L., de Perez, E. C., Furlow, J., Baethgen, W., Thomson, M. C., & Mason, S. J. 2019. On the use and misuse of climate change projections in international development. *Wiley Interdisciplinary Reviews: Climate Change* 10(3):e579.
Oga, T., Nishimura, K., Tsukino, M., Sato, S., & Hajiro, T. 2003. Analysis of the factors related to mortality in chronic obstructive pulmonary disease: role of exercise capacity and health status. *American Journal of Respiratory and Critical Care Medicine* 167(4):544–549. https://doi.org/10.1164/rccm.200206-583OC
Oliveira, B., de Moura, A. P., & Cunha, L. M. 2019. Increasing pulse consumption to improve human health and food security and to mitigate climate change. *Climate Change-Resilient Agriculture and Agroforestry: Ecosystem Services and Sustainability* 21–35.
Olsen, J. R., Niedzwiedz, C., Nicholls, N., Wheeler, B. W., Ho, F. K., & Pell, J. P. 2025. Sociodemographic and geographic inequalities in exposure to projected hot and extreme summer days in England: A nationwide socio-spatial analysis. *Environment International* 197. https://doi.org/10.1016/j.envint.2025.109351
OpenDOSM. 2020a. My Census 2020 Kedah. Department of Statistics Malaysia. https://open.dosm.gov.my/dashboard/kawasanku/Kedah
OpenDOSM.2020b. My Census 2020 Kelantan. https://open.dosm.gov.my/dashboard/kawasanku/Kelantan
OpenDOSM.2025. OpenDOSM. Department of Statistics Malaysia. https://open.dosm.gov.my/
Orellano, P., Reynoso, J., Quaranta, N., Bardach, A., & Ciapponi, A. 2020. Short-term exposure to particulate matter (PM_{10} and $PM_{2.5}$), nitrogen dioxide (NO_2), and ozone (O_3) and all-cause and cause-specific mortality: Systematic review and meta-analysis. *Environment International* 142:105876.
Otu, E., Ashworth, K., Tsekleves, E., & Ackley, A. 2024. Empowering London primary school communities to know and tackle air pollution exposure. *Sustainability* 16(17):7491.
Pan, R., Zheng, H., Ding, Z., Xu, Z., Ho, H. C., Hossain, M. Z., Huang, C., Yi, W., Song, J., & Cheng, J. 2022. Attributing hypertensive life expectancy loss to ambient heat exposure: a multicenter study in eastern China. *Environmental*

Research 208:112726.

Parasin, N., & Amnuaylojaroen, T. 2024. Effect of $PM_{2.5}$ on burden of mortality from non-communicable diseases in northern Thailand. *PeerJ*, 12:e18055.

Payus, C., Anuar, S. I., Chee, F. P., Rumaling, M. I., & Soegianto, A. 2023. 2019 Southeast Asia Transboundary Haze and its Influence on Particulate Matter Variations: A Case Study in Kota Kinabalu, Sabah. *AIMS Environmental Science* 10(4):547-558.

Pinichka, C., Bundhamcharoen, K., & Shibuya, K. 2016. Diseases Burden of Chronic Obstructive Pulmonary Disease (COPD) Attributable to Ground-Level Ozone in Thailand: Estimates Based on Surface Monitoring Measurements Data. *Global Journal of Health Science* 8(1):1–13. https://doi.org/10.5539/gjhs.v8n1p1

Pinichka, C., Makka, N., Sukkumnoed, D., Chariyalertsak, S., Inchai, P., & Bundhamcharoen, K. 2017. Burden of disease attributed to ambient air pollution in Thailand: A GIS-based approach. *PloS One* 12(12): e0189909.

Prüss-Ustün, A., van Deventer, E., Mudu, P., Campbell-Lendrum, D., Vickers, C., Ivanov, I., Forastiere, F., Gumy, S., Dora, C., & Adair-Rohani, H. 2019. Environmental risks and non-communicable diseases. *BMJ,* 364.

Radi, M. F. M., Hashim, J. H., Jaafar, M. H., Hod, R., Ahmad, N., Nawi, A. M., Baloch, G. M., Ismail, R., & Ayub, N. I. F. 2018. Leptospirosis outbreak after the 2014 major flooding event in Kelantan, Malaysia: a spatial-temporal analysis. The *American Journal of Tropical Medicine and Hygiene* 98(5): 1281.

Rahman, E. A., Hamzah, F. M., Latif, M. T., & Dominick, D. 2022. Assessment of $PM_{2.5}$ Patterns in Malaysia Using the Clustering Method. *Aerosol and Air Quality Research* 22(1):210161.

Rajagopalan, S., Al-Kindi, S. G., & Brook, R. D.2018. Air Pollution and Cardiovascular Disease: JACC State-of-the-Art Review. *Journal of the American College of Cardiology* 17(72):2054–2070. Elsevier USA. https://doi.org/10.1016/j.jacc.2018.07.099

Ramasamy, S. V. 2017. Logging in Ulu Muda forest reserve: is Penang's water security under threat. Penang Institute. 1–7.

Rayroux, C., Gasche-Soccal, P., & Janssens, J. P. 2020. Air pollution and its impact on the respiratory system. *Revue Medicale Suisse* 16(715):2211-2216.

Riahi, K., van Vuuren, D. P., Kriegler, E., Edmonds, J., O'Neill, B. C., Fujimori, S., Bauer, N., Calvin, K., Dellink, R., Fricko, O., Lutz, W., Popp, A., Cuaresma, J. C., Kc, S., Leimbach, M., Jiang, L., Kram, T., Rao, S., Emmerling, J., … Tavoni, M. 2017. The Shared Socioeconomic Pathways and their energy, land use, and greenhouse gas emissions implications: An overview. *Global Environmental Change* 42:153–168. https://doi.org/https://doi.org/10.1016/j.gloenvcha.2016.05.009

Riou, J., Hauser, A., Fesser, A., Althaus, C. L., Egger, M., & Konstantinoudis, G. 2023. Direct and indirect effects of the COVID-19 pandemic on mortality in Switzerland. *Nature Communications* 14(1): 90.

Rittiphairoj, T., Reilly, A., Reddy, C. L., Barrenho, E., Colombo, F., & Atun, R. 2022. The state of cardiovascular disease in G20+ countries. Health Systems Innovation Lab, Harvard University, 1–65.

Rivera, J. A., & Arnould, G. 2020. Evaluation of the ability of CMIP6 models to simulate precipitation over Southwestern South America: Climatic features and long-term trends (1901–2014). *Atmospheric Research* 241:104953.

Rodrigues, P. C. de O., Pinheiro, S. de L., Junger, W., Ignotti, E., & Hacon, S. de S. 2017. Climatic variability and morbidity and mortality associated with particulate matter. *Revista de Saude Publica* 51(91).

Roth, G. A., Johnson, C. O., Nguyen, G., Naghavi, M., Feigin, V. L., Murray, C. J. L., Forouzanfar, M. H., & Vos, T. 2015. Methods for Estimating the Global Burden of Cerebrovascular Diseases. *Neuroepidemiology* 45(3):146–151. https://doi.org/10.1159/000441083

Roth, G. A., Mensah, G. A., Johnson, C. O., Addolorato, G., Ammirati, E., Baddour, L. M., Barengo, N. C., Beaton, A., Benjamin, E. J., Benziger, C. P., Bonny, A., Brauer, M., Brodmann, M., Cahill, T. J., Carapetis, J. R., Catapano, A. L., Chugh, S., Cooper, L. T., Coresh, J., … Fuster, V. 2020. Global Burden of Cardiovascular Diseases and Risk Factors, 1990-2019: Update From the GBD 2019 Study. *Journal of the American College of Cardiology* 76(25): 2982–3021. https://doi.org/10.1016/j.jacc.2020.11.010

Roumeliotis, S., Abd ElHafeez, S., Jager, K. J., Dekker, F. W., Stel, V. S., Pitino, A., ... & Tripepi, G. 2021. Be careful with ecological associations. *Nephrology* 26(6):501-505.

Rovira, J., Domingo, J. L., & Schuhmacher, M. 2020. Air quality, health impacts and burden of disease due to air pollution (PM_{10}, $PM_{2.5}$, NO_2 and O_3): Application of AirQ+ model to the Camp de Tarragona County (Catalonia, Spain). *Science of the Total Environment* 703:135538.

Rozita, W. M. W., Zamtira, S., Mohd, F. I., Mohd, T. L., Nurul, I. A., Muhammad, I. A. W., & Mazrura, S.2022. Air Pollution, Cardiovascular and Respiratory Admissions in Klang Valley, Malaysia - Finding the Effects. *Nature Environment and Pollution Technology* 21(4):1565–1573. https://doi.org/10.46488/NEPT.2022.v21i04.009

Rylance, J., Fullerton, D. G., Scriven, J., Aljurayyan, A. N., Mzinza, D., Barrett, S., Wright, A. K. A., Wootton, D. G., Glennie, S. J., & Baple, K. 2015. Household air pollution causes dose-dependent inflammation and altered phagocytosis in human macrophages. *American Journal of Respiratory Cell and Molecular Biology* 52(5):584–593.

Saeed, F., Schleussner, C., & Ashfaq, M. 2021. Deadly heat stress to become commonplace across South Asia already at 1.5°C of global warming. *Geophysical Research Letters* 48(7):e2020GL091191.

Sah, S. S., Maulud, K. N. A., Karim, O. A., Sharil, S., & Yaseen, Z. M. 2023. Extensive assessment of climate change impacts on coastal zone paddy growth using multispectral analysis and hydrodynamic modeling. *Science of the total environment* 868:161585.

Sahani, M. R. Y., Vlh, P., Snh, M., & Bakar, A. N. 2022. Impacts of climate change and environmental degradation on children in Malaysia. https://data.noaa.gov/dataset/dataset/global-surface-

Sansuddin, N., Ramli, N. A., Yahaya, A. S., Yusof, N. F. F. M., Ghazali, N. A., & Madhoun, W. A. Al. 2011. Statistical analysis of PM10 concentrations at different locations in Malaysia. *Environmental Monitoring and Assessment* 180(1–4): 573–588. https://doi.org/10.1007/s10661-010-1806-8.

Sanzia, M., Akanda, M. K. M., Hasan, A. N., & Ashik, M. 2026. Lifestyle interventions: Exercise, nutrition and diabetes prevention in aging. In Diabetes, Aging, and Management Strategies (pp. 331-345). *Academic Press.*

Sarkar, D., Kumar, A., Imam, F., Ghosh, S., Marshall, J. D., Apte, J., ... & Dey, S. 2026.

Contrasting patterns in ambient $PM_{2.5}$ exposure disparity across population subgroups in urban and rural India. *GeoHealth* 10(1):e2025GH001387.

Sathiamurthy, E., Abd Halim, S., Supar, L. M., Hamid, A. A. A. A., Hui, K. Y., & Pauzi, N. S. 2019. Kelantan central basin flood, December 2014: Causes and extend.

Saxena, P., & Sonwani, S. 2019. Criteria air pollutants and their impact on environmental health. *Springer* (1)

Schulte, P. A., Bhattacharya, A., Butler, C. R., Chun, H. K., Jacklitsch, B., Jacobs, T., Kiefer, M., Lincoln, J., Pendergrass, S., Shire, J., Watson, J., & Wagner, G. R. 2016. Advancing the framework for considering the effects of climate change on worker safety and health. *Journal of Occupational and Environmental Hygiene* 13(11):847–865. https://doi.org/10.1080/15459624.2016.1179388

Selvarajah, S. 2012. Geographical Variation of Cardiovascular Risk Factors in Malaysia. *In Med J Malaysia* (67). https://www.researchgate.net/publication/224955450

Sentian, J., Herman, F., Yih, C. Y., & Wui, J. C. H. 2019. Long-term air pollution trend analysis in Malaysia. *International Journal of Environmental Impacts* 2(4):309–324. https://doi.org/10.2495/EI-V2-N4-309-324

Shafqat, A., & Park, E. 2025. Broad Applications of Distributed Lag Non-Linear Model in Public Health: A Comprehensive Review. *GeoHealth* 9(12). https://doi.org/10.1029/2025GH001608

Shima, Masayuki. 2023. Epidemiological studies on the health impact of air pollution in Japan: Their contribution to the improvement of ambient air quality. *Environmental Health and Preventive Medicine* 30: 30-30

Shirinde, J., & Wichmann, J. 2023. Temperature modifies the association between air pollution and respiratory disease mortality in Cape Town, South Africa. *International Journal of Environmental Health Research* 33(11):1122–1131.

Siiba, A., Kangmennaang, J., Baatiema, L., & Luginaah, I. 2024. The relationship between climate change, globalization and non-communicable diseases in Africa: A systematic review. *PLoS ONE* 19. https://doi.org/10.1371/journal.pone.0297393

Skýbová, D., Šlachtová, H., Tomášková, H., Dalecká, A., & Maďar, R. 2021. Risk of chronic diseases limiting longevity and healthy aging by lifestyle and socio-economic factors during the life-course–a narrative review. *Medycyna Pracy*, 72(5):535-548

Sofwan, N. M., Mahiyuddin, W. R. W., Latif, M. T., Ayub, N. A., Yatim, A. N. M., Mohtar, A. A. A., Othman, M., Aizuddin, A. N., & Sahani, M. 2021. Risks of exposure to ambient air pollutants on the admission of respiratory and cardiovascular diseases in Kuala Lumpur. *Sustainable Cities and Society* 75. https://doi.org/10.1016/j.scs.2021.103390

Stocker, T. F., Qin, D., Plattner, G.-K., Alexander, L. V, Allen, S. K., Bindoff, N. L., Bréon, F.-M., Church, J. A., Cubasch, U., & Emori, S. 2013. Technical summary. In Climate change 2013: the physical science basis. Contribution of Working Group I to the Fifth Assessment Report of the Intergovernmental Panel on Climate Change (pp. 33–115). Cambridge University Press.

Sun, J., & GBD 2023 Demographics Collaborators. 2025. Global age-sex-specific all-cause mortality and life expectancy estimates for 204 countries and territories and 660 subnational locations, 1950-2023: a demographic analysis for the Global Burden of Disease Study 2023. *The Lancet* 406(10513):1731-1810.

Swe, E. E., Htet, K. K. K., Thekkur, P., Aung, L. L., Aye, L. L., & Myint, T. 2020. Increasing trends in admissions due to non-communicable diseases over 2012 to 2017: findings from three large cities in Myanmar. *Tropical Medicine and Health* 48(1): 24.

Szopa, S., Naik, V., Adhikary, B., Artaxo, P., Berntsen, T., Collins, W. D., Fuzzi, S., Gallardo, L., Kiendler-Scharr, A., & Klimont, Z. 2023. Short-Lived Climate Forcers (Chapter 6). IPCC 2021: Climate Change 2021: The Physical Science Basis. Contribution of Working Group I to the Sixth Assessment Report of the Intergovernmental Panel on Climate Change. 817–922.

Tajudin, M. A. B. A., Khan, M. F., Mahiyuddin, W. R. W., Hod, R., Latif, M. T., Hamid, A. H., Rahman, S. A., & Sahani, M. 2019. Risk of concentrations of major air pollutants on the prevalence of cardiovascular and respiratory diseases in urbanized area of Kuala Lumpur, Malaysia. *Ecotoxicology and Environmental Safety* 171: 290–300. https://doi.org/10.1016/j.ecoenv.2018.12.057.

Tajudin, M. A. B. A., Madaniyazi, L., Seposo, X., Sahani, M., Tobías, A., Latif, M. T., Wan Mahiyuddin, W. R., Ibrahim, M. F., Tamaki, S., Moji, K., Hashizume, M., & Ng, C. F. S. 2024a. Short-term associations of PM_{10} attributed to biomass burning with respiratory and cardiovascular hospital admissions in Peninsular Malaysia. *International Journal of Epidemiology* 53(4):1–8. https://doi.org/10.1093/ije/dyae102

Tam, T. H., Rahman, M. Z. A., Harun, S., Try, S., Shahid, S., Jamal, M. H., Ismail, Z., Razak, K. A., Ghani, M. K., & Wahab, Y. F. A. 2021. Flood Hazard Assessment Under Climate Change Scenarios in Kelantan River Basin, Malaysia. https://doi.org/10.21203/rs.3.rs-858810/v1

Tan, K. C. 2018. Trends of rainfall regime in Peninsular Malaysia during northeast and southwest monsoons. *Journal of Physics: Conference Series* 995(1):12122.

Tang, H., Cheng, Z., Li, N., Mao, S., Ma, R., He, H., Niu, Z., Chen, X., & Xiang, H. 2020. The short-and long-term associations of particulate matter with inflammation and blood coagulation markers: a meta-analysis. *Environmental Pollution* 267:115630.

Tangang, F. T., Juneng, L., Salimun, E., Sei, K. M., & Jui Le & Halimatun Muhamad, L. 2012. Climate Change and Variability over Malaysia: Gaps in Science and Research Information (Perubahan dan Keragaman Iklim di Malaysia: Jurang dalam Maklumat Sains dan Penyelidikan). *Sains Malaysiana* 11(41).

Thaifa, H., Muhammad, M., Zia Ul-Saufie, A., Hadi, N. A., Sulong, A., & Prasasti, C. I. 2025. A Data-Driven Approach to Forecasting Air Pollution: Predicting $PM_{2.5}$ Levels in Shah Alam.

Thomas, H., Diamond, J., Vieco, A., Chaudhuri, S., Shinnar, E., Cromer, S., Perel, P., Mensah, G. A., Narula, J., Johnson, C. O., Roth, G. A., & Moran, A. E. 2018. Global Atlas of Cardiovascular Disease 2000-2016: The Path to Prevention and Control. *Global Heart Elsevier B.V* 3(13):143–163. https://doi.org/10.1016/j.gheart.2018.09.511

Thompson, A. M. S., Zanobetti, A., Silverman, F., Schwartz, J., Coull, B., Urch, B., Speck, M., Brook, J. R., Manno, M., & Gold, D. R. 2009. Baseline repeated measures from controlled human exposure studies: associations between ambient air pollution exposure and the systemic inflammatory biomarkers IL-6 and fibrinogen. *Environmental Health Perspectives* 118(1):120.

Tran, C. T., Nguyen, L. M. T., Wu, C. F., & Chien, K. L. 2024. Short-term Exposure to $PM_{2.5}$ and Cardiorespiratory Mortality and Morbidity: Case-crossover Analyses in Ho Chi Minh City, Vietnam. *Aerosol and Air Quality Research* 24(10). https://doi.org/10.4209/aaqr.240107

Tran, H. M., Tsai, F. J., Lee, Y. L., Chang, J. H., Chang, L. Te, Chang, T. Y., Chung, K. F., Kuo, H. P., Lee, K. Y., Chuang, K. J., & Chuang, H. C. 2023. The impact of air pollution on respiratory diseases in an era of climate change: A review of the current evidence. *Science of the Total Environment* (898). https://doi.org/10.1016/j.scitotenv.2023.166340

Ueda, K., Nitta, H., & Ono, M. 2009. Effects of fine particulate matter on daily mortality for specific heart diseases in Japan. *Circulation Journal* 73(7):1248–1254. https://doi.org/10.1253/circj.CJ-08-1149

Usmani, R. S. A., Saeed, A., Abdullahi, A. M., Pillai, T. R., Jhanjhi, N. Z., & Hashem, I. A. T. 2020. Air pollution and its health impacts in Malaysia: a review. *Air Quality, Atmosphere and Health* 9(13):1093–1118). https://doi.org/10.1007/s11869-020-00867-x

Vallianou, N. G., Geladari, E. V, Kounatidis, D., Geladari, C. V, Stratigou, T., Dourakis, S. P., Andreadis, E. A., & Dalamaga, M. 2021. Diabetes mellitus in the era of climate change. *Diabetes & Metabolism* 47(4):101205.

van Vuuren, D. P., Edmonds, J., Kainuma, M., Riahi, K., Thomson, A., Hibbard, K., Hurtt, G. C., Kram, T., Krey, V., Lamarque, J.-F., Masui, T., Meinshausen, M., Nakicenovic, N., Smith, S. J., & Rose, S. K. 2011. The representative concentration pathways: an overview. *Climatic Change* 109(1):5. https://doi.org/10.1007/s10584-011-0148-z

Varaden, D., Leidland, E., Lim, S., & Barratt, B. 2021. "I am an air quality scientist"– Using citizen science to characterise school children's exposure to air pollution. *Environmental Research* 201: 111536.

Vicedo-Cabrera, A. M., Sera, F., & Gasparrini, A. 2019. Hands-on Tutorial on a Modeling Framework for Projections of Climate Change Impacts on Health. *Epidemiology* 30(3):321–329. https://doi.org/10.1097/EDE.0000000000000982

Villányi, V., Turk, B., Batic, F., & Csintalan, Z. 2010. Ozone pollution and its bioindication. *Air Pollution* 153.

Vos, T., Lim, S. S., Abbafati, C., Abbas, K. M., Abbasi, M., Abbasifard, M., Abbasi-Kangevari, M., Abbastabar, H., Abd-Allah, F., & Abdelalim, A. 2020. Global burden of 369 diseases and injuries in 204 countries and territories, 1990–2019: a systematic analysis for the Global Burden of Disease Study 2019. *The Lancet* 396(10258):1204–1222.

Vose, A., McCravy, M., Birukova, A., Yang, Z., Hollingsworth, J. W., Que, L. G., & Tighe, R. M. 2021. Wood smoke particle exposure in mice reduces the severity of influenza infection. *Toxicology and Applied Pharmacology* 426:115645.

Walley, J., Wright, J., & Smith, I. (Eds.). 2025. Public Health: An action guide to improving health locally and globally. Oxford University Press.

Wan Azmi, W. N. F., Pillai, T. R., Latif, M. T., Shaharudin, R., & Koshy, S. 2024. Development of land use regression model to estimate particulate matter (PM_{10}) and nitrogen dioxide (NO_2) concentrations in Peninsular Malaysia. *Atmospheric Environment* 21. https://doi.org/10.1016/j.aeaoa.2024.100244.

Wan Mahiyuddin, W. R., Sahani, M., Aripin, R., Latif, M. T., Thach, T. Q., & Wong, C. M. 2013. Short-term effects of daily air pollution on mortality. *Atmospheric Environment* 65: 69–79. https://doi.org/10.1016/j.atmosenv.2012.10.019.

Wang, H., Qian, G., Shi, J., Lu, W., Chen, Y., Fang, K., Shen, Y., Rong, H., Huangfu, X., & Feng, Y. 2024. Association between short-term exposure to ambient air pollution and upper respiratory tract infection in Kunshan. *International Journal*

of Biometeorology 68(2):189–197.
Wang, Q., Wang, J., Zhou, J., Ban, J., & Li, T. 2019a. Estimation of PM $_{2\cdot5}$ -associated disease burden in China in 2020 and 2030 using population and air quality scenarios: a modelling study. *The Lancet Planetary Health* 3(2):e71–e80. https://doi.org/10.1016/S2542-5196(18)30277-8
Wang, X., Zhang, R., & Yu, W. 2019. The effects of $PM_{2.5}$ concentrations and relative humidity on atmospheric visibility in Beijing. Journal of Geophysical Research: Atmospheres, 124(4):2235-2259.
Wang, Y., & Wang, J. 2020. Modelling and prediction of global non-communicable diseases. *BMC Public Health* 20:1–13.
Wang, Y., Hu, J., Zhu, J., Li, J., Qin, M., Liao, H., Chen, K., & Wang, M. 2021. Health Burden and economic impacts attributed to $PM_{2.5}$ and O_3 in china from 2010 to 2050 under different representative concentration pathway scenarios. *Resources, Conservation and Recycling* 173. https://doi.org/10.1016/j.resconrec.2021.105731
Weiss, M. C., Sneha A., Jyotsna S. Jagai, and Robert M. S. 2023. Transportation-related environmental mixtures and diabetes prevalence and control in urban/metropolitann counties in the United States. *Journal of the Endocrine Society* 7(6)
WHO AQG 2021. WHO Air Quality Guideline. https://www.who.int/news-room/feature-stories/detail/what-are-the-who-air-quality-guidelines [7 Mei 2026]
WHO. 2020. WHO methods and data sources for Global Burden of Disease estimates 2000-2019. http://www.who.int/gho/mortality_burden_disease/en/index.html
WHO. 2021. WHO global air quality guidelines: particulate matter ($PM_{2.5}$ and PM_{10}), ozone, nitrogen dioxide, sulfur dioxide and carbon monoxide. https://apps.who.int/iris/handle/10665/345329.
WHO.2022. Air Pollution.https://www.who.int/health-topics/air-pollution#tab=tab_2
Wong, W. M., & Su, W. 2025. Air pollution and health burden: a generalized additive mixed model approach to $PM_{2.5}$, life Expectancy, and respiratory infections and tuberculosis in Thailand, Malaysia, and Singapore. Air Quality, Atmosphere and Health. https://doi.org/10.1007/s11869-025-01872-8.
Woo, S. H., Lee, S. M., Park, K. C., Park, G. N., Cho, B., Kim, I., Kim, J., & Hong, S. 2018. Effects of fine particulate matter on Pseudomonas aeruginosa adhesion and biofilm formation in vitro. *BioMed Research International* 1: 6287932.
World Health Organisation. 2020. WHO methods and data sources for global burden of disease estimates 2000-2019. https://www.who.int/docs/default-source/gho-documents/global-health-estimates/ghe2019_daly-methods.pdf
World Health Organization. 2008. The global burden of disease: 2004 update.
Xiao, C., Li, S., Zhou, W., Shang, D., Zhao, S., Zhu, X., Chen, K., & Wang, R. 2013. The effect of air pollutants on the microecology of the respiratory tract of rats. *Environmental Toxicology and Pharmacology* 36(2):588–594.
Xu, F., Huang, Q., Yue, H., Feng, X., Xu, H., He, C., Yin, P., & Bryan, B. A. 2023. The challenge of population aging for mitigating deaths from $PM_{2.5}$ air pollution in China. *Nature Communications* 14(1). https://doi.org/10.1038/s41467-023-40908-4
Xu, J., Yao, M., Wu, W., Qiao, X., Zhang, H., Wang, P., Yang, X., Zhao, X., & Zhang, J. 2021. Estimation of ambient $PM_{2.5}$-related mortality burden in China by 2030 under climate and population change scenarios: A modeling study. *Environment*

International 156. https://doi.org/10.1016/j.envint.2021.106733
Xu, X. Y., Leung, A. Y. M., Smith, R., Wong, J. Y. H., Chau, P. H., & Fong, D. Y. T.2020. The relative risk of developing type 2 diabetes among individuals with prediabetes compared with individuals with normoglycaemia: Meta-analysis and meta-regression. *Journal of Advanced Nursing* 76(12):3329–3345.
Yadav, M. K., Go, Y. Y., Jun, I., Chae, S.-W., & Song, J.-J. 2020. Urban particles elevated Streptococcus pneumoniae biofilms, colonization of the human middle ear epithelial cells, mouse nasopharynx and transit to the middle ear and lungs. *Scientific Reports* 10(1):5969.
Yang, B.-Y., Fan, S., Thiering, E., Seissler, J., Nowak, D., Dong, G.-H., & Heinrich, J. 2020. Ambient air pollution and diabetes: a systematic review and meta-analysis. *Environmental Research* 180:108817.
Yang, J., & Li, M. 2023. Epidemiology of noncommunicable diseases. In Textbook of Clinical Epidemiology: For Medical Students (pp. 213-226). Singapore: Springer Nature Singapore.
Yang, L., & Bao, F. 2025. Economic and health impacts of PM2. 5 pollution in China's urban air: Assessing the financial burden. *Ecotoxicology and Environmental Safety* 303:118575.
Yang, L., Zhang, Y., Qi, W., Zhao, T., Zhang, L., Zhou, L., & Ye, L. 2022. Adverse effects of PM2.5on cardiovascular diseases. *Reviews on Environmental Health* 37(1):71–80. https://doi.org/10.1515/reveh-2020-0155
Yang, Y., Qi, J., Ruan, Z., Yin, P., Zhang, S., Liu, J., Liu, Y., Li, R., Wang, L., & Lin, H. 2020. Changes in Life Expectancy of Respiratory Diseases from Attaining Daily $PM_{2.5}$ Standard in China: A Nationwide Observational Study. *Innovation* 1(3). https://doi.org/10.1016/j.xinn.2020.100064
Yatim, A. N. M., Latif, M. T., Sofwan, N. M., Ahamad, F., Khan, M. F., Mahiyuddin, W. R. W., & Sahani, M. 2021. The association between temperature and cause-specific mortality in the Klang Valley, Malaysia. *Environmental Science and Pollution Research* 28(42): 60209–60220. https://doi.org/10.1007/s11356-021-14962-8
Yin, Y., Li, Y., Xu, S., Wang, X., Wang, Y., Wang, S., ... & Wang, J. 2026. Flood risk assessment in Kelantan State, Malaysia based on the weighted integrated spatial evaluation model. *Journal of Hydrology: Regional Studies* 64:103221.
Zakaria, U. A., Saudi, A. S. M., Abu, I. F., Azid, A., Balakrishnan, A., Amin, N. A., & Rizman, Z. I. 2018. The assessment of ambient air pollution pattern in Shah Alam, Selangor, Malaysia. *Journal of Fundamental and Applied Sciences* 9(4S):772. https://doi.org/10.4314/jfas.v9i4s.43.
Zanobetti, A., Franklin, M., Koutrakis, P., & Schwartz, J. 2009. Fine particulate air pollution and its components in association with cause-specific emergency admissions. *Environmental Health* 8(1):58.
Zeng, Q., Wang, H., Wang, K., Zhou, H., Wang, T., & Wen, F.2021. Eosinophilic phenotype was associated with better early clinical remission in elderly patients but not middle-aged patients with acute exacerbations of COPD. *International Journal of Clinical Practice* 75(9):e14415. https://doi.org/10.1111/ijcp.14415
Zhang, F., & Stewart, R. 2020. Indoor air quality in South East Queensland dwellings during 2019-2020 bushfires. The 54th International Conference of the Architectural Science Association (ANZAScA) 2020.
Zhang, J.-D., Cheng, X.-F., Min, S.-H., Guo, R.-Q., Wang, R.-N., He, Y.-T., Zhang, Y.-L., & Li, B.2024. Burden of non-communicable diseases attributable to high

temperature in a changing climate from 1990 to 2019: a global analysis. *BMC Public Health* 24(1):2475.

Zhang, K., Chen, G., He, J., Chen, Z., Pan, M., Tong, J., ... & Xiang, H. 2024. DNA methylation mediates the effects of $PM_{2.5}$ and O_3 on ceramide metabolism: A novel mechanistic link between air pollution and insulin resistance. *Journal of hazardous materials* 469:133864.

Zhang, K., Chengxia K., Fang H., Zhang J., Ding C., Guo Z., Na H., Yang Z., Ningning H., and Xiaodong S.2023. Global, regional, and national epidemiology of diabetes in children from 1990 to 2019. *JAMA pediatrics* 177(8) : 837-846.

Zhang, W., Ruan, Y., Ling, J., & Wang, L. 2024. A study of the correlation between meteorological factors and hospitalization for acute lower respiratory infections in children. *BMC Public Health* 24(1): 3135.

Zhang, Y., Lazzarini, P. A., McPhail, S. M., van Netten, J. J., Armstrong, D. G., & Pacella, R. E. 2020. Global disability burdens of diabetes-related lower-extremity complications in 1990 and 2016. *Diabetes care* 43(5):964-974

Zhao, Y., Huang, Z., Wang, S., Hu, J., Xiao, J., Li, X., Liu, T., Zeng, W., Guo, L., & Du, Q. 2019. Morbidity burden of respiratory diseases attributable to ambient temperature: a case study in a subtropical city in China. *Environmental Health* 18:1–8.

Zhao, Z., Wang, J., Zhao, H., Zhang, T., Yang, X., Xu, X., ... & Zhou, M. 2026. Premature mortality projection for cardiovascular diseases to 2030: a sub-national evaluation towards the SDG 3.4 goals in China. *The Lancet Regional Health–Western Pacific.*

Zhou, H., Geng, H., Dong, C., & Bai, T. 2021. The short-term harvesting effects of ambient particulate matter on mortality in Taiyuan elderly residents: A time-series analysis with a generalized additive distributed lag model. *Ecotoxicology and Environmental Safety* 207. https://doi.org/10.1016/j.ecoenv.2020.111235

Zhu, F., Ding, R., Lei, R., Cheng, H., Liu, J., Shen, C., ... & Cao, J. 2019. The short-term effects of air pollution on respiratory diseases and lung cancer mortality in Hefei: A time-series analysis. *Respiratory medicine* 146:57-65

Zulkifli, M. M., Abdul Rahman, R., Muhamad, R., Abdul Kadir, A., Roslan, N. S., & Mustafa, N. 2024. The lived experience of resilience in chronic disease among adults in Asian countries: a scoping review of qualitative studies. *BMC psychology* 12(1):77