Systematic Literature Review on the Effects of a Heatwave on Air Quality

by

Grace Jeon

A project report submitted in partial fulfillment of the requirements for the degree of

BACHELOR OF TECHNOLOGY IN ENVIRONMENTAL ENGINEERING

in

SCHOOL OF CONSTRUCTION AND THE ENVIRONMENT

(Environmental Engineering)

Submitted to:

Goran Krstic, Ph.D., Project Course Faculty, Capstone Project

Nicholas Fox, Project Course Faculty, Communications

Project adviser(s):

Goran Krstic, Ph.D.

BRITISH COLUMBIA INSTITUTE OF TECHNOLOGY

Burnaby

April 23rd, 2023

Abstract

This systematic literature review aimed to investigate the relationship between heatwaves and air quality. The review focused on studies that analyzed air quality during heatwaves and the differences in effects between urban and rural areas. The review's findings showed that heatwaves lead to increased air pollutant concentrations, including particulate matter and ozone, with different outcomes depending on the location and degree of urbanization. However, some studies reported no impact of high-temperature conditions on pollutant levels, inconsistent with earlier findings. Study limitations, such as the limited generalizability of the findings to other regions, may account for this inconsistency.

The literature review also found limited data on the impact of heatwave-induced air quality on human health. Only one study reported potential increases in chronic obstructive pulmonary disease deaths and respiratory diseases. The review also examined the effects of the 2021 Vancouver heatwave on air quality with the definition of heatwave as at least three consecutive days with a temperature of at least 32.22°C. The review revealed that the degree of urbanization did not affect air pollutant levels in Vancouver. However, all selected stations showed an increased trend in ozone pollution after the defined 2021 Vancouver heatwave period, with the Pitt Meadows station severely exceeding CAAQS for ozone pollution.

The review identified some limitations, including insufficient data validation with primary data, lack of relevant data on the interaction between high temperature and ozone pollution, and limited generalizability to other regions with different environmental conditions and pollutant sources.

The study's findings highlight the need for further research to develop effective strategies to mitigate climate change and improve air quality. Policymakers, researchers, and practitioners can use these findings to develop evidence-based interventions to address the impact of heatwaves on air quality.

Table of Contents

List of Tables

List of Figures

List of Acronyms

Air Quality Objectives (AQO)

Automatic Urban and Rural Network (AURN)

Beijing-Tianjin-Hebei (BTH)

Canadian Ambient Air Quality Standards (CAAQS)

Centers for Disease Control and Prevention (CDC)

Chronic Obstructive Pulmonary Disease (COPD)

Common Air Contaminants (CAC)

Convergent Cross-Mapping (CCM)

Environment and Climate Change Canada (ECCC)

Extreme Meteorological Events (EUMEs)

Intergovernmental Panel on Climate Change (IPCC)

IPCC's 5th Assessment Report (AR5)

Journal Storage (JSTOR)

Maximum Daily 8-H Average (MDA8)

National Ambient Air Quality Objectives (NAAQO)

National Oceanic and Atmospheric Administration (NOAA)

National Weather Service (NWS)

Out-of-Hospital Cardiac Arrest (OHCA)

Particulate Matter (PM)

Prairie Climate Centre (PCC)

Reporting Standards Systematic Evidence Syntheses (ROSES)

Universal Thermal Climate Index (UTCI)

Volatile Organic Compounds (VOCs)

World Health Organization (WHO)

World Meteorological Organization (WMO)

Acknowledgments

I would like to express my sincere gratitude to those who have contributed to the successful completion of my capstone project. First and foremost, I am grateful to Dr. Goran Krstic, my advisor, for his invaluable guidance, support, and feedback throughout my research. His expertise and input have been essential in helping me complete this project, and I am deeply appreciative of the time and effort he dedicated to assisting me.

I would also like to extend my thanks to Dr. Zahra Tooyserkani for her valuable feedback during the project proposal stage. Her insights and suggestions were critical in helping me clarify my research objectives.

Additionally, I am thankful for all the faculties in the Environmental Engineering program at BCIT, including the communication course instructors, for providing me with the knowledge and skills required to complete this work. Their dedication to teaching and research has been a great source of inspiration.

Finally, I want to express my gratitude to my fiancé, Cyrus Pereira, for his unwavering support and encouragement throughout my studies in the Environmental Engineering program at BCIT.

Chapter 1: Introduction

The Province of British Columbia experienced extreme heatwaves in 2021 and 2022 that reached peak temperatures of 49 °C, which significantly impacted human health and the environment. During a heatwave in 2021, over 600 deaths were reported, with 93% of those occurring from June 25 to July 1, 2021 (The Canadian Press, 2022). Additionally, the high temperatures during this period led to widespread wildfires, one of which destroyed 90% of the town of Lytton and resulted in the loss of hundreds of homes (Vjosa, 2021). These events worsened air quality in Lytton and the City of Vancouver, which experienced the worst air quality of any major city in the world shortly after the wildfire (Steacy, 2021).

Compared to historical summer conditions in British Columbia, the recent increase in heatwaves is a new and concerning trend. It raises questions about the long-term impacts of these events on air quality and the potential causes for their increased frequency. Further research is necessary to fully understand the effects of heatwaves on air quality and to develop strategies to mitigate the consequences of these events. This paper aims to provide a better understanding of the relationship between heatwaves and air pollution by performing a systematic review and an analysis of the 2021 Vancouver heatwave.

1.1 Increasing Trend of Extreme Weather and Climate Events

According to the Intergovernmental Panel on Climate Change (IPCC), extreme weather and climate events have increased since 1950 (IPCC, 2014). The IPCC's 5th Assessment Report (AR5) stated that the increase in the frequency of heatwaves since the mid-20th century is very likely due to human influence (IPCC, 2014). The AR5 also projects that with continued warming, heatwaves will become more frequent and intense (IPCC, 2014). This trend of *"more frequent and intense extreme climate events"* is supported again in the AR6's Working Group II report (IPCC, 2022).

National Oceanic and Atmospheric Administration (NOAA) also reported that the ten warmest years on record occurred since 2010. In fact, 2022 ranked the sixth-warmest year based on NOAA's temperature data (NOAA, 2023). Moreover, the increasing trend of the NOAA can support the trend of increased extreme climate events. For example, the data gathered by NOAA's Merged Land Ocean Global Surface Temperature Analysis shows the increased global temperature trend over the years in Figure 1 (NOAA, 2022). This figure measures global and hemispheric anomalies against the 1901-2000 average, while coordinate anomalies are measured against the 1991-2020 average. Regional anomalies are measured against the 1910-2000 average. The annual global temperature graph trend indicates more significant temperature increases in recent years.

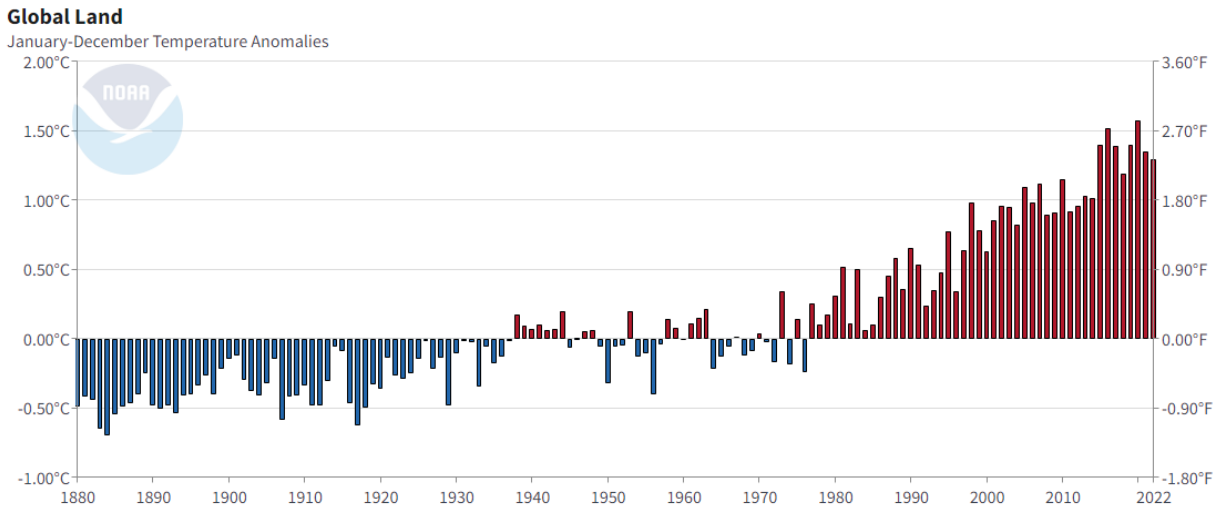

Figure 1. Annual Global Temperature (Land Only): 1880 to 2022 (Reproduced from NOAA, 2022)

1.2 Relationship between Global Warming and Heatwaves

Since the 1970s, the annual global temperature has been increasing. It is defined as global warming when increases continue for over 30 years (IPCC, 2014). Although global warming is not the same as heatwaves, they are related. Studies show that 1.5 °C global warming can significantly increase the magnitude and frequency of heatwaves (Dosio et al., 2018; Guo et al., 2018; Yang et al., 2020). Furthermore, Dosio et al. (2018) conducted additional research for 2.0 °C with the same conditions as 1.5 °C and reported that 2.0 °C global warming would double the frequency of extreme heatwaves worldwide.

Nevertheless, projected data for the average annual number of high-temperature days by the Climate Atlas of Canada, established by the Prairie Climate Centre (PCC), shows an increasing trend compared to historical data regardless of annual global temperature (PCC, 2019). It is important to acknowledge that while the projected data is included as a potential climate scenario worldwide, including the BC region, it does not serve as evidence for the current frequency of heatwaves. This is because no published peer-reviewed paper was available on recent heatwave frequency in the region at the time of this research. The climate projection data is based on 24 statistically downscaled global climate models, which the Climate Atlas of Canada programmed.

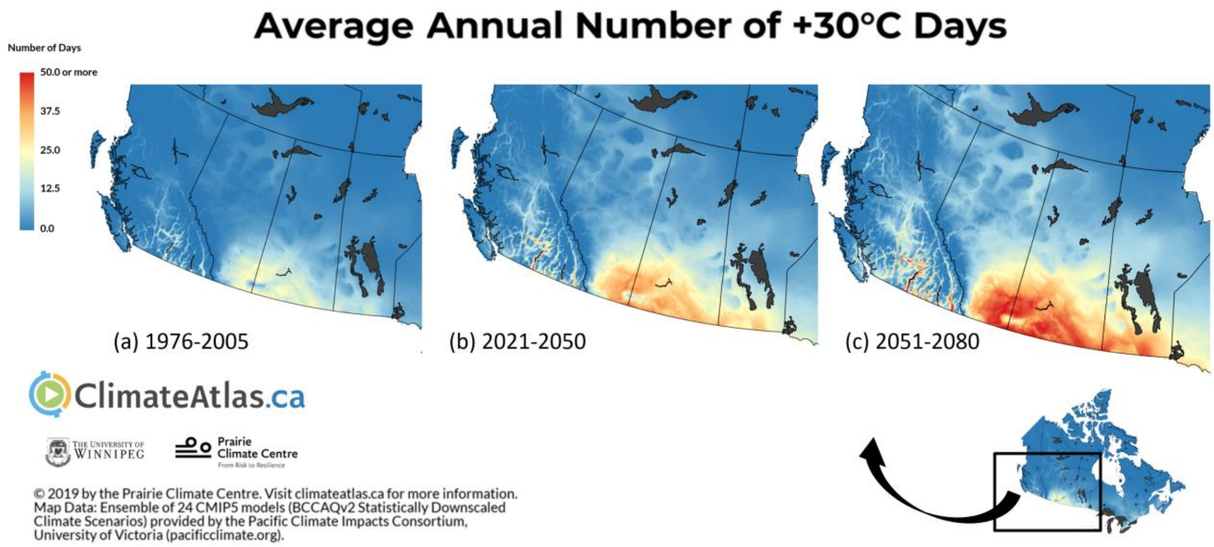

Figure 2. Average Annual Number of + 30°C days in Canada: (a) 1976 - 2005, (b) 2021-2050, (c) 2051-2080. (a) present historical data from 1976 to 2005. Projections (b) and (c) were made under the low-carbon scenario. (Redrawn from PCC, 2019).

Despite the low carbon scenario that assumes greenhouse gas emissions will not increase over time to minimize other impacts on climate warming, projected high-temperature days are as high as 50 days or more in the future (Figure 2). The data indicates a significant increase since most high-temperature days from 1976 to 2005 were less than 30 days yearly. However, more steps are required to consider the high-temperature days as the heatwave has various characteristics, which will be described below.

1.3 Heatwave Definition and Criteria

Defining a heatwave can be difficult as several components determine such conditions (Smoyer-tomic, 2003). Definitions of what constitutes a heatwave differ depending on the different characteristics of an event (e.g., frequency and duration) and the type of measurement (absolute or relative). Therefore, setting a heatwave definition for this research before the analysis was a critical step. One of many ways to define a heatwave is the set criteria for heat warnings by the government. For example, Environment and Climate Change Canada (ECCC) sets its heat warning criteria per province and territory, and set criteria for the Southwest part of BC, including the City of Vancouver and Richmond, are set for when two or more consecutive days of maximum temperature in the daytime is expected to reach 29 °C or higher and minimum temperature during nighttime is likely to fall to 16 °C or higher (ECCC, 2017). On the other hand, the World Meteorological Organization (WMO) defines a heatwave as "a period that the daily maximum temperature for at least five consecutive days exceeds the average maximum temperature by 5 °C" (WMO, 2022).

During this research, three articles were found to provide a definition of a heatwave directly, and its characteristics (Di Napoli et al., 2019; Gonzalez et al., 2019; Van Oldenborgh et al., 2022), and seven articles were indirectly describing a heatwave (i.e., containing a deeper explanation of a heatwave in the introduction). In this research, the definition of a heatwave was set with the same definition from Gonzalez et al. (2019), which is "*an interval of least three consecutive days with a temperature of at least 32.22 °C*" according to the National Weather Service (NWS). However, it is worth noting that other definitions of heatwaves from Di Napoli et al. (2019), such as the Universal Thermal Climate Index (UTCI) 95^{th} percentiles (15° ± 2°C and 34.5° ± 1.5°C, respectively), which take into account factors such as humidity and wind speed in addition to temperature. Therefore, the definition of a heatwave from Gonzalez et al. (2019) was chosen as it seems to fit the best to the purpose of the analysis, finding a potential relationship between Vancouver 2021 heatwave and air quality while simplifying other factors like humidity and wind speed.

1.4 Effects of Heatwaves on Human Health and Economic

Centers for Disease Control and Prevention (CDC) considers heatwaves as the most fatal of all-natural disasters because the leading cause of weather-related deaths in the US was extreme heat from 2000 to 2009 (Figure 3) (CDC, n.d).

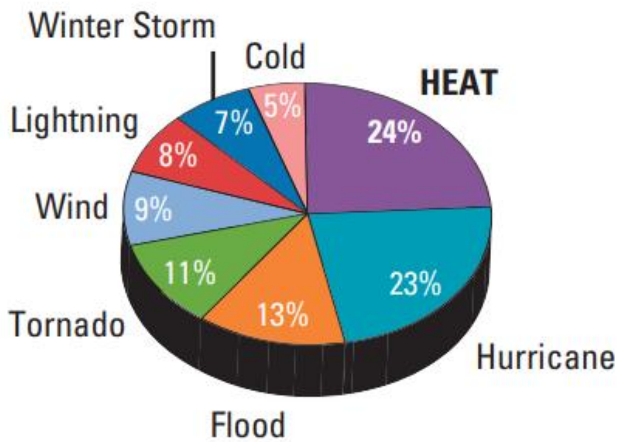

Figure 3. Deaths in the United States attributed to weather conditions, 2000-2009. (Reproduced from CDC, n.d)

Besides deaths, extreme heat can affect human health in various ways, such as heat exhaustion, heat stroke, kidney failure, and worsening conditions like heart disease (Seltenrich, 2015). Extreme heat can also change human's physiological response to high temperatures (Khosla, 2021). Under extreme heat conditions, symptoms like increased sweating, redistributed blood flow to the skin, increased oxygen demand, and adjusted circulation maintain body temperature at its optimal state. In addition, humidity amplifies the symptoms and extreme heat (Seltenrich, 2015). However, NOAA states that heatwaves can occur with or without high humidity (NOAA, 2021).

In addition to excess mortality and health issues, extreme heat can cause economic loss. A case study in China reported that extreme heat caused a loss of productivity in self-paced indoor workers and a loss of capacity in outdoor workers due to occupational safety requirements (Xia et al., 2018). In the study, Xia et al. reported that 3.43 % of Ninjing's gross value of production in 2013 was reduced due to the heatwave. However, the report holds limitations to the data realities as extreme heat only occurs in a particular space for a short period, forcing research to focus on small regions. Callahan and Mankin (2022) attempted to quantify the effect of extreme heat on global economic growth by using data from a worldwide sample of subnational regions. As a result, empirical estimation was made for cumulative losses from extreme anthropogenic heat during 1992 – 2013, which ranged from $5 trillion to $29.3 trillion US dollars (Callahan & Mankin, 2022).

1.5 Heatwaves and Air Quality

Heatwaves can also affect air quality. Poor air quality is usually a result of air pollution. The World Health Organization (WHO) defines air pollution as *"the contamination of the environment by chemical, physical, or biological substances that modifies the natural characteristics of the atmosphere"* (WHO, 2019). Poor air quality can cause health problems like asthma, cardiovascular diseases, stroke, and lung cancer (Transport & Environment, 2019). Air pollution is caused by the presence of air pollutants, which are classified as suspended particulate matter (PM) and gasses and vapours (Vallero, 2008). When a contaminant's concentration in the air is abnormally high (i.e., higher than the concentration in normal ambient air) and has net detrimental effects, the contaminant is defined as an air pollutant. Air pollutants can be categorized into two parts: primary and secondary pollutants. Primary pollutants (e.g., carbon monoxide, sulphur oxides, volatile organic compounds) are the ones that are directly emitted into the atmosphere from a source, and secondary pollutants (e.g., sulfuric acid, nitrogen dioxide, ozone) are the ones that are formed by reactions of primary pollutants (Vallero, 2008).

When hot weather continues, primary pollutants tend to increase. For example, one of the primary pollutants, NOx, can undergo a chemical reaction with volatile organic compounds (VOCs) in the presence of sunlight and produce ozone that is toxic at ground level (Vallero, 2008). In addition, extreme heat provides more extensive sunlight than usual, which can create a higher level of ground-level ozone. Furthermore, heatwaves often accompany high atmospheric pressure with stagnant air above ground level. The layer of stagnant air is critical for ambient air quality as it prevents the distribution of air pollutants, increasing the concentration of contaminants in the air, hence the more substantial air pollution (Vallero, 2008). Some researchers reported findings on the indirect relationship between the high temperature of the environment to the frequent occurrence of ozone pollution (Pyrgou et al., 2018; Westervelt et al., 2019).

Air pollution is a significant risk factor for respiratory diseases, and exposure to high levels of pollutants can lead to exacerbation of air quality-related illnesses such as chronic obstructive pulmonary disease (COPD) (Fu et al., 2022). For example, Lin et al. (2009) reported that for each 1 °C increase in temperature above the baseline, the hospitalization rate for COPD increased by 7.6 %. Moreover, the indirect relationship between the frequent occurrence of ozone pollution and the high temperature can further exacerbate the respiratory problems of people with vulnerable conditions (Lin et al., 2009; Pyrgou et al., 2018; Westervelt et al., 2019).

1.6 Air Quality Standards

The increasing public awareness and demand for better environmental quality have resulted in the establishment of more laws, rules, and policies to address air pollution (Vallero, 2008). Different countries and regions have set up air quality targets such as National Ambient Air Quality Objectives (NAAQO), Canadian Ambient Air Quality Standards (CAAQS), and Provincial Air Quality Objectives in BC (Province of BC, 2021). In the United States, six common air contaminants (CAC) were established by the US Environmental Protection Agency (EPA), including PM, ozone (O_3), carbon monoxide (CO), sulphur dioxide (SO_2), nitrogen dioxide (NO_2), and lead (Pb). These standards and CAC serve as reference points for air quality analysis (EPA, 2014).

In British Columbia, the government has established non-legally binding air quality objectives to manage and regulate the province's air quality. These objectives measure current and historical air quality, guide environmental impact assessments, inform regulatory development, and develop strategies to manage air quality during episodes such as air quality advisories. The Minister of Environment, authorized under the British Columbia Environmental Management Act, developed these objectives. In addition, the province uses a suite of ambient air quality criteria at the provincial and national levels, including AQOs, NAAQOs, and CAAQS, to inform decisions on managing air contaminants. Metro Vancouver has also established its air quality objectives within its region (Province of BC, 2021).

To simplify the existing framework of air quality criteria and reflect current practices, Table 1 identifies only the most stringent criteria for each averaging period and management level, along with the current CAAQS in effect. This table is meant to be updated when new objectives are adopted, or clarifications are made.

Table 1. Summary of BC ambient air quality objectives. (Reproduced from Province of BC, 2021).

Contaminant	Avg. Period	Air Quality Objective		Source	Date Adopted by Source
		µg/m³	ppb		
Formaldehyde (HCHO)	1 hour	**60**[6]	50	Provincial AQO	1995
Nitrogen Dioxide (NO_2)	1-hour	113	**60**[7]	Provincial AQO	2021
		113	**60**[7]	2020 CAAQS	2017
	Annual	32	**17**[8]	Provincial AQO	2021
		32	**17**[8]	2020 CAAQS	2017
Ozone (O_3)	1-hour	**160**	82	NAAQO[9]	1989
	8-hour	123	**62**[10]	2020 CAAQS	2013
Particulate Matter <2.5 microns ($PM_{2.5}$)	24-hour	**25**[11]	-	Provincial AQO	2009
		27[12]	-	2020 CAAQS	2013
	Annual	**8**[13]	-	Provincial AQO	2009
		8.8[14]	-	2020 CAAQS	2013
Particulate Matter <10 microns (PM_{10})	24-hour	**50**	-	Provincial AQO	1995
Sulphur Dioxide (SO_2)	1-hour	196	**75**[15]	Interim Provincial AQO	2016
	1-hour	183	**70**[16]	2020 CAAQS	2017
	Annual	13	**5**[17]	2020 CAAQS	2017
Total Suspended Particulate (TSP)	24-hour	**120**	-	NAAQO	1974
	Annual	**60**[18]	-	NAAQO	1974

1.7 Research Problem Statement

The research problem addressed in this systematic literature review is examining the effects of heatwaves on air quality. The study aims to synthesize existing literature on the topic and analyze historical air quality data from the City of Vancouver during the 2021 heatwave to better understand the relationship between heatwaves and air pollution. The findings of this review will provide important insights to researchers and the general public into the impact of heatwaves on air quality and the potential health and environmental risks associated with elevated levels of air pollutants during these events.

1.8 Project Objectives

This systematic literature review aims to understand the effect of heatwaves on air quality with five main objectives:

- The first objective is to comprehensively review the existing literature on the impact of heatwaves on air quality. This will include a comprehensive search of relevant sources and a thorough evaluation of the quality and validity of the selected studies.
- The second objective is to analyze historical air quality data from the City of Vancouver during the 2021 heatwave. The data will be analyzed to observe the relationship between heatwaves and air pollution and identify emerging patterns or trends.
- The third objective is to identify gaps in the current knowledge of the effects of heatwaves on air quality. This will help guide future research efforts and ensure critical areas are noticed.
- The fourth objective is to synthesize the findings of the literature review and data analysis to gain a comprehensive understanding of the impact of heatwaves on air quality. The synthesis will include a discussion of the strengths and weaknesses of the existing evidence and a consideration of the implications of the findings.
- The final objective is to provide recommendations for future research to further advance our knowledge of the effects of heatwaves on air quality. This will include suggestions for future studies to fill any knowledge gaps identified during the review and suggestions for improving the quality of prospective studies.

1.9 Project Scope

The systematic literature review focused on investigating heatwaves' impact on air quality. The review’s scope included examining the relationship between heatwaves and air pollutants and the resulting detrimental effects on human health and the environment. The study was limited to a specific group of air pollutants and their relationship with heatwaves. The air quality assessment was restricted to ambient air, excluding indoor air quality. The research utilized online data sources that were accessible and deemed appropriate for the study's objectives. The findings of this review will contribute to a better understanding of the impact of heatwaves on air quality and its effects, considering the limitation of only using online data sources.

Chapter 2: Methods

2.1 Systematic Literature Review Guideline

The literature on the impact of heatwaves on air quality is abundant, but the methods used to study it vary greatly. A systematic literature review was chosen for this project's research method to get the most out of available and relevant studies. This method provides a systematic and standardized approach to searching and identifying studies. The Reporting Standards Systematic Evidence Syntheses (ROSES) tool was utilized in the development of the search, screen, review, and writing strategies for the project (Haddaway et al., 2018). While adopting the ROSES forms and flow diagrams for Systematic Review, several modifications were made to fit the project's specific needs (Haddaway et al., 2017). Removal of the following sections from the ROSES was done as part of modifications: stakeholder engagement, methods protocol, assessment of the risk of publication, and demonstrating procedural. Also, the search strategy regarding languages was simplified to English only.

2.2 Systematic Literature Search Strategy

This systematic literature review targeted published resources and grey literature from Jan 2018 to Dec 2022. For effective data screening, a list of keywords and their combinations was tested on the BCIT Library database for validity.

- Heatwaves
- High temperature
- Air quality
- Air pollutant
- Global warming
- Climate crisis

From the test, it was noticed that data results from several keywords show high irrelevancy if the keyword is used alone. Therefore, the keywords were categorized into heatwaves and high temperature in one group and the rest in the other. The first set of search sequences was made so that one keyword from each group was selected, resulting in eight different sequences. After assessing search results from each sequence, it was determined that having high temperature as a primary keyword resulted in irrelevant sources. Therefore, the final sequence for the data collection was selected as a combination of three keywords: *"Heatwaves" AND "Air" AND "Pollution".* After preliminary search screening, it was noticed that lots of literature are related to energy, which does not align with this review. Therefore, to finer narrowing down to relevant literature, an additional keyword was added to the final sequence: *"Heatwaves" AND "Air" AND "Pollution". AND NOT "Energy".* With this additional keyword, the total number of initial literature (i.e., search results without identifying and eliminating duplicates) was shrunk from 557 to 200.

Four search engines were used for data collection with the final sequence: BCIT Library, Science Direct, Google Scholar, and Journal Storage (JSTOR). Initial search data from each database and its filters are summarized in Table 2.

Table 2. Databases and Search Results with Search Sequence of "Heatwaves" AND "Air" AND "Pollution." AND NOT "Energy"

Database	Numbers of Results	Additional Filters
BCIT Library	44	Discipline (Environmental Science, Public Health, General Science) Excluded Subject Terms (Life Science & Biomedicine, Geoscience, Multidisciplinary, Earth Science, Precipitation) Excluded Content Type (Newsletter)
Science Direct	105	Article Type (Review articles, Research articles) Publication Title (Environmental Research, Atmospheric Environment, Environmental Pollution, Atmospheric Research, Global Environmental Change, Atmospheric Pollution Research) Subject Areas (Environmental Science, Earth and Planetary Sciences)
Google Scholar*	4	Include patents and citation
JSTOR	47	Subject (Environmental Science, Environmental Studies)

*Due to a lack of a search filter, different search sequence is used for the search: *air quality OR global warming OR climate crisis OR air pollutant OR high temperature "Heatwaves"*

2.3 Study Selection

According to the ROSES flow diagram, a few strategies were used to screen the large quantity of literature from the initial search: elimination of duplicates, exclusion from title and abstracts screening, and exclusion after the full-text screening (Haddaway et al., 2017). Out of 200 works, one duplicate was identified, and a new quantity of total literature data was created, 199. Through titles and abstract screening, 110 pieces of literature were excluded. The exclusion standard was that literature handles completely unrelated topics than this review, such as COVID-19 or marine environment research. During the same screening, three different labels were assigned to articles, as described in Table 3.

Table 3. Labelling Criteria during Title and Abstract Screening

Label	Description
1st	Contents of the literature are *directly* related to the topic
2nd	Contents of the literature are *somewhat* related to the topic
3rd	Contents of the literature are *maybe* related to the topic

As a result, 37 *directly* related literature, 21 *somewhat* related, and 31 *maybe* related literature were identified. Out of 89 records, one resource could not get full access as it was part of the conference presentation. With the remaining 88 records, a full-text screening was conducted in order of the labels in Table 3. From that, additional 46 pieces of literature were excluded due to lack of relevance (33 pieces) and incompleteness of3 pieces), leaving 42 pieces of literature for this research. Including two pre-screened articles from sources other than the listed sources in Table 2, 7 articles and 37 studies were included in the review. Upon critical appraisal of the articles, focusing on the topic's relevance to this research's objectives, 15 pieces were excluded as a lack of direct relation to this research's topic, and 14 pieces for being heavily focused on subjects that are not in line with the topic (i.e., heavy focus on mortality due to overall climate change). Three more articles were excluded during narrative synthesis due to insufficient connection, weak study results, and more statistical projection research. Details of the findings from the critical appraisal of the resources, which are discussed in this review, are listed in the literature matrix (Appendix 2). Figure 4 shows summarized screening data for the review.

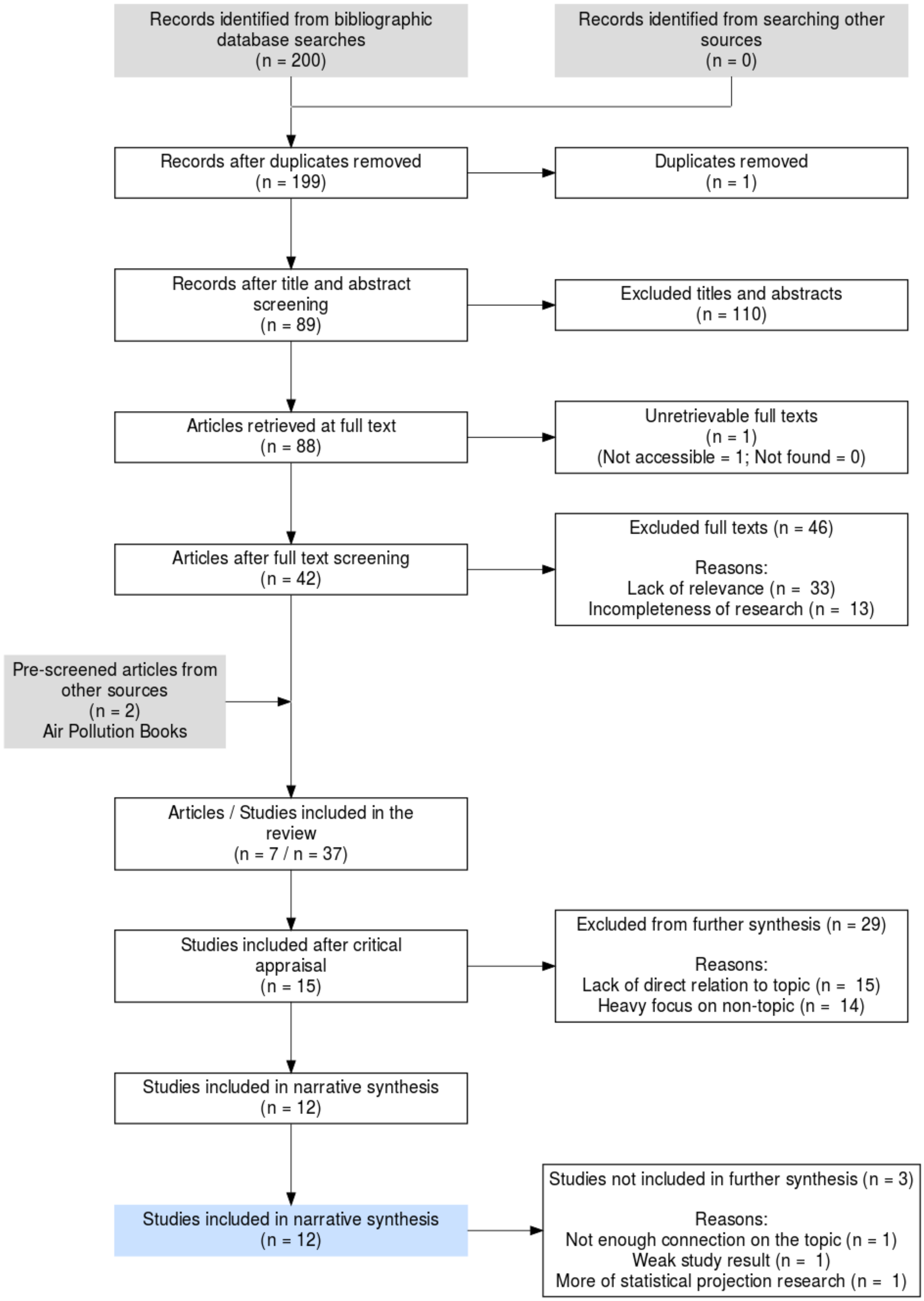

Figure 4. Systematic Literature Search and Review Flow Diagram (Adapted from Haddaway et al., 2017)

2.4 Data Collection for 2021 Vancouver Heatwave Analysis

Besides the listed online database, government databases were used to gather historical temperature and air quality data for the 2021 Vancouver Heatwave analysis. The necessity of this analysis was identified during preliminary research of this project's original intention, identifying any potential effects of a heatwave on air quality in BC, Canada. The initial investigation showed a lack of available literature for a specific location, so the project's scope was extended beyond the BC region. However, reviewing initially selected resources led to the possibility of addressing the 2021 Vancouver heatwave effect on air quality.

The government database used for historical temperature data is the ECCC climate data website (ECCC, 2021). The historical temperature data station used to gather temperature data from June 2021 to September 2022 to analyze the 2021 Vancouver heatwave is the Vancouver Harbour station. This station is currently operated by NAV Canada and is located at a latitude of 49°17'43.270" N and a longitude of 123°07'18.730" W, with an elevation of 2.50 m. The station has a Climate ID of 1108446 and a WMO ID of 71201.

From the ECCC database, historical data from the Vancouver Harbour station, consisting of 11 different parameters from June 2021 to September 2021, was obtained as a .csv file. Out of 11 parameters, only three parameters were extracted for the analysis: maximum temperature (°C), minimum temperature (°C), and mean temperature (°C). As per the predetermined heatwave definition under section 1.3, conditional formatting was applied to the maximum temperature column to identify any days that exceeded 32.22 °C, which provided the start date and end date of the 2021 Vancouver heatwave.

Based on the defined period of the heatwave, the historical air quality data was obtained from the BC Ministry of Environment's air quality database (BC Ministry of Environment, n.d). The search was conducted between June 1, 2021, and August 1, 2021, using the following filters: Region - Lower Mainland, Owner - All, Type - Max, Time Base - 1 Hour. Three air quality stations were selected for data collection to provide a better understanding of the overall air quality (Figure 5).

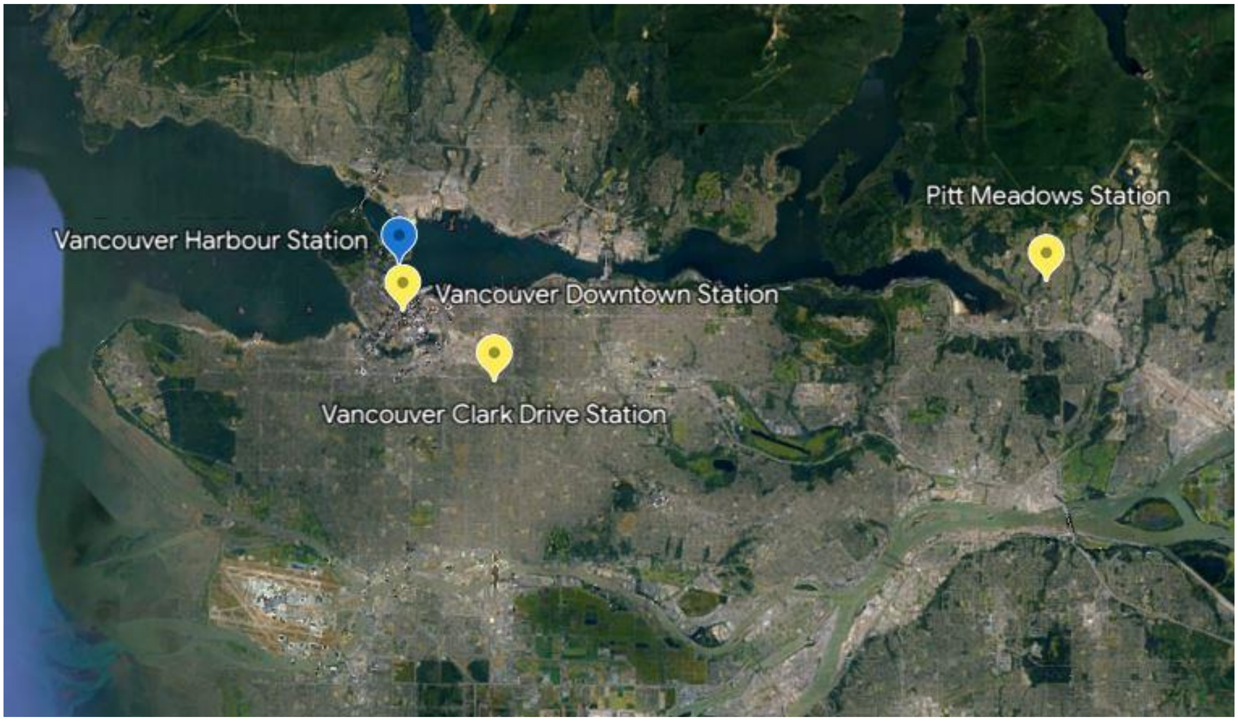

Figure 5. Location of the stations. The blue indicates the temperature data station, and the yellow indicates the air quality data station.

The Vancouver downtown station was selected to be in line with the temperature data station, and two other stations were chosen to see if there were any differences in air quality based on the urbanization of the area. The Vancouver Clark Drive station was selected to represent a less urbanized area than the downtown station, and the Pitt Meadows station was selected to represent the least urbanized area. The data collected from these stations included hourly maximum values for various air pollutants such as carbon monoxide (CO), nitrogen dioxide (NO_2), ozone (O_3), sulphur dioxide (SO_2), and particulate matter of different sizes ($PM_{2.5}$ and PM_{10}).

The collected data were analyzed using statistical methods, including descriptive statistics, correlation analysis, and regression analysis, to explore the effects of the 2021 Vancouver heatwaves on air quality. The hourly maximum values for each pollutant were averaged for each station and compared with the BC ambient air quality objectives.

Chapter 3: Results and Discussion

3.1 Overview of Included Studies

Overall, it is difficult to determine a clear trend among the sources regarding the effects of heatwaves on air quality. However, the sources provide a range of findings and observations related to the issue, such as the relationship between air temperature and ozone concentration, the impact of heatwaves on particulate matter and other air pollutants, and the role of various environmental factors in exacerbating air pollution during heatwaves.

However, some common themes emerge from the sources. For example, many sources note that heatwaves can contribute to increased levels of air pollution, particularly in urban areas with high emissions from sources such as traffic and industry. Several sources also mention the potential health impacts of heatwave-related air pollution, including respiratory problems and mortality from conditions such as COPD. Additionally, some sources highlight the importance of addressing the links between heatwaves and air quality in adaptation policies and measures to protect public health. The following sections will discuss the noticed common themes in detail.

3.2 Summary of Findings on the Effects of Heatwaves on Air Quality

Increase in air pollutants during heatwaves

Studies from Northern Italy (Ragosta et al., 2021) and California, US (Masri et al., 2022) suggest that heatwaves can increase PM concentrations, worsening air quality and potentially exacerbating health effects associated with PM exposure. Masri et al. (2022) examined daily PM data to investigate the relationship between heatwaves and air pollution. For that, 10-minute intervals of Purple Air $PM_{2.5}$ data were downloaded using ThingSpeak's API provided by the PurpleAir company, and its target was all days spanning 2018 through 2020 (PurpleAir, n.d). The meta-analysis found that monthly average $PM_{2.5}$ concentrations were the highest during the late summer and early fall months (Figure 6) (Masri et al., 2022).

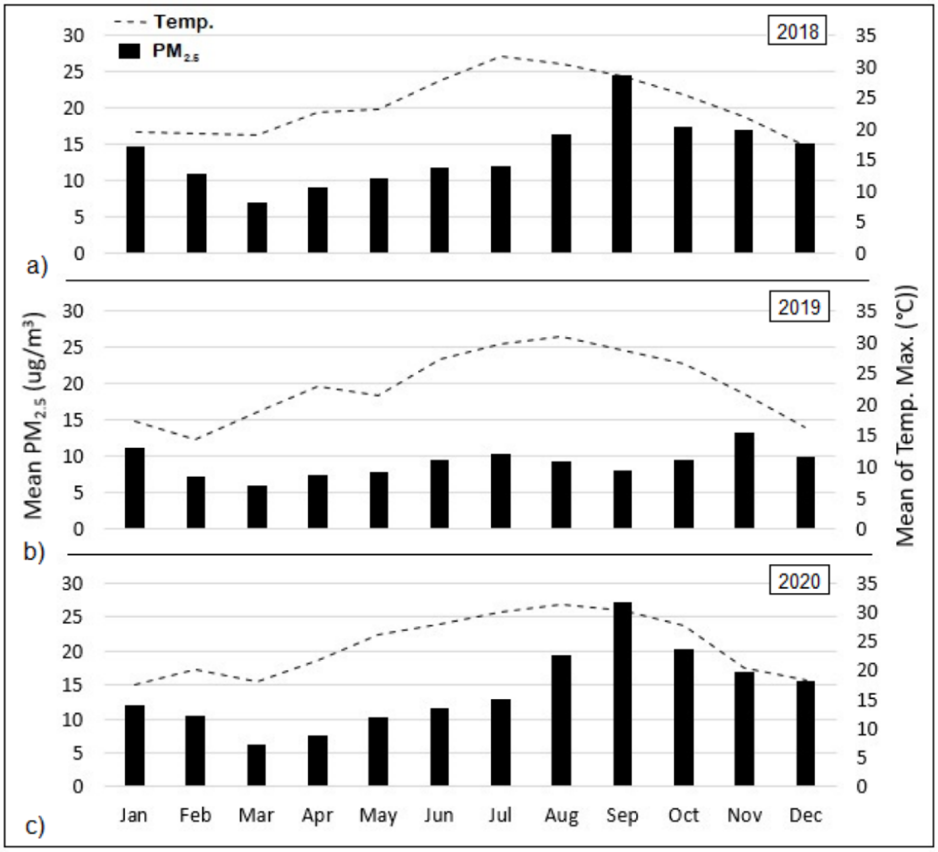

Figure 6. Monthly average $PM_{2.5}$ concentrations in California, US. (Reproduced from Masri et al., 2022)

Data from 2019 and 2020 showed that the highest $PM_{2.5}$ concentration level was observed during August, September, and October, also the peak wildfire season. Specifically, the authors reported a 6.59 µg/m^3 increase in $PM_{2.5}$ concentrations during heatwave days compared to non-heatwave days. Additionally, the meta-analysis found that PM concentrations remained elevated for several days after the heatwave had ended, indicating that the effects of heatwaves on air quality can persist beyond the duration of the heatwave itself (Masri et al., 2022).

Likewise, a statistical investigation conducted for the potential correlation structure of air pollutants such as NO_x, O_3, PM_{10}, and $PM_{2.5}$ during hot days and heatwaves from 2015 to 2017 in monitoring sites located in Northern Italy found that heatwaves can increase PM concentrations (PM_{10} and $PM_{2.5}$), some sampling sites reporting the concentration percentage increase in the range of 15-31 %. The study also highlighted that the effects of heatwaves on PM concentrations might be more pronounced in urban areas, where the urban heat island effect can exacerbate the impacts of heatwaves on air quality (Ragosta et al., 2021).

However, a study that analyzed a year-long record of meteorological data and $PM_{2.5}$ measurements in Tianjin, China, reported that most $PM_{2.5}$ components had higher concentrations in winter, except SO_4^{2-} being higher concentrations in summer, which is inconsistent with the findings of studies in California and Northern Italy (Shao et al., 2021). Despite the inconsistency regarding the seasonal concentration of $PM_{2.5}$, Shao et al. (2021) reported that three extreme meteorological events (EUMEs), including temperature inversion, atmospheric stagnant, and heatwave, had significant impacts on $PM_{2.5}$ components, with NO_3^- being the most affected components by all three EUMEs (Shao et al., 2021).

Another main finding from this review was the findings on the potential heatwaves effect on increased ozone pollution. A study analyzed the concentrations of air pollutants trend from June to August 2013 to 2017 in the Beijing-Tianjin-Hebei (BTH) region, China found that the mean concentration of ozone, [O_3], was significantly higher during heatwave events compared to the non-heatwave period (Wang et al., 2022). The [O_3] and the maximum daily 8-h average (MDA8) [O_3] were found generally increase over the five years by comparing the data from June to August 2017 with those in 2013-2016; the study found a 25.9% increase in MDA8 [O_3] (Wang et al., 2022). Figure 7 shows the data for the duration with observed MDA8 [O_3] of 160 $\mu g/m^3$ or higher and the duration of heatwave events. While the occurrences of MDA8 [O_3] exceedance in 2017 showed higher results than those in 2013-2016, heatwave occurrences also increased. The frequency, duration, and intensity of heatwaves in the region also increased significantly in 2017, providing favourable weather conditions for forming and accumulating O_3 (Wang et al., 2022).

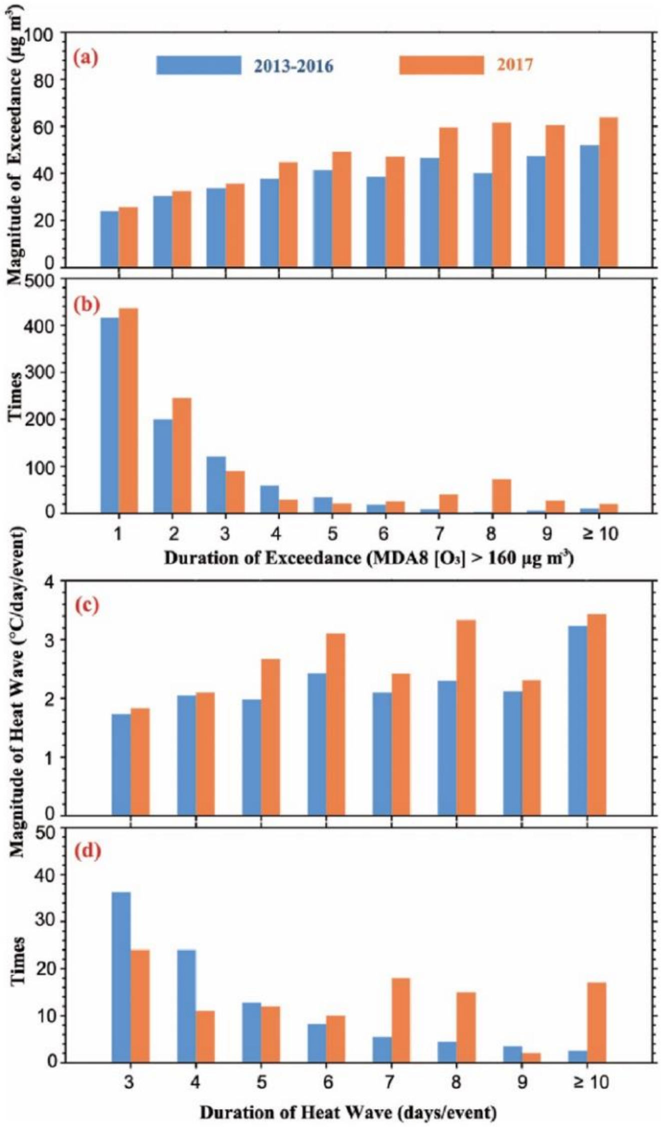

Figure 7. Summary of O_3 concentration analysis in BTH region, China. (a) Magnitude and (b) times of the duration of exceedance with the observed MDHA8 [O_3] exceeding 160 µg/m^3; (c) magnitude and (d) times of heatwave events (daily max air temp.>32 °C). (Reproduced from Wang et al, 2022)

However, another analysis within the BTH region reported that although the temperature was a critical meteorological influencing factor for [O_3], meteorological influences, including temperature, were relatively weak in summer (Chen et al., 2019). The study used ground ozone observation data during 2006-2016 to investigate the causality influence of individual meteorological factors on ozone concentrations in Beijing by using a convergent cross-mapping (CCM) method. The findings showed that meteorological factors had little influence on ozone concentrations in Beijing during the summer. The main reason for the high ozone levels was the rapid increase in VOCs and other precursors. The increase in VOCs and NOx biogenic emissions due to vegetation growth during the summer significantly contributed to the high ozone levels. The authors reported that this finding was consistent with previous studies that indicate warming has led to an increase in biogenic emissions in Beijing, and climate change may be a significant driver of the increasing ozone pollution episodes in China (Chen et al., 2019). A study in New York City in 2017 reported a similar conclusion regarding the relationship between biogenic emissions and ozone concentration. Zhao et al. (2019) used a high-resolution model to assess the impact of biogenic emissions on elevated surface ozone. The study identified two unique characteristics of the planetary boundary layer and demonstrated that biogenic emissions could significantly enhance surface ozone concentrations during heatwaves. The process analyses indicated that photochemical reactions were the most significant positive contributor to surface ozone enhancement (Zhao et al., 2019).

Moreover, a statistical analysis of surface ozone measurement over the United Kingdom from 1999 to 2019 reported that suburban and urban environments showed higher increases in ozone concentration (Finch & Palmer, 2022). The mean ozone trend across all Automatic Urban and Rural Network (AURN) sites was 0.41 $\mu g/m^3$ per year, and more significant trends in the suburban and urban environment (0.36- 0.75 $\mu g/m^3$ per year) were observed compared to rural environments (0.16 $\mu g/m^3$ per year). The authors suggested that these trends in urban surface ozone are coincident with and likely caused by a pronounced decline in surface concentrations of NO_2, which is a proxy for NO_x linked to reduced emissions from the transport sector. The study also found an increase in the probability of high mean ozone and a decrease in the probability of extreme (elevated) ozone events. Overall, the study suggested that heatwaves may impact ozone concentrations, particularly in urban environments, and that reducing NO_x emissions from the transport sector can be an effective strategy to mitigate the effects of ozone pollution (Finch & Palmer, 2022). This was consistent with the findings of Ragosta et al. (2021), more pronounced effects of heatwaves on PM concentrations in urban areas.

However, during the same study, Ragosta et al. (2021) found that while PM concentrations are higher during heatwaves, NO_2 and O_3 concentrations are not influenced by heatwaves, which shows inconsistent conclusions for heatwaves' effect on the level of ozone. The inconsistency may come from various study limitations, such as how the data was obtained (i.e., different meteorological sensors) or limited generalizability of study findings to other regions (Chen et al., 2019; Ragosta et al., 2021; Finch & Palmer., 2022; Wang et al., 2022).

On top of inconsistent conclusions, a systematic literature review investigating the links between heatwaves and air pollution conducted in 2022 found that the link between heatwaves and poor air quality has not been sufficiently acknowledged by academia, with evident gaps in applied small states research (Moncada & Spiteri, 2022).

Impact on human health

The effects of exposure to high temperatures on human health have been widely explored. For instance, exposure to high temperatures may increase the risk of out-of-hospital cardiac arrest (OHCA) events, especially in specific population subgroups, such as those with pre-existing hypertension and ischemic heart disease (Wang et al., 2018). In addition, extreme temperatures are also known to be related to higher mortality rates in certain conditions. For example, a study in Northwest India investigated the mortality rate during the heatwaves period with high baseline temperatures, using a reference temperature of 30 °C when prior studies used 15 °C or 20 °C, and found that heatwaves present risks for mortality (Nori-Sarma et al., 2019). Moreover, an analysis by Conte Keivabu (2022) reported that the 2003 heatwave in Barcelona had impacted individuals with low socioeconomic status and increased their vulnerability.

As this review focused on heatwaves' effects on air quality, the impact on human health had to be related to heatwave-induced air quality. Unfortunately, although the studies reported extreme heat weather could impact respiratory health, literature focused on both factors was not available in the databases except for one study on chronic obstructive pulmonary disease deaths conducted in Shanghai, China (Fu et al., 2022). Fu et al. (2022) concluded that extremely high temperatures significantly impacted the risk of COPD deaths. The difference between this study and others is that the authors extended their scope to identify the ozone-temperature interaction. Fu’s literature review-based analysis suggested three potential factors for the effects of high temperature and ozone on respiratory diseases (Fu et al., 2022):

1. The combination of climate change and outdoor ozone pollution has been linked to increased mortality caused by cardiovascular disease. Although limited data is available on the biological consequences of the interaction between these two environmental problems, one experimental study has suggested that ozone may activate the fibrinolytic pathway at moderate temperatures but damage it at high temperatures (Kahle et al., 2015).

2. The body's response to environmental toxicants is regulated by its thermoregulatory system. Exposure to hot environments may increase lung ventilation and greater uptake of airborne pollutants.
3. High summer temperatures may increase the susceptibility of patients with pre-existing respiratory diseases, such as COPD, to ozone pollution.

Studies have suggested lung function problems may arise due to climate change parameters, especially in patients with pre-existing lung diseases such as asthma, COPD, and respiratory infections (such as COVID-19). Thus, patients with severe lung diseases may be more susceptible to the effects of both ozone and high temperatures, and ozone pollution may exacerbate the impact of thermal effects on individuals. In addition, ozone exposure has been linked to airway damage and inflammation, which can lead to morbidity and mortality in adults (Fu et al., 2022).

3.3 Findings of the Effects of the Vancouver Heatwave 2021 on Air Quality

As mentioned in sections 1.3 and 2.4, to determine the 2021 Vancouver heatwave period, a definition of a heatwave was arbitrarily set as "an interval of at least three consecutive days with a temperature of at least 32.22 °C" (Gonzalez, 2019). Historical temperature data was obtained from the Vancouver Harbour station records. The data was filtered on the maximum temperature column to identify the heatwave period, and dates that exceeded 32.21 °C for at least three consecutive days were identified. After analyzing the data, only one result emerged, indicating that the 2021 Vancouver heatwave period was from June 26, 2021, to June 28, 2021 (Appendix 1).

As the primary air quality monitoring station's database, the Vancouver downtown station had limited availability of the listed air pollutants, six air pollutants were selected for the analysis: PM, NO_x, NO_3, NO, CO, and SO_2. Figure 8 shows the summarized air quality data from all three stations: the Vancouver downtown station ("Robson"), the Vancouver Clark Drive station ("Clark"), and the Pitt Meadows station ("Pitt Meadows"). Each graph highlights the previously determined 2021 Vancouver heatwave period with a red box.

Figure 8. Air Quality Data for June – July 2021. Collected from Robson, Clark, and Pitt Meadows stations' database. Red Highlight Indicates the Defined 2021 Vancouver Heatwave Period (June 26 – June 28).

Firstly, data from three stations were compared to identify different heatwave impacts per urbanization according to the findings from this review (Ragosta et al., 2021; Finch & Palmer, 2022). Although levels of PM data were not available, comparing the other pollutants data, the graph does not show consistency in a severe increase in pollutants during the heatwave period. Overall, air quality data shows that the degree of urbanization does not impact the level of air pollutants. For instance, the O_3 level showed the highest trend from the Pitt Meadows station, representing the minor urbanized area, and the Clark station had a higher trend of NO, NO_2, and NO_x than the Robson station.

Data within a range of five days of the defined heatwave period in 2021, June 26 – June 28, were assessed to identify potential heatwave effects on air quality. Previously, findings from this review on potential heat effects on increased ozone pollution were described (Chen et al., 2019; Zhao et al., 2019; Ragosta et al., 2021; Finch & Palmer, 2022; Moncada & Spiteri, 2022; Wang et al., 2022). Despite the highest trend in the least urbanized station in Pitt Meadows, all three stations showed an increased trend after the heatwave period. The Robson station had the highest [O_3] on June 29 at 63.7 ppb, 1.7 ppb higher than the CAAQS (62 ppb for an 8hr average period). The Clark station showed generally higher [O_3] from June 23 – June 28, yet the [O_3] did not exceed CAAQS. The Pitt Meadows station showed a dramatically increased [O_3] on June 26 (92.9 ppb) compared to June 25 (38.4 ppb). From June 26 – June 28, [O_3] data from the Pitt Meadows station showed severely exceeded CAAQS, indicating severe ozone pollution.

3.4 Uncertainties and Limitations of the Study

The study on the effects of heatwaves on air quality identified several limitations that could impact the accuracy and applicability of its findings. One of the limitations was the use of low-cost sensors for $PM_{2.5}$ measurements, which may not provide the most precise readings (Masri et al., 2022). Another limitation was the insufficient data and validation with primary data, which could undermine the study's credibility (Fu et al., 2022). Additionally, there was a lack of relevant data on the interaction between high temperature and ozone pollution, which could affect the accuracy of the findings (Shao et al., 2021).

Moreover, the 2021 Vancouver heatwave analysis for potential heatwave effects on air quality had limited generalizability to other regions with different environmental conditions and pollutant sources. As a result, the study's findings may not represent other areas with varying pollution levels or weather patterns. Furthermore, the quality and accuracy of historical data may be limited due to inconsistent data collection from different stations, which could affect the reliability of the study's results.

Overall, these limitations suggest the need for further research to better understand the effects of heatwaves on air quality and to ensure that findings apply to a broader range of locations and populations. Additional studies using more accurate sensors and extensive data collection methods may provide more reliable and representative findings.

Chapter 4: Conclusions and Recommendations

Recent heatwaves in BC have raised questions about their long-term impact on air quality. This systematic literature review explores the relationship between heatwaves and air quality by analyzing studies focusing on air quality during heatwaves and the differences in effects between urban and rural areas. The review's key findings reveal that heatwaves increase air pollutant concentrations, including PM and ozone concentrations, with varying results depending on location and urbanization level. Ozone concentration increases during and after heatwaves, with more severe effects in hotter and more urban areas. However, some studies reported no impact of high-temperature conditions on pollutant levels, inconsistent with earlier findings. Study limitations may account for this inconsistency, such as the limited generalizability of study findings to other regions.

Although limited literature exists regarding the impact of heatwave-induced air quality on human health, one study reported potential increases in COPD deaths and respiratory diseases. This review also examined the effects of the 2021 Vancouver heatwave on air quality, defining a heatwave as at least three consecutive days with a temperature of at least 32.22°C. The defined 2021 Vancouver heatwave period was from June 26 to 28, 2021. Historical air quality data analysis showed that the degree of urbanization did not affect air pollutant levels in Vancouver. All selected stations showed an increased trend in ozone pollution after the heatwave period, with the Pitt Meadows station severely exceeding CAAQS for ozone pollution.

The study's limitations include insufficient data and validation with primary data, a lack of relevant data on the interaction between high temperature and ozone pollution, and limited generalizability to other regions with different environmental conditions and pollutant sources. In conclusion, this systematic literature review provides valuable insights into the effects of heatwaves on air quality, highlighting the need for further research to develop effective strategies to mitigate climate change and improve air quality. Policymakers, researchers, and practitioners can use these findings to develop evidence-based interventions to address the impact of heatwaves on air quality.

References

BC Ministry of Environment. (n.d). Station Report. *BC Air Data Archive*. [Website] https://envistaweb.env.gov.bc.ca/

Callahan, C. W., & Mankin, J. S. (2022). Globally unequal effect of extreme heat on economic growth. *Science Advances*, 8(43), eadd3726-eadd3726. https://doi.org/10.1126/sciadv.add3726

CDC. (n.d). Climate Change and Extreme Heat Events. *Centers for Disease Control and Prevention*. https://www.cdc.gov/climateandhealth/pubs/ClimateChangeandExtremeHeatEvents.pdf

Chen, Z., Zhuang, Y., Xie, X., Chen, D., Cheng, N., Yang, L., & Li, R. (2019). Understanding long-term variations of meteorological influences on ground ozone concentrations in beijing during 2006–2016. *Environmental Pollution (1987), 245*, 29-37. https://doi.org/10.1016/j.envpol.2018.10.117

Conte Keivabu, R. (2022). Extreme temperature and mortality by educational attainment in spain, 2012–2018. *European Journal of Population*, 38(5), 1145-1182. https://doi.org/10.1007/s10680-022-09641-4

Di Napoli, C., Pappenberger, F., & Cloke, H. L. (2019). Verification of heat stress thresholds for a health-based heat-wave definition. *Journal of Applied Meteorology and Climatology*, 58(6), 1177-1194. https://doi.org/10.1175/JAMC-D-18-0246.1

Dosio, A., Mentaschi, L., Fischer, E. M., & Wyser, K. (2017;2018;). Extreme heatwaves under 1.5 °C and 2 °C global warming. *Environmental Research Letters*, 13(5), 54006. https://doi.org/10.1088/1748-9326/aab827

The Canadian Press (2022, June 24), Vancouver BC Highest Temperature Each Year – Current Results. *Toronto Star.* https://www.thestar.com/news/canada/2022/06/24/a-timeline-of-bcs-record-setting-extreme-heat-event-in-june-2021.html

ECCC. (2017), Criteria for public weather alerts. *Government of Canada*. https://www.canada.ca/en/environment-climate-change/services/types-weather-forecasts-use/public/criteria-alerts.html#heat.

ECCC. (2021). Daily Data Report. *Government of Canada.* https://climate.weather.gc.ca/climate_data/daily_data_e.html?StationID=51442&timeframe=2&StartYear=1840&EndYear=2023&Day=19&Year=2021&Month=6#

EPA. (2014). Criteria Air Pollutants. *EPA*. https://www.epa.gov/criteria-air-pollutants

Finch, D. P., & Palmer, P. I. (2020). Increasing ambient surface ozone levels over the UK accompanied by fewer extreme events. *Atmospheric Environment (1994)*, 237, 117627. https://doi.org/10.1016/j.atmosenv.2020.117627

Fu, S., Zhou, Y., Peng, L., Ye, X., Yang, D., Yang, S., Zhou, J., & Luo, B. (2022). Interactive effects of high temperature and ozone on COPD deaths in shanghai. *Atmospheric Environment* (1994), 278, 119092. https://doi.org/10.1016/j.atmosenv.2022.119092

Gonzalez, J. E., Ortiz, L., Smith, B. K., Devineni, N., Colle, B., Booth, J. F., Ravindranath, A., Rivera, L., Horton, R., Towey, K., Kushnir, Y., Manley, D., Bader, D., & Rosenzweig, C. (2019). New york city panel on climate change 2019 report chapter 2: New methods for assessing extreme temperatures, heavy downpours, and drought. *Annals of the New York Academy of Sciences*, 1439(1), 30-70. https://doi.org/10.1111/nyas.14007

Guo, X., Huang, J., Luo, Y., Zhao, Z., & Xu, Y. (2017). Projection of heatwaves over china for eight different global warming targets using 12 CMIP5 models*. Theoretical and Applied Climatology*, 128(3-4), 507-522. https://doi.org/10.1007/s00704-015-1718-

Haddaway, N. R., Macura, B., Whaley, P., & Pullin, A. (2017). *ROSES for Systematic Review Reports* (1.0) [Microsoft Excel]. https://www.roses-reporting.com/systematic-review-reports

Haddaway, N. R., Macura, B., Whaley, P., & Pullin, A. S. (2018). ROSES RepOrting standards for systematic evidence syntheses: Pro forma, flow-diagram and descriptive summary of the plan and conduct of environmental systematic reviews and systematic maps. *Environmental Evidence*, 7(1), 1-8. https://doi.org/10.1186/s13750-018-0121-7

IPCC. (2014). Synthesis report summary for Policymakers Chapter - IPCC. *AR5 Synthesis Report: Climate Change 2014*. https://www.ipcc.ch/report/ar5/syr/.

IPCC. (2022). Full report of the Working Group II. *Climate Change 2022: Impacts, Adaptation and Vulnerability*. https://report.ipcc.ch/ar6/wg2/IPCC_AR6_WGII_FullReport.pdf

Kahle, J. J., Neas, L. M., Devlin, R. B., Case, M. W., Schmitt, M. T., Madden, M. C., & Diaz-Sanchez, D. (2015). Interaction effects of temperature and ozone on lung function and markers of systemic inflammation, coagulation, and fibrinolysis: A crossover study of healthy young volunteers. *Environmental Health Perspectives*, 123(4), 310-310. https://doi.org/10.1289/ehp.1307986

Khosla, R., Jani, A., & Perera, R. (2021). Health risks of extreme heat. *BMJ (Online)*, 375, n2438-n2438. https://doi.org/10.1136/bmj.n2438

Lin, S., Luo, M., Walker, R. J., Liu, X., Hwang, S., & Chinery, R. (2009). Extreme high temperatures and hospital admissions for respiratory and cardiovascular diseases. *Epidemiology (Cambridge, Mass.)*, 20(5), 738-746. https://doi.org/10.1097/EDE.0b013e3181ad5522

Moncada, S. S., & Spiteri, M. M. (2022). Strengthening resilience to address climate change and chronic diseases: Evidence from small states: Stefano moncada. *European Journal of Public Health*, 32(Suppl 3), https://doi.org/10.1093/eurpub/ckac129.222

Masri, S., Jin, Y., & Wu, J. (2022). Compound risk of air pollution and heat days and the influence of wildfire by SES across California, 2018–2020: Implications for environmental justice in the context of climate change. *Climate (Basel)*, 10(10), 145. https://doi.org/10.3390/cli10100145

Nduka, I. C. (2021). Characterization and trends of hot-polluted-episodes and their implications on public health over pearl river delta region of china. *ProQuest Central*. https://www.proquest.com/dissertations-theses/characterization-trends-hot-polluted-episodes/docview/2655571403/se-2.

NOAA. (2021). During a heatwave. *NOAA's National Weather Service*. https://www.weather.gov/safety/heat-during#:~:text=A%20heat%20wave%20is%20a,with%20or%20without%20high%20humidity

NOAA. (2022). Global Time Series. *National Oceanic and Atmospheric Administration.* https://www.ncei.noaa.gov/access/monitoring/climate-at-a-glance/global/time-series/globe/land/ann/1/1880-2022

NOAA. (2023, January 18). Climate Change: Global Temperature. *NOAA Climate.gov*. https://www.climate.gov/news-features/understanding-climate/climate-change-global-temperature#:~:text=2022%20was%20the%20sixth%2Dwarmest,period%20(1880%2D1900).

Nori-Sarma, A., Anderson, G. B., Rajiva, A., ShahAzhar, G., Gupta, P., Pednekar, M. S., Son, J., Peng, R. D., & Bell, M. L. (2019). The impact of heatwaves on mortality in northwest india. *Environmental Research*, 176, 108546. https://doi.org/10.1016/j.envres.2019.108546

PCC. (2019). Climate maps of Canada – version 2. *The Climate Atlas of Canada.* https://climateatlas.ca

Province of BC (2021), Provincial Air Quality Objective Fact Sheet. *B.C. Ambient Air Quality Objectives.* https://www2.gov.bc.ca/assets/gov/environment/air-land-water/air/reports-pub/prov_air_qual_objectives_fact_sheet.pdf.

PurpleAir (n.d), *PurpleAir Inc*. [website] https://www2.purpleair.com/

Pyrgou, A., Hadjinicolaou, P., & Santamouris, M. (2018). Enhanced near-surface ozone under heatwave conditions in a mediterranean island. *Scientific Reports*, 8(1), 9191-10. https://doi.org/10.1038/s41598-018-27590-z

Ragosta, M., D'Emilio, M., Casaletto, L., & Telesca, V. (2021). A statistical procedure for analyzing the behavior of air pollutants during temperature extreme events: The case study of emilia-romagna region (northern italy). *Applied Sciences*, 11(17), 8266. https://doi.org/10.3390/app11178266

Shao, M., Dai, Q., Yu, Z., Zhang, Y., Xie, M., & Feng, Y. (2021). Responses in PM.sub.2.5 and its chemical components to typical unfavorable meteorological events in the suburban area of Tianjin, China. *The Science of the Total Environment*, 788, https://doi.org/10.1016/j.scitotenv.2021.147814

Seltenrich, N. (2015). Between extremes: Health effects of heat and cold. *Environmental Health Perspectives*, 123(11), A275-A279. https://doi.org/10.1289/ehp.123-A275

Smoyer-tomic, K., Kuhn, R., & Hudson, A. (2003), Heatwave hazards: An overview of heatwave impacts in Canada. *Natural Hazards*, 28(2-3), 465-486. doi:https://doi.org/10.1023/A:1022946528157

Steacy, L. (2021, August 13). Vancouver's air quality worst of any 'major city' in world due wildfire smoke, heat. *CityNews.* https://vancouver.citynews.ca/2021/08/13/vancouver-air-quality-wqorst-wildifres/

Transport & Environment (2019). Why is air quality so important? *Transport & Environment.* https://www.transportenvironment.org/challenges/air-quality/why-is-air-quality-so-important/.

Van Oldenborgh, G. J., Wehner, M. F., Vautard, R., Otto, F. E. L., Seneviratne, S. I., Stott, P. A., Hegerl, G. C., Philip, S. Y., & Kew, S. F. (2022). Attributing and projecting heatwaves is hard: We can do better. *Earth's Future*, 10(6), e2021EF002271-n/a. https://doi.org/10.1029/2021EF002271

Vallero, D. A. (2008). The Science of Air Pollution. *Fundamentals of air pollution* (4th ed. pp.43-81). Elsevier.

Vjosa, I. (2021, July 10). Heatwave spread fire that 'erased' Canadian town. *The New York Times.* https://www.nytimes.com/2021/07/10/world/canada/canadian-wildfire-british-columbia.html.

Wang, Y., Chen, Y., Ko, C., Guo, Y. L., & Sung, F. (2018). Pre-existing comorbidity modify emergency room visit for out-of-hospital cardiac arrest in association with ambient environments. *PloS One*, 13(9), e0204593-e0204593. https://doi.org/10.1371/journal.pone.0204593

Wang, R., Bei, N., Hu, B., Wu, J., Liu, S., Li, X., Jiang, Q., Tie, X., & Li, G. (2022). The relationship between the intensified heatwaves and deteriorated summertime ozone pollution in the Beijing–Tianjin–Hebei region, china, during 2013–2017. *Environmental Pollution (1987)*, *314*, 120256-120256. https://doi.org/10.1016/j.envpol.2022.120256

Westervelt, D. M., Ma, C. T., He, M. Z., Fiore, A. M., Kinney, P. L., Kioumourtzoglou, M., Wang, S., Xing, J., Ding, D., & Correa, G. (2019). Mid-21st century ozone air quality and health burden in China under emissions scenarios and climate change. *Environmental Research Letters*, 14(7), 74030. https://doi.org/10.1088/1748-9326/ab260b

WHO. (2019, Nov 14). Air Pollution. *World Health Organization*. https://www.who.int/health-topics/air-pollution

WMO. (2022, July 19), WMO has no immediate plans to name heatwaves. *The World Meteorological Organization*. https://public.wmo.int/en/media/news/wmo-has-no-immediate-plans-name-heatwaves

Xia, Y., Li, Y., Guan, D., Tinoco, D. M., Xia, J., Yan, Z., Yang, J., Liu, Q., & Huo, H. (2018). Assessment of the economic impacts of heatwaves: A case study of Nanjing, China. *Journal of Cleaner Production*, 171, 811-819. https://doi.org/10.1016/j.jclepro.2017.10.069

Yang, Y., Jin, C., & Ali, S. (2020, November 1). Projection of heatwave in china under global warming targets of 1.5 °C and 2 °C by the ISIMIP models. *Atmospheric Research,* 244, 105057. doi:https://doi.org/10.1016/j.atmosres.2020.105057

Zhao, K., Bao, Y., Huang, J., Wu, Y., Moshary, F., Arend, M., Wang, Y., & Lee, X. (2019). A high-resolution modeling study of a heatwave-driven ozone exceedance event in new york city and surrounding regions. *Atmospheric Environment (1994)*, 199, 368-379. https://doi.org/10.1016/j.atmosenv.2018.10.059

Appendices

1. Historical Temperature Raw Data - Vancouver Harbour station

Year	Month	Day	Max Temp (°C)	Min Temp (°C)	Mean Temp (°C)
2021	6	1	25.9	12.9	19.4
2021	6	2	28.3	14.1	21.2
2021	6	3	24.2	16	20.1
2021	6	4	18.3	12.6	15.5
2021	6	5	18.4	11.1	14.7
2021	6	6	12.2	9.5	10.8
2021	6	7	16.8	9.8	13.3
2021	6	8	18.7	8.1	13.4
2021	6	9	18.7	11	14.8
2021	6	10	17.8	10.7	14.2
2021	6	11	17.3	12	14.6
2021	6	12	21.6	12.2	16.9
2021	6	13	17.2	13.8	15.5
2021	6	14	20.1	14.2	17.1
2021	6	15	20	12.9	16.4
2021	6	16	21.2	13.4	17.3
2021	6	17	24.3	12.6	18.4
2021	6	18	21.6	12.6	17.1
2021	6	19	21.7	14.5	18.1
2021	6	20	25.2	13.7	19.5
2021	6	21	25.4	15.2	20.3
2021	6	22	25.3	15.2	20.3
2021	6	23	23.6	15.2	19.4
2021	6	24	24	15	19.5
2021	6	25	27.9	17.3	22.6
2021	6	26	33.7	17.8	25.8
2021	6	27	33.1	18.5	25.8
2021	6	28	33.8	18.3	26
2021	6	29	31.1	19.2	25.2
2021	6	30	25	18.4	21.7
2021	7	1	23.6	18.3	20.9
2021	7	2	23.9	17.2	20.5
2021	7	3	24.5	16	20.2
2021	7	4	25.4	15.8	20.6
2021	7	5	26.7	17.8	22.2
2021	7	6	26.2	17.4	21.8
2021	7	7	23.1	17.3	20.2
2021	7	8	22	16	19

2021	7	9	26	18.2	22.1
2021	7	10	24.9	17.6	21.2
2021	7	11	24.8	15.7	20.3
2021	7	12	26.5	15.6	21
2021	7	13	26.2	15.9	21.1
2021	7	14	25.7	15.9	20.8
2021	7	15	23.1	15.1	19.1
2021	7	16	20.7	14.8	17.8
2021	7	17	24.9	16.2	20.5
2021	7	18	25.6	15.3	20.4
2021	7	19	27.6	16	21.8
2021	7	20	24.6	16.9	20.8
2021	7	21	22.7	15	18.9
2021	7	22	23.9	15.2	19.5
2021	7	23	26.6	16.6	21.6
2021	7	24	26.9	15.7	21.3
2021	7	25	27.4	16.6	22
2021	7	26	27.3	15.9	21.6
2021	7	27	26.1	16.6	21.4
2021	7	28	27.5	15	21.3
2021	7	29	28.3	15.9	22.1
2021	7	30	29.3	16.5	22.9
2021	7	31	25.9	18.5	22.2
2021	8	1	27.9	19	23.5
2021	8	2	26.8	18.8	22.8
2021	8	3	27.9	17.1	22.5
2021	8	4	28.9	16	22.4
2021	8	5	29.6	19.1	24.3
2021	8	6	23	19.1	21
2021	8	7	19.5	14.5	17
2021	8	8	22.5	15.2	18.9
2021	8	9	24	16.8	20.4
2021	8	10	25.1	16.7	20.9
2021	8	11	26.5	16.9	21.7
2021	8	12	30.9	19.2	25
2021	8	13	32.2	16.9	24.6
2021	8	14	29.6	17.3	23.4
2021	8	15	26.8	18.3	22.5
2021	8	16	20.2	16.3	18.2
2021	8	17	22.3	15	18.7
2021	8	18	22.8	14.2	18.5
2021	8	19	25.8	16.2	21

2021	8	20	17.7	15.3	16.5
2021	8	21	20	14.9	17.5
2021	8	22	21	15.5	18.3
2021	8	23	21	13.8	17.4
2021	8	24	22.9	12.3	17.6
2021	8	25	25.2	13.4	19.3
2021	8	26	17.6	14.7	16.1
2021	8	27	21.4	14.4	17.9
2021	8	28	22.6	12.4	17.5
2021	8	29	22.9	13.1	18
2021	8	30	18.3	14.1	16.2
2021	8	31	18.1	12	15.1
2021	9	1	19.6	9.8	14.7
2021	9	2	23.1	11.3	17.2
2021	9	3	21.8	12.4	17.1
2021	9	4	17.6	13.5	15.6
2021	9	5	20.8	14.6	17.7
2021	9	6	23.4	14.9	19.1
2021	9	7	23	13.3	18.1
2021	9	8	24.8	15.6	20.2
2021	9	9	26.6	15.8	21.2
2021	9	10	22.9	16.2	19.5
2021	9	11	16.8	14.9	15.9
2021	9	12	20	14.7	17.3
2021	9	13	19.3	11.8	15.6
2021	9	14	14.5	13.3	13.9
2021	9	15	17.9	12.6	15.3
2021	9	16	17.2	8.8	13
2021	9	17	14.2	11.1	12.7
2021	9	18	18.8	12.5	15.6
2021	9	19	14.9	11.7	13.3
2021	9	20	17.4	11.5	14.4
2021	9	21	18.8	11.6	15.2
2021	9	22	18.6	12.4	15.5
2021	9	23	18.6	11.9	15.2
2021	9	24	19.7	11.2	15.4
2021	9	25	22.3	11.8	17
2021	9	26	16.8	12.5	14.6
2021	9	27	15.6	12.7	14.1
2021	9	28	17.4	11.7	14.6
2021	9	29	13.3	10.7	12
2021	9	30	15.1	12.2	13.7

2. Literature Matrix

Bibliographic Information			Abstracting: record relevant characteristics and findings					Appraising: assess the quality of the research			Aligning: state how the source contibutes to *your* research question	
Source number / short name	Publication date	Reference list entry (using the style required by your program)	Research question/aim and rationale	Research design and main methods	Key finding(s) and/or claims	Main conclusion (if any / if different than key findings)	Summarizes author comments on validity and generalizability, including significant limitations, threats or weaknesses	Is the source's research question clearly focused and well articulated?	Does the source explain and justify the research design and the key decisions about methods? If so, quote, paraphrase or summarize supporting passages.	Does the source present results, key findings, and conclusions clearly? Are conclusions substantiated by the evidence presented?	How do this source's main findings and/or conclusion contribute to your understanding of your research question? Given your appraisal of the source, is it of high enough quality to include in your literature review? If you decide to include the source with reservations, note them here.	Other Notes
Masri et al. (2022)	10/1/2022	[illegible]	How do wildfires and heatwaves contribute to increased air pollution and health risks, and how can these risks be mitigated? This study aimed to examine the occurrence of compound risk (CR) days characterized by high temperature and high PM2.5 at the census tract level in California and to understand how such days have been impacted by the occurrence of wildfires. The study also aimed to examine the correlation between CR days and socioeconomic factors at the census tract level.	[illegible]	[illegible]	[illegible]	[illegible]	Yes, clear focus on examining the occurrence of CR days at the census tract level in California.	(1) the use of low-cost sensors allowed for more excellent spatial coverage and data resolution than traditional air quality monitoring methods, and that the inclusion of wildfire data was necessary to understand the impact of wildfires on compound risk days (2) five-year average data of the American Community Survey was used as "averages provide a more stable representation of community-level factors, and because 2018 was the most recent year for which five-year average data was available and since wildfire burned area was greatest in the more recent, as	Yes, the summarization of the statistical results was clear.	Higher PM2.5 concentration was observed in Summer from 2018-2020, more recent year shows a higher degree of temperature. Drawing results from statistical data can be adapted to the research. Additional socioeconomic effects on the end part of the heat wave and poor air quality might be related. This will be included in the result and discussion.	California, PM2.5
Ragosta et al (2021)	9/6/2021	[illegible]	The research question investigates the variations in the correlation structure of four air pollutants during extreme temperature events in the Emilia Romagna region, Northern Italy. The rationale is to improve the knowledge of how excessive heat impacts air quality.	[illegible]	[illegible]	[illegible]	[illegible]	Yes, clear statements on the investigation of the variations in the correlation structure of four air pollutants during extreme temperature events in Emilia Romagna region, Nothern Italy, in summer from 2015 to 2017.	Yes. The research method was based on multivariate techniques, which allowed the researchers to highlight the variations in the air quality of the study area due to the occurrence of heat waves.	Yes, the examined data show higher PM concentrations, whereas Nox and O3 concentrations seem to be not influenced by heat waves.	Difference trends per air pollutants might be referable when analyzing the 2021 Vancouver heat wave and air quality data. It also can be used as evidence (research proof) for a relationship between heat waves and air quality. This will be included in the result and discussion.	Italy, PM, Nox, O3
Qureshi et al (2022)	7/24/2022	[illegible]	What is the Heat Vulnerability Index (HVI) of Amiens, France, during extreme heat days, and how can it be mapped using various data sources? The study aims to evaluate HVI in Amiens for intense heat days recorded during three years (2018-2020) and identify hot zones through comprehensive GIS analysis. The rationale is that urbanization, anthropogenic activities, and social determinants contribute to heat-related mortalities. The 2003 strong heat wave in France resulted in catastrophic health consequences that may be attributed to urbanization and other anthropogenic activities.	[illegible]	[illegible]	[illegible]	[illegible]	Yes, a clear research question, aim, and rationale were provided.	The justification for using chosen data was their relevancy to assessing heat vulnerability.	Yes, three typical areas were identified to have high HVI.	A strong relationship between heat waves and air quality. High risk of extreme heat and air pollution are not only subject to the big cities. This will be included in the result and discussion.	Frence
Fu et al. (2022)	6/1/2022	[illegible]	How does the interaction between temperature and ozone affect chronic obstructive pulmonary disease (COPD) deaths in Shanghai? The aim is to explore the potential interaction between temperature and ozone on the risk of health hazards. The rationale is that heatwaves and increased global temperature are associated with increased ozone concentration and COPD deaths.	[illegible]	[illegible]	[illegible]	[illegible]	Yes, the study shows clear focus on the potential interaction between temperature and ozone on deaths of COPD	A bivariate polynomial model was used to establish the interaction term between temperature and ozone; the model can't provide specific parameter estimates, but it can visualize the effects of two factors on COPD mortality	Yes. The increasing temperature was significantly associated with COPD deaths, and with each 10ug/m3 ozone increase in summer, the relative risk associated with COPD deaths increased.	Another strong relationship between heat waves and air quality (ozone level), although this research's method didn't specify how heat waves can affect air quality. It just confirmed that there is an interactive effect between two factors, and it impacts COPD deaths. This will be included in the result and discussion.	China (Shanghai), COPD
Shao et al. (2021)	9/20/2021	[illegible]	What is the role of extremely unfavorable meteorological events (EUMEs) in processing atmospheric PM2.5 pollution? The aim of this study is to examine the variations of PM2.5 mass and its chemical components associated with various meteorological parameters and three EUMEs. The rationale is that the impact of meteorology, particularly EUMEs, on processing atmospheric PM2.5 pollution has not been fully addressed.	[illegible]	[illegible]	[illegible]	[illegible]	Yes. A clear focus on the investigation of the role of meteorology in processing atmospheric PM2.5 pollution	Yes, a year long in situ measurement was utilized with meteorological observations for this study.	Yes, which are listed under abstracting columns.	Clear evidence of heatwave's effect on some of the air pollutants (especially PM2.5). This will be included in the result and discussion.	China (Tianjin), PM2.5
Mika et al. (2018)	February, 2018	[illegible]	How does projected regional climate change affect urban air pollution (UAP) and urban heat island (UHI) properties, and what are the associated human health effects? The study aims to examine the impact of climate change on UAP and UHI and its consequences for human health. The rationale is that climate change affects various environmental factors, which can impact UAP and UHI. Therefore, understanding the implications of these changes is essential for developing strategies to mitigate the impact of climate change on human health.	[illegible]	[illegible]	[illegible]	[illegible]	Yes, the article explores how projected regional climate change affects UAP and UHI properties and reviews the human health effects associated with these urban stressors	The source justifies the research design by using the Representative Concentration Pathways (RCP4.5) scenario for 2046-2065, which is characterized by a 1.4 K global warming and maps for temperature, precipitation, air pressure, and cloudiness changes.	Yes. The presented evidence support the findings such as the fact that regions with more anticyclonic and cloudless weather and increased temperature will suffer from stronger UAP and UHI.	Although this study explores the effects of climate change on urban air pollution and urban heat island, it did not provide any evidence by itself. Therefore, this study maybe used for reference but won't be a part of the result and discussion.	Review; theoretical exploration on the subject.
Moncada & Spiteri (2022)	10/25/2022	[illegible]	The research question is to assess the level of preparedness of the European Union, with a focus on adaptation to heatwaves, since the extreme European heatwave of 2003. The aim is to discover what measures Malta is adopting to tackle the problems arising from the interaction between poor air quality and heatwaves. The rationale behind the research is that climate change is disproportionately impacting small states, with higher costs per capita associated with coping with the immediate risks of environmental and climatic events.	[illegible]	[illegible]	[illegible]	[illegible]	Yes, a clear focus on assessing the European Union's preparedness level (especially on adaptation to heat waves).	The source explained the research design and critical decisions about methods (using a systematic literature review to investigate the links between heat-waves and air pollution post-2003, which was followed by a qualitative content analysis to assess the preparedness of climate change adaptation measures in this regard).	Yes. The presented evidence substantiated the study's conclusion; academia has yet to sufficiently acknowledge the link between heat waves and poor air quality. There are evident gaps in applied small states research.	Similar to Mike et al. (2018). It does not provide evidence, but it's an excellent resource to show how the other review was done and its results. Although, the result would be restricted to 2003, which may not be feasible in the research context. This may be included in the result and discussion.	Review; an insufficient link between heat waves and poor air quality post-2003.
Nduka (2021)	August, 2021	[illegible]	The aim of the study was to comprehensively analyze the characteristics, mechanisms, drivers, trends, and implications of Hot-and-Polluted Episodes (HPEs) on human health during their co-occurrence in the Pearl River Delta region, China. The study was conducted due to the significant impact of air pollution and heat waves on public health, economy, environment, and general well-being.	[illegible]	[illegible]	[illegible]	[illegible]	Yes. A clear focus on investigations of hot-and-polluted episods (HPEs).	the source uses two sets of numerical model simulations to study the Total Aerosol Radiative Forcing (TARF) effect. The source also applies K-means clustering to group the HPEs into three clusters based on their characteristics and mechanism.	Yes. The result shows that for PM2.5, the region exceeded WHO safe levels over 75% of the time but exceeded the Chinese rural standard by just 25% and ~0% for the urban standard. The O3 standard by the WHO was exceeded by 69 and 57%, but exceedance for the Chinese standard was just over 5% and 0% for 1.5 and 1.33 conversion rates.	This study seems more of a statistical projection research than proving the heat wave's effect on air quality. It will be excluded from the result and discussion.	Projection; China; HPE
Wang et al (2022)	12/1/2022	[illegible]	What is the contribution of weather shifts to O3 concentration variability owing to climate change in the Beijing–Tianjin–Hebei (BTH) region, China? The research aims to identify the relationship between extreme summer heat and high O3 concentrations in the BTH region. The rationale is to understand the impact of weather shifts and anthropogenic emission changes on O3 pollution, which harms human health and ecosystems.	[illegible]	[illegible]	[illegible]	[illegible]	Yes, as described under abstracting columns.	Yes. The authors explain that they used a combination of regional air chemistry model simulations with near-surface observations to identify the relationship between extreme summer heat and high O3 concentrations in the BTH region. They justify this approach by stating that it allows them to understand the impact of weather shifts and anthropogenic emission changes on O3 pollution.	Yes, the source clearly presents the results, key findings, and conclusions.	Another evidence of heat wave events affecting one of the air pollutants (O3 pollution) [e.g., "Sensitivity simulations have demonstrated that consecutive occurrences of unfavorable weather conditions (heat wave events) substantially aggravate O3 pollution, constituting one of the most important factors responsible for worsening summertime O3 pollution over the BTH region during JJA 2017"]. This resrouce will be used in the result and discussion.	Heat waves, O3 pollution; China (Beiging-Tianjin-Hebei region)
Jaén et al. (2021)	2/1/2021	[illegible]	[illegible]	[illegible]	[illegible]	[illegible]	[illegible]	Yes, as described under abstracting columns.	The study states that the high-resolution forecast air quality ARAMIS system integrates WRF and CMAQ models. However, the system has its limitations, as described under abstracting columns.	The conclusions are substantiated by the evidence presented, including measured and modeled ozone concentrations and trajectory analysis.	Although high temperatures under heat wave conditions characterized the subject two high ozone episodes, the study includes other weather factors, such as sea breeze, in its analysis/projection. Although the only line that suits the project is "All combined with high temperatures and strong solar radiation enhanced ozone formation" yet, this may not be strong enough evidence to use in the result and discussion.	Barcelona, High ozone episode/heat waves
Zhao et al. (2019)	2/15/2019	[illegible]	[illegible]	[illegible]	[illegible]	[illegible]	[illegible]	Yes, as described under abstracting columns.	The study used the Weather Research and Forecasting model coupled with Chemistry (WRF/Chem) to investigate the heat-wave driven ozone exceedance event. The simulations were evaluated with various observational data, including in situ measurements of air quality and meteorological variables as well as Lidar-measured vertical profiles.	Yes. The study had clear conclusions as described under abstracting columns. The presented evidence substantiated the findings.	A piece of backing evidence for " a high temperature (> 32'C) together with strong solar radiation and weak wind speed was conducive to ozone formation". The study also states that high temperature and NO&NO2 were the main contributors to ozone exceedance events. This study may be used for results and discussion.	NYC, O3 level, Heatwave
Li et al. (2020)	9/1/2020	[illegible]	[illegible]	[illegible]	[illegible]	[illegible]	[illegible]	Yes. A clear aim to quantitatively understand the variation of aerosols across space and time in the city and its underlying mechanism.	The study used a combination of a long-term (2010-2017) observation network and the WRF-Chem model to investigate the diurnal and seasonal variations of UAPI and its relationship with Urban Heat Island (UHI) in the metropolitan area of Berlin	Yes, the presented evidence substantiated the findings.	The connection between heatwave's effect on air quality and urban aerosol pollution island (UAPI) is not strong enough, yet the study focused on UHI. This study won't be used in the result and discussion.	Germany (Berlin), UAPI, UHI
Royé et al. (2019)	June, 2019	[illegible]	[illegible]	[illegible]	[illegible]	[illegible]	[illegible]	The research question is well-articulated: to analyze the temporal pattern of ischemic stroke in Madrid, Spain, during a 13-year period and investigate the relationship between ischemic stroke incidence and environmental factors on a daily scale.	Yes, the study uses a quasi-Poisson regression model to analyze the temporal pattern of ischemic stroke and a biometeorological index to represent human thermal comfort on IS. In addition, a non-linear lag model was fitted in a generalized additive model to assess potential delayed and non-linear effects of air pollutants and Apparent Temperature on IS.	Yes, the presented evidence substantiated the findings, which is no significant relationship between air pollutant concentrations and IS morbidity and mortality.	The study findings are related to IS morbidity and mortality rates. This does not show a direct relation to the main subject. This study may not be used.	Spain (Madrid), IS
Chen et al. (2019)	February, 2019	[illegible]	[illegible]	[illegible]	[illegible]	[illegible]	[illegible]	Yes, a clear focus on quantifying the causality influence of individual meteorological factors on ozone concentrations in Beijing.	Yes, a convergent cross-mapping method covers data accurately.	The conclusions are substantiated by the evidence presented, including the stable meteorological influences on ozone concentrations, the key role of temperature, humidity, and air pressure, and the variations in meteorological influences on ozone concentrations across seasons and years.	The study's findings on the meteorological influences on ozone concentrations provide insight into how heatwaves may impact air quality. This study will be used.	China (Beijing), CCM
Finch & Palmer (2020)	9/15/2020	[illegible]	[illegible]	[illegible]	[illegible]	[illegible]	[illegible]	Yes, the source's research question is focused and well-articulated. The research question is to report a statistical analysis of surface ozone (O3) measurements over the UK from 1999-2019.	Yes, they used data from AURN to check nationwide compliance with ambient air quality directives and a gamma probability distribution to describe changes in surface ozone.	Yes. the presented evidence substantiated the findings.	The study did not find a discernible trend in the number of days exceeding O3 limits set by regulatory agencies, the declining annual maximum ozone concentrations imply that such measures may be effective in reducing the impact of heatwaves on air quality. This study will be used.	UK, surface O3, AURN
Schnell et al. (2021)	1/15/2021	[illegible]	[illegible]	[illegible]	[illegible]	[illegible]	[illegible]	Yes, the aim is clear.	Yes, relatively new approaches.	Yes. the presented evidence substantiated the findings.	Their insights into the nonlinear relationship between emissions and air quality suggest the need for a nuanced approach to managing emissions during heatwaves. However, this source does not provide enough context to be utilized in the review, this won'd be used.	North America, COVID-19