SYSTEMATIC LITERATURE REVIEW RESEARCH

Prifysgol Cymru
Y Drindod Dewi Sant
University of Wales
Trinity Saint David

Sefydliad Dysgu Canol Dinas /

Institute of Inner-City Learning

MSc Public Health and

Social Care in Practice

Effect of Extreme Temperature on Stroke Incidence and Mortality in General

Name: - Bhadreshkumar Bhupatbhai Surani

Student Number: - 2331964

Dr Raheela Shaikh

Dissertation submitted as part of the requirements for the award of MSc Public Health and Social Care in Practice May/2024

Declaration

I, Bhadreshkumar Bhupatbhai Surani declare that this dissertation has been composed by myself, that the work contained herein is entirely my own except where explicitly stated otherwise in the text, and that this work has not been submitted for any other degree or qualification, in whole or in part, except as specified.

Signature: Bhadreshkumar Surani

Date: 13/05/2025

Acknowledgement

I would like to express my sincere gratitude to my supervisor, Dr Raheela Shaikh, for her expert guidance, continuous support, and valuable feedback throughout the course of this dissertation. Their insights and encouragement have been critical in shaping this work.

I also extend heartfelt thanks to the academic and administrative staff at University of Wales Trinity Saint David for their unwavering support and to the librarians for their assistance in navigating research databases.

A special thank you to my classmates and peers for their collaboration and motivation throughout this academic journey. I am especially grateful to my dear friend Ankit Patel, whose support, encouragement, and thoughtful discussions consistently helped me stay focused and determined.

Lastly, I am deeply thankful to my family for their patience, understanding, and belief in me during the challenges of this research process. Your love has been my anchor.

ABSTRACT

Background: Stroke is a leading global cause of mortality and disability. Recent studies have emphasized the growing impact of extreme temperatures, both heatwaves and cold spells on stroke incidence and mortality, a concern heightened by climate change. This systematic literature review investigates the relationship between extreme temperatures and stroke outcomes at a global level.

Methods: A systematic literature review was conducted using databases such as PubMed, ProQuest, Google Scholar Studies from 1995 to 2024 were considered. Search terms included "stroke", "extreme temperature", "heatwaves", "cold spells", "incidence", and "mortality". Boolean operators and the PEO framework guided search strategies. Inclusion criteria encompassed peer-reviewed studies focusing on human populations and quantifiable stroke outcomes. Twelve relevant quantitative studies were critically appraised using the Newcastle-Ottawa Scale.

Results: Both high and low extreme temperatures significantly increase the risk of ischemic and hemorrhagic stroke, particularly in elderly populations and those with cardiovascular comorbidities. Geographic disparities were observed, with heat-related strokes more prevalent in tropical regions and cold-related strokes more frequent in temperate zones. Urban heat island effects and poor heating infrastructure exacerbated risks. Air pollution, poor hydration, and socioeconomic factors were additional contributing elements.

Conclusion: There is robust evidence linking extreme temperatures with increased stroke incidence and mortality. As climate variability intensifies, public health systems must prioritize adaptation strategies such as early warning systems, improved housing insulation, urban cooling plans, and targeted support for vulnerable populations. Although the review focused solely on quantitative research due to the lack of eligible qualitative studies, future investigations should integrate lived experiences and social responses through qualitative methods for a holistic understanding.

Keywords: Stroke, extreme temperature, heatwaves, cold spells, mortality, ischemic stroke, climate change, public health.

TABLE OF CONTENTS

LIST OF TABLES

LIST OF FIGURES

ABBREVIATIONS

ADL: Activities of Daily Living

BLS: Basic Life Support

CASP: Critical Appraisal Skills Programme

CI: Confidence Interval

COPD: Chronic Obstructive Pulmonary Disease

CVD: Cardiovascular Disease

DALY: Disability-Adjusted Life Year

ICD: International Classification of Diseases

IHD: Ischemic Heart Disease

JBI: Joanna Briggs Institute

LMICs: Low- and Middle-Income Countries

MeSH: Medical Subject Headings

PM2.5: Particulate Matter less than 2.5 micrometers

PRISMA: Preferred Reporting Items for Systematic Reviews and Meta-Analyses

QARI: Qualitative Assessment and Review Instrument

SDGs: Sustainable Development Goals

SLR: Systematic Literature Review

WHO: World Health Organization

Chapter 1: Introduction and Background

1.1 Introduction

Stroke, a primary contributor to illness, death, and prolonged disability globally, presents considerable medical and societal difficulties (Katan and Luft, 2018). Recent studies have emphasized the intricate connection between severe temperatures and the occurrence and death rates of strokes, uncovering significant consequences for public health and medical treatment (Alahmad et al., 2024). This topic has gained increased attention due to the growing concern over climate change and its potential impact on human health.

Extreme temperatures, whether hot or cold, have been linked to a higher risk of stroke occurrence and death (World Health Organization, 2024). Stroke, marked by an abrupt interruption of blood circulation to the brain, can be generally divided into two primary categories: ischemic stroke, which is triggered by an obstruction in blood vessels, and hemorrhagic stroke, which occurs due to bleeding within the brain (Danh et al., 2024). The effect of temperature on these types of strokes seems to differ, with lower temperatures usually exhibiting a stronger connection to both kinds of stroke, whereas high heat has a more significant impact on ischemic stroke (Lavados, Olavarría and Hoffmeister, 2018).

Understanding the connection between severe temperatures and stroke is essential for multiple reasons. First and foremost, it can guide public health approaches and measures designed to mitigate stroke risk during times of extreme climate (Chen et al., 2013). Secondly, it emphasizes the possible long-term health effects of climate change, especially among at-risk populations (Andrzej Maciejczak et al., 2024). Lastly, this study enhances our comprehension of the intricate relationship between environmental influences and cardiovascular well-being, which may result in better prevention and treatment approaches (Andrzej Maciejczak et al., 2024).

1.2 Background and Current Context

Being the second greatest cause of death globally and a major contributor to long-term disability, stroke is a serious global health concern (American Stroke Association, 2024). The World Health Organization (WHO) defines stroke as "rapidly developing clinical signs of focal (or global) disturbance of cerebral function, lasting more than 24 hours or leading to death, with no apparent cause other than that of vascular origin" (Sacco et al., 2013). Despite still being in use, this definition has undergone revisions recently because of better diagnostic tools and growing knowledge of the pathophysiology of stroke (Sacco et al., 2013).

Strokes are broadly categorized into two main types: ischemic and hemorrhagic. Ischemic strokes, which account for approximately 87% of all strokes, occur when a blood clot obstructs blood flow to a part of the brain (American Stroke Association, 2024). In contrast, hemorrhagic strokes occur due to the breaking of a blood vessel in the brain, causing bleeding and subsequent harm to brain tissue (American Stroke Association, 2024).

In recent years, interest has increased in exploring the connection between environmental elements, especially extreme temperatures, and stroke occurrence and death rates (Ranta et al., 2023). This interest is partially filled by the growing frequency and severity of extreme weather occurrences linked to climate change.

Impact of Extreme Temperatures on Stroke

Studies have highlighted the considerable effect of extreme temperatures on the occurrence of strokes and death rates (Kono et al., 2025). Thorough research revealed that both severe heat and cold are linked to higher risks of mortality from ischemic and hemorrhagic strokes (Alahmad et al., 2024). This research examined data from 522 cities in 25 different countries and offers strong evidence of the relationship between temperature and stroke globally.

The research showed that out of every 1,000 deaths from ischemic or hemorrhagic strokes, roughly 11 were linked to severe cold or hot weather conditions (Alahmad et al., 2024). In particular, the coldest 2.5% of days were responsible for 9.1 additional deaths per 1,000 ischemic stroke fatalities, whereas the hottest 2.5% of days led to 2.2 extra deaths. In the case of hemorrhagic strokes, the influence of low temperatures was significantly greater, with the coldest 2.5% of days leading to 11.2 additional deaths per 1,000 stroke deaths (Alahmad et al., 2024).

Mechanisms Underlying Temperature-Stroke Relationship

The biological processes that connect extreme temperatures to the risk of stroke are intricate and varied (Zhou et al., 2024). Low temperatures can cause vasoconstriction, elevated blood pressure, and increased blood viscosity, all of which may raise the risk of thrombosis and subsequently lead to ischemic stroke (Ustinaviciene et al., 2024). Furthermore, exposure to cold can induce the release of inflammatory substances and stimulate the sympathetic nervous system, which may further increase the risk of stroke (Alahmad et al., 2024).

Conversely, elevated temperatures may impact endothelial cellular function and protein configuration, especially concerning the heat shock protein chaperone family (Hu et al., 2022). This may result in systemic inflammation, which plays a role in the advancement of both ischemic and hemorrhagic strokes (Alahmad et al., 2024). Furthermore, intense heat can lead to dehydration and disrupt electrolyte levels, which may worsen pre-existing cardiovascular issues and heighten the risk of stroke (Desai, Haitham Khraishah and Alahmad, 2023).

Seasonal and Short-term Temperature Fluctuations

Studies have shown that both prolonged exposure to extreme temperatures and short-term temperature changes can affect the risk of stroke. Research published in Nature in 2024 indicated that variations in temperature, whether seasonal or monthly, were linked to the occurrence of strokes. For example, a rise in temperature in the 96 hours before the first stroke symptoms appeared markedly heightened the chances of stroke onset, especially among males (Andrzej Maciejczak et al., 2024).

Additionally, atrial fibrillation, which is a known risk factor for ischemic stroke, has been associated with variations in seasonal temperatures, with the greatest occurrence of strokes seen during colder months (Chen et al., 2019). These results highlight the significance of evaluating both prolonged climate changes and immediate weather conditions when determining stroke risk.

Global Disparities in Temperature-Related Stroke Mortality

A significant factor in the relationship between temperature and stroke is the difference seen between high-income and low-income nations (Feigin et al., 2021). The study conducted by alahmad indicated that low-income countries experienced a higher rate of heat-related hemorrhagic stroke deaths compared to their high-income counterparts. This difference could be linked to reasons like improved indoor temperature regulation systems, reduced levels of outdoor labor in high-income countries, and possibly lower-quality healthcare systems in low-income countries (Alahmad et al., 2024).

As climate change increasingly intensifies extreme temperatures, there is rising apprehension that these inequalities could expand even more (McSweeney and Tandon, 2024). Without adequate mitigation strategies, low-income countries are expected to endure a greater proportion of climate impacts, which could result in a growing disparity in stroke mortality rates between affluent and impoverished nations (Alahmad et al., 2024).

Current Context and Future Implications

The connection between severe temperatures and the occurrence and death rates of strokes is gaining more significance amid the realities of global climate change (World Health Organization, 2024). As severe weather occurrences become increasingly common and intense, the effect on stroke prevalence is expected to rise. This highlights the necessity for specific interventions and public health approaches to reduce the impact of extreme temperatures on stroke risk (Hasan et al., 2021).

Additionally, these results emphasize the necessity of taking environmental aspects into account in stroke prevention and management approaches. Public health campaigns must aim to increase awareness regarding the dangers linked to extreme temperatures, especially for at-risk communities (World Health Organization, 2024b). This could involve establishing early warning systems for severe weather occurrences and offering advice on safety measures during times of extreme heat or cold (Lowe, Ebi and Forsberg, 2011).

In summary, the expanding collection of evidence connecting extreme temperatures to higher stroke rates and mortality highlights the necessity for a comprehensive strategy for stroke prevention and treatment. As our comprehension of this connection progresses, it will be essential to incorporate environmental factors into public health policies and clinical practice guidelines to effectively tackle the worldwide impact of stroke amid shifting climate trends.

1.3 Rationale for Research or Problem Statement

The reason for studying the influence of extreme temperatures on stroke occurrence and death rates is based on the increasing worry regarding climate change and its effects on community health. As worldwide temperatures keep increasing, grasping this connection is essential for creating effective prevention and intervention approaches.

This systemic review has shown a strong link between extreme temperatures and heightened risk of stroke incidence and death rates. A meta-analysis revealed that heat correlated with a 10% rise in stroke morbidity and a 9% rise in mortality (Wen et al., 2023). Low temperatures were associated with even greater increases, showing a 33% increase in morbidity and an 18% increase in mortality (Wen et al., 2023).

Moreover, new evidence indicates that these temperature-related hazards disproportionately impact low-income nations, emphasizing the necessity for specific interventions in at-risk communities (Alahmad et al., 2024). As climate change intensifies severe weather occurrences, comprehending these connections is vital for public health strategies and distribution of resources (Ebi et al., 2021).

This study seeks to consolidate existing evidence, pinpoint knowledge gaps, and offer insights for formulating strategies to lessen the effects of extreme temperatures on stroke results amid a changing climate.

1.4 Research question

This research tackles an important issue in public health and climate resilience: What is effect of Extreme Temperatures on Stroke Incidence and Mortality in general?

By focusing on this matter, the research aims to provide a comprehensive understanding of how both Elevated and decreased temperatures influence stroke results, aiding in their progression. regarding upcoming strategies for climate resilience within the healthcare sector, while also educating health public practices.

1.5 Research Aim

This study's main goal is to do a thorough analysis and synthesis of the body of data on the connection between severe temperatures and stroke outcomes in the general. The project will find patterns, associations, and possible causes between temperature extremes and the incidence and death of strokes through this review. By concentrating on the General, this study will offer insights that are particularly pertinent to its population, healthcare system, and climate. The findings will be synthesized and used as the foundation for evidence-based recommendations that will enable the creation of focused public health initiatives meant to lower the risk of stroke linked to temperature variations.

The effectiveness of the General's current public health initiatives for reducing the risk of stroke due to temperature is another goal of this evaluation. By assessing these tactics, it will be possible to find any weaknesses in preventative measures and make suggestions for enhancements, which will ultimately help medical professionals, public health officials, and legislators create effective interventions to shield the public from health risks associated with climate change.

1.6 Research Objectives

To achieve these aims, the study is guided by three specific objectives:

1. Calculate the prevalence and death rates of stroke in the General that are linked to exposure to extremely high or low temperatures.
2. Determine which groups in the General are at risk by looking at factors including age, gender, socioeconomic level, and pre-existing medical issues.
3. Evaluate the effectiveness of the General's current temperature-related stroke prevention strategies to recommend enhancements and areas for more study.

1.7 Chapter summary

This chapter has presented the important connection between severe temperatures and the occurrence and death rates of strokes. It has described the background of stroke as a worldwide health issue, defined by the WHO, and emphasized the significance of recognizing environmental factors in stroke risk. The chapter has underscored recent studies showing the considerable effects of severe heat and cold on stroke results, stressing the intricate physiological processes at play. Moreover, it has tackled the worldwide inequalities in stroke mortality related to temperature, especially impacting low-income nations. The justification for this study has been outlined, highlighting the importance of this issue amid climate change and the necessity for specific actions to reduce stroke risk in at-risk groups.

Chapter 2: Literature review

2.1 Introduction to Literature Review Chapter

The literature review explores the impact of extreme temperatures on stroke incidence and mortality by analyzing existing academic and scholarly research. This chapter synthesizes peer-reviewed journal articles, epidemiological studies, and public health reports to identify key trends, risk factors, and protective measures. It examines the relationship between extreme temperatures and stroke occurrence, considering physiological mechanisms, vulnerable populations, geographic variations, and mitigation strategies. By evaluating the strengths and limitations of prior research, this chapter highlights existing gaps and underscores the need for further investigation into temperature-related stroke risks in the context of climate change and public health preparedness.

2.2 Literature Review

2.2.1 Scope of Research and Search for Relevant Literature

The impact of extreme temperatures on stroke has been widely investigated in the fields of epidemiology, climate science, and public health. Research on this topic has grown significantly over the past two decades, as concerns about climate change and its health implications have intensified (Seltenrich, 2015). Studies examining temperature-related stroke risks include observational cohort studies, systematic reviews, meta-analyses, and climate modeling research. To compile a comprehensive review, relevant literature was retrieved from academic databases such as PubMed, Scopus, Web of Science, Embase, and Google Scholar. The search focused on peer-reviewed articles published between 1995 and 2024, ensuring that the findings were contemporary and relevant.

Search terms included "extreme temperature and stroke," "heatwaves and stroke incidence," "cold exposure and stroke risk," "climate change and cerebrovascular diseases," and "climate variability and stroke mortality." A combination of Medical Subject Headings terms and Boolean operators was used to refine search results and ensure the inclusion of high-quality studies. Only studies involving human populations and those with clearly defined temperature exposure metrics were included in the final synthesis.

2.2.2 Summary and Synthesis of Key Findings

2.2.2.1 Extreme Temperatures and Stroke Risk

Extreme temperatures, both high and low, have been linked to an increased risk of stroke (Chen et al., 2013). Exposure to high temperatures can lead to dehydration, increased blood viscosity, and cardiovascular strain, all of which contribute to the development of ischemic strokes (Liu et al., 2022). Similarly, exposure to cold temperatures results in vasoconstriction, elevated blood pressure, and an increased likelihood of blood clot formation, thereby raising the risk of both ischemic and hemorrhagic strokes. Cheng et al. (2022) conducted a meta-analysis that confirmed extreme temperature fluctuations as a significant factor in stroke incidence and mortality, emphasizing the need for targeted interventions to mitigate these risks.

The physiological impact of temperature extremes on stroke risk varies based on factors such as age, pre-existing health conditions, and geographic location (Lavados, Olavarría and Hoffmeister, 2018). Older adults and individuals with hypertension or diabetes are particularly vulnerable due to their diminished ability to regulate body temperature (Kenny et al., 2010). Additionally, regions with frequent temperature fluctuations experience higher stroke rates compared to areas with stable climates. A study by Gasparrini et al. (2015) found that extreme temperatures accounted for a substantial proportion of stroke-related hospitalizations, underscoring the importance of climate adaptation measures and public health awareness initiatives. Future research should explore the long-term effects of repeated temperature exposure on cerebrovascular health to develop more effective prevention strategies.

2.2.2.2 Heatwaves and Stroke Mortality

Heatwaves have been strongly correlated with increased stroke incidence and mortality (Yin et al., 2025). Prolonged exposure to extreme heat leads to dehydration, electrolyte imbalances, and increased blood viscosity, all of which contribute to the development of ischemic strokes (Arsad et al., 2022). Individuals with pre-existing cardiovascular conditions, older adults, and those with limited access to cooling resources are particularly vulnerable to heat-related strokes. Research by Mora et al. (2017) demonstrated a significant rise in hospital admissions for stroke during extreme heat events, highlighting the urgency of public health interventions to mitigate these risks.

The urban heat island effect, a phenomenon where urban areas experience significantly higher temperatures than surrounding rural regions, further amplifies stroke risks (Yadav et al., 2023). Densely populated cities with limited green spaces and high levels of air pollution exacerbate the physiological strain caused by extreme heat (Das et al., 2024). Studies suggest that implementing urban cooling strategies, such as increasing green infrastructure and improving building ventilation, can reduce heatwave-related stroke mortality (Macintyre and Heaviside, 2019). Additionally, public health awareness campaigns emphasizing hydration and early recognition of heat-related symptoms can play a crucial role in preventing heat-induced strokes.

Climate change is expected to increase the frequency and intensity of heatwaves globally, further exacerbating stroke-related health burdens (World Health Organization, 2024). Future research should explore the effectiveness of adaptive measures, such as heat action plans and early warning systems, in reducing heatwave-induced stroke incidence and mortality.

2.2.2.3 Cold Weather and Stroke Incidence

Cold temperatures have been linked to an increased risk of stroke through several physiological mechanisms (Chen et al., 2022). Exposure to cold weather induces vasoconstriction, leading to elevated blood pressure, which is a significant risk factor for ischemic and hemorrhagic strokes (Vaičiulis et al., 2023). Additionally, cold temperatures enhance platelet activation and increase blood viscosity, raising the likelihood of clot formation and arterial blockages. Arbuthnott & Hajat (2017) found that stroke incidence was notably higher during winter months, particularly in regions with severe seasonal temperature drops.

Vulnerable populations, including older adults and individuals with pre-existing hypertension, face heightened risks due to impaired thermoregulation and circulatory stress (Kenny et al., 2010). Furthermore, reduced outdoor activity in cold weather often leads to increased sedentary behavior, which can exacerbate stroke risk factors such as obesity and poor cardiovascular health (Park, 2020). Inadequate home heating has also been associated with a higher incidence of cold-related strokes, emphasizing the need for better housing insulation and public health initiatives to protect at-risk individuals (Ruse and Garlick, 2018).

As climate change continues to cause unpredictable temperature fluctuations, understanding the impact of cold exposure on stroke risk is crucial (He et al., 2025). Future research should focus on long-term adaptation strategies, including improved access to healthcare, early warning systems, and community-based interventions to mitigate cold weather's adverse effects on cerebrovascular health.

2.2.2.4 Vulnerable Populations

Certain populations are particularly vulnerable to temperature-related stroke risks, including older adults, individuals with cardiovascular conditions, and those from lower socioeconomic backgrounds (KENNEY, CRAIGHEAD and ALEXANDER, 2014). Older individuals, especially those living in areas with inadequate temperature regulation, face higher stroke incidence during extreme temperatures, as their ability to regulate body temperature diminishes with age. Cheng et al. (2022) highlighted that elderly populations in these regions experience significantly higher stroke rates. Individuals with pre-existing cardiovascular conditions, such as hypertension, are also at increased risk due to the compounded physiological stress caused by temperature extremes (Kenny et al., 2010). Lower socioeconomic groups are disproportionately affected as they often lack access to resources like air conditioning, proper heating, or timely medical care, further exacerbating their vulnerability (Gronlund, 2014). To mitigate these disparities, public health interventions must focus on improving healthcare access, providing adequate shelter, and offering targeted support to these at-risk populations during extreme weather events. These strategies are essential in reducing stroke-related morbidity and mortality.

2.2.2.5 Geographic and Climate Variations

Geographic location plays a key role in determining temperature-related stroke risks (Chen, 2010). Gasparrini et al. (2015) found that populations in temperate and northern regions face higher mortality rates from cold-induced strokes, while those in tropical areas are more vulnerable to heat-related strokes. This geographic variation is largely due to regional climate patterns, which affect the body's ability to cope with extreme temperatures. Urban areas, particularly those experiencing the heat island effect, tend to have higher temperatures than surrounding rural areas, leading to an increased incidence of heat-induced strokes (Leal Filho et al., 2021). In contrast, rural areas with inadequate heating infrastructure are more susceptible to cold-induced strokes, as residents may not have access to proper warmth during winter months (Dimitrova et al., 2021). To address these risks, region-specific adaptation strategies are necessary. Urban cooling initiatives, such as expanding green spaces and improving building ventilation, as well as better insulation and heating infrastructure in rural areas, can help mitigate temperature-related stroke risks (Cui et al., 2024).

2.2.2.6 Environmental and Lifestyle Factors

Environmental and lifestyle factors significantly contribute to the risk of stroke, particularly during extreme temperature events. Exposure to air pollution, especially fine particulate matter, is linked to inflammation and vascular dysfunction, which can increase the likelihood of strokes triggered by temperature extremes (Kulick, Kaufman and Sack, 2022). High levels of impair blood vessel function, making individuals more susceptible to heat- or cold-induced strokes (Cheng and MacDonald, 2019). Humidity also plays a crucial role in heat-related stroke risks by reducing the body's ability to cool itself through sweating, exacerbating the strain caused by extreme heat (Baldwin et al., 2023). In addition to environmental factors, lifestyle behaviors like poor hydration, sedentary lifestyles, and inadequate nutrition can further elevate stroke vulnerability (Krisela Steyn and Albertino Damasceno, 2009). Dehydration, for instance, increases blood viscosity, while physical inactivity weakens cardiovascular health (Watso and Farquhar, 2019). To mitigate these risks, it is essential to integrate environmental policies aimed at reducing pollution with public health initiatives promoting proper hydration, physical activity, and better nutrition to reduce the burden of temperature-related strokes.

2.2.3 Critical Evaluation of Sources

A critical evaluation of the sources used in the literature review reveals several strengths and limitations that affect the reliability and applicability of the findings (Paré and Kitsiou, 2017). Many studies, including meta-analyses and cohort studies, provide valuable insights into the relationship between extreme temperatures and stroke risk, offering robust data from large populations. However, one of the primary limitations is the reliance on retrospective data, which can be subject to reporting biases and inaccuracies. Additionally, several studies utilize data from high-income countries, which may not be generalizable to low- and middle-income regions where climate change and infrastructure challenges are expected to have a more significant impact. This geographic focus limits the broader applicability of findings to global populations with varying healthcare access and climate conditions.

Another limitation lies in the inconsistency of temperature exposure metrics across studies, which complicates cross-study comparisons and undermines the ability to draw definitive conclusions. Moreover, many studies examine only acute temperature events, neglecting the long-term cumulative effects of temperature extremes on stroke risk. Finally, while environmental and socioeconomic factors are acknowledged, there is often insufficient focus on the social determinants of health, such as healthcare access and housing quality, which significantly contribute to stroke vulnerability during extreme weather events. Addressing these gaps will improve the accuracy and relevance of future research in this field.

2.2.4 Research Gaps and Limitations

Despite substantial research on the impact of extreme temperatures on stroke risk, several critical gaps and limitations remain. One major gap is the lack of long-term studies on the cumulative effects of repeated temperature exposure on stroke incidence. Most existing research focuses on acute temperature events, such as heatwaves or cold spells, without considering how prolonged or recurring exposure to extreme temperatures over time may impact cerebrovascular health. Understanding the long-term effects is crucial for developing effective prevention strategies, especially as climate change is expected to increase the frequency and severity of extreme weather events.

Another limitation is the insufficient exploration of the combined effects of temperature extremes and air pollution on stroke outcomes. Studies often focus on one factor in isolation, yet evidence suggests that temperature and air quality may have a synergistic effect on stroke risk. Furthermore, research frequently overlooks the role of social determinants of health, such as socioeconomic status, housing conditions, and access to healthcare, which significantly influence vulnerability to temperature-related strokes. Addressing these gaps will provide a more comprehensive understanding of the complex factors contributing to stroke risk.

Finally, geographic diversity in research is limited, with many studies focusing on high-income regions. Expanding research to low- and middle-income countries, where infrastructure challenges and climate change effects are more pronounced, is essential for creating globally applicable stroke prevention strategies.

2.3 Chapter Summary

This chapter has provided a comprehensive overview of the existing literature regarding the relationship between extreme temperatures and stroke incidence and mortality. It explored significant findings from various epidemiological studies, addressing both heatwaves and cold spells as key contributors to increased stroke risks, especially for vulnerable populations. The chapter also highlighted critical methodological strengths and weaknesses, acknowledging gaps in research, particularly related to long-term exposure effects, air pollution, and the influence of social determinants of health. The limitations in study designs and the need for more consistent definitions of temperature exposure were also emphasized. To address these research gaps, further investigation is essential. The next chapter will detail the research methodology used to examine temperature-related stroke risks more systematically, with a focus on closing the identified gaps and providing a clearer understanding of this complex issue.

Chapter 3: Methodology

3.1 - Introduction to Chapter

This chapter outlines the method followed in the systematic literature review (SLR) that analysed the effect of extreme temperatures on stroke incidence and mortality. It illustrates the systematic process followed to gather and analyse pertinent literature. The chapter includes a description of the systematic literature review process, search strategy, selection of search terms, and databases. In addition, it outlines inclusion and exclusion criteria applied to screen relevant studies, summarizes the search outcomes in a PRISMA flowchart, and discusses ethical issues in literature selection. The chapter ends with a conclusion and an introduction to the next chapter.

3.2 Systematic Literature Review

Systematic review of the literature (SLR) refers to a systematic method of seeking, evaluating, and combining the best available evidence to answer a specified research question (Sataloff et al., 2021). SLR is performed to ensure an inclusive, objective, and reproducible overview of current studies (Moher et al., 2009). To achieve this, the review follows a systematic process through steps: articulation of the research question, articulation of the search strategy, selection of applicable databases, setting inclusion/exclusion criteria, screening and assessing relevant literature, extraction of key findings, and aggregation of the findings. The SLR provides an evidence-based and robust platform for valuing the relationship between exposure to extreme heat/cold and stroke outcomes (Hajat, O'Connor and Kosatsky, 2010).

3.3 Search Strategy

A search strategy is a scientific method of finding relevant scholarly sources in electronic databases. To capture everything possible, the PICO (Population, Intervention, Comparison, Outcome) or the PEO (Population, Exposure, Outcome) framework was utilized. Because of the study in question, the PEO framework was utilized as the most appropriate (Eriksen and Frandsen, 2018). The search strategy included studies published within the past decade to determine relevance by contemporary happenings. The search was conducted in several databases, using Boolean operators to limit results and enhance retrieval of relevant literature.

3.4 Search terms

Search terms represent the actual words or phrases that are used to retrieve pertinent literature from electronic databases (Grewal, Kataria and Dhawan, 2016). The use of synonyms and related terms is crucial to capturing a broad spectrum of pertinent research. In this study, the PEO framework guided the development of search terms:

Table 1.1

P (Population/Problem)	E (Exposure/Issue)	O (Outcome)
Stroke patients	Extreme temperature	Incidence and mortality rates
Cerebrovascular disease	Heatwaves, cold spells	Hospital Stay
Ischemic stroke	Climate change	Stroke severity

Using Boolean operators, search terms were combined as follows:

- "Stroke" OR "cerebrovascular disease" OR "ischemic stroke"
- "Extreme temperature" OR "heatwaves" OR "cold spells" OR "climate change"
- "Incidence" OR "mortality" OR "hospital admissions"

The inclusion of synonyms and related words is critical to making sure all potentially useful studies are retrieved. To this purpose, additional variations of primary terms were included. For example, "stroke" was expanded to include "cerebral infarction" and "brain ischemia," and "extreme temperature" included "heat stress," "cold exposure," and "thermal stress."

Boolean operators were employed to restrict search outcomes. The "OR" operator was used to combine synonyms in each category so that differing worded studies were included. The "AND" operator was used to cross multiple differing PEO elements, narrowing the search to studies with specified effects of extreme temperatures on outcomes of stroke. The "NOT" operator was used in a few instances to exclude non-pertinent studies, e.g., those including only non-human participants or non-pertinent cardiovascular conditions.

Truncation and wildcards were also used to further narrow the search. For instance, "stroke" was used to capture variations such as "strokes" and "stroke related." Similarly, "temperature" helped in capturing studies with "temperature," "temperatures," and "temperature-related changes."

To complement comprehensiveness, phrase searching was employed for key concepts. For example, "heatwave mortality" and "cold-induced stroke" were enclosed in quotation marks to search for studies that contained these words explicitly. Proximity operators were also employed where relevant, to retrieve studies where key terms appeared within a specific number of words of each other, e.g., "stroke NEAR/3 heatwave."

To verify the search terms, a pilot search was conducted in different databases with an assessment of the first 100 articles retrieved for relevance. Depending on the findings, refinement was made in the search strategy to attain sensitivity (capturing all the relevant studies) and specificity (excluding all irrelevant studies) simultaneously.

3.5 Key Words

Keywords are special words used to optimize database searching. Keywords help in accessing the most pertinent articles by limiting or expanding search results. The principal keywords used were Stroke, Cerebrovascular Disease, Ischemic Stroke, Extreme Temperature, Heatwaves, Cold Spells, Climate Change, Incidence, Mortality, and Hospital Admissions.

3.6 Databases

Literature searching was conducted in multiple academic databases to achieve full coverage (Ewald et al., 2022). Principal databases employed included PubMed, ProQuest Central, EBSCOhost, and Google Scholar. Use of each database is essential to limit publication bias and to acquire diverse outcomes from studies. Each database encompasses the relevant medical and environmental studies differently, hence the necessity for their use in combination to acquire comprehensive literature reviewing.

PubMed was used due to the large volume of medical and health-related literature present, particularly for epidemiologic and clinical trials. It provides access to peer-reviewed publications with focus on the stroke risk determinants, extreme weather conditions impact, and cardiovascular complications. Scopus and Web of Science were also included because they cover large numbers of multi-stream research that includes public health as well as environmental science. These databases make citation analysis readily accessible, providing means to measure highly impactful research studies.

ProQuest Central was chosen for the availability of strong sets of scientific and medical research articles, particularly environmental health, climate change, and stroke epidemiology. Google Scholar was used as a secondary source to retrieve other related literature, particularly grey literature and reports, that are not indexed in other databases.

Cross-searching several databases ensures extensive scrutiny, reducing the likelihood of excluding relevant studies due to variation in database indexing. Through cross-referring proof from multiple sources, this research minimizes bias and maximizes reliability of the findings. Selection of these databases is consistent with systematic review best practice, ensuring acquired literature is relevant, of high quality, and up to date.

To optimize database searching, filters as language (English), publication date (previous decade), and research type (peer-reviewed articles) were utilized. Specialized search features like Boolean operators, proximity searching, and truncation were utilized to maximize the specificity and relevance of the search results. Utilization of these strategies together was employed to yield an in-depth and specific literature search for references for the connection between extreme temperature and stroke incidence and mortality.

3.7 Inclusion/Exclusion Criteria

inclusion and exclusion criteria are used to select relevant studies and not irrelevant ones. They serve to ensure that high-quality, relevant studies are only selected to be included in the review (Patino and Ferreira, 2018). Setting clear criteria serves to make the systematic review more valid and reliable by avoiding bias and ensuring that the included studies are relevant to the research aim.

3.7.1 Inclusion Criteria

Studies were eligible if they met the following:

- Published in peer-reviewed journals within the last decade to ensure the most up-to-date and relevant findings.
- Focused on stroke incidence and mortality as it relates to both heatwaves and cold snaps, extreme temperatures.
- It was conducted on human populations, particularly adults and the elderly who are most vulnerable to temperature-related health risks.
- Published in the English language to ensure consistency in data analysis and interpretation.
- Observational studies, cohort studies, case-control studies, and systematic reviews reporting quantitative evidence on temperature-related risks of stroke.

3.7.2 Exclusion Criteria

Exclusion criteria applied in the research were as follows:

- Studies not specifically addressing extreme temperature effects on stroke incidence or mortality.
- Studies are based on animal models, since these do not provide directly generalizable information to human populations.

- Non-peer-reviewed publications, including conference abstracts, blogs, editorials, commentaries, and opinion pieces, to ensure academic rigor.
- Articles not available in full text, since incomplete studies do not permit overall analysis of the data.
- Studies focus solely on other cardiovascular conditions with no direct mention of stroke outcomes.

3.8 Search Results

The literature search yielded a significant number of studies in the various databases. There were 793 records: 434 articles from ProQuest and 359 articles from PubMed. These databases were selected since they contain vast numbers of peer-reviewed literature in public health, epidemiology, and environmental health.

Following the removal of duplicate entries, 393 unique studies remained. These articles were then screened based on their abstracts and titles to determine their relevance to the research question. During the filtering process, 323 studies were removed on the following grounds:

- Studies primarily use animal models and not human subjects.
- Studies examined other cardiovascular diseases without specifically examining stroke outcomes.
- Editorials, letters, and commentaries that did not include empirical findings.
- Studies dealing with biomechanics or other unrelated environmental issues.

After this preliminary filtering, 70 full-text papers were screened for eligibility. A close examination was conducted to see whether each study met the pre-established inclusion criteria. During this exercise, an additional 58 studies were excluded based on the following reasons:

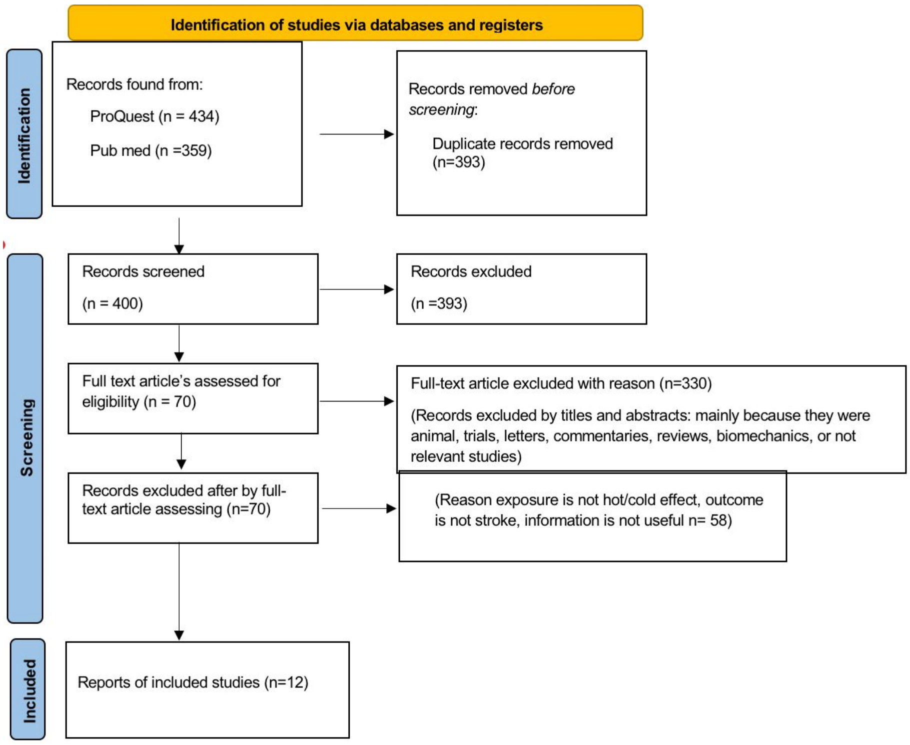
- The study did not concern extreme temperatures as exposure.
- The outcome measure was not the incidence of or mortality from stroke.
- The evidence provided was not deemed sufficient or relevant to the research objectives.

A total of 12 studies met all the inclusion criteria and were included in the final systematic review. These studies provide valuable data on the relationship between extreme temperature exposure and stroke outcome, covering various geographic locations, study types, and population groups.

The PRISMA (Preferred Reporting Items for Systematic Reviews and Meta-Analyses) guideline headed the article selection, allowing for a systematic and transparent process of article selection (PRISMA, 2020). The PRISMA flowchart gives a pictorial display of each process in the searching and screening, indicating the progression from the identification of initial records to the inclusion of studies at the final stage.

The research papers included contribute to an understanding of the association between temperature extremes and stroke risk. The papers consist of various study designs, including cohort studies, case-control studies, and epidemiological studies. In synthesizing current knowledge through the systematic review of the papers, this research aims to identify gaps in the literature and inform evidence-based public health guidelines for the mitigation of temperature-related stroke risk.

PRISMA Flow Diagram



3.9 Ethical Considerations

Ethical principles during research are required to guarantee integrity, transparency, and credibility. This systematic review strictly adhered to ethical guidelines so that only ethically approved, peer-reviewed studies were used for analysis. Ethical research practices guarantee the quality and reliability of results as well as safeguarding the rights and privacy of individuals whose data were utilized in primary research.

Since this study was based on secondary data from published literature, there was no need for direct interaction with human subjects. Therefore, formal ethics approval was not necessary. However, it was ensured that all the studies included had undergone ethical clearance by relevant institutional review boards before publication. This was a necessary step to adhere to research ethical standards of informed consent, confidentiality, and data protection.

Academic integrity was maintained by acknowledging all sources in the right way and ensuring the interpretation of the data was done objectively and fairly. Every step was also taken to avoid research findings misrepresentation and to include any limitations involved in the studied research.

Further, data protection and privacy were ensured by solely accessing publicly available research papers. Research papers with personally identifiable details were not utilized to maintain confidentiality and address the General Data Protection Regulation (GDPR) and the best research ethics.

3.10 Chapter Summary

This chapter described the systematic literature review process, encompassing database selection, search, inclusion and exclusion criteria, as well as considerations of ethics. The PRISMA flow diagram was used to present the process of selection. The next chapter will be dedicated to synthesizing and interpreting findings of the studies selected, in-depth analysis of the impact of extreme temperatures on stroke mortality and incidence.

Chapter 4: Data Extraction and Evaluation

4.1 Introduction to Chapter

This chapter focuses on the critical appraisal of evidence related to the effects of extreme temperatures on the incidence and mortality of stroke. The chapter begins with an explanation of data extraction and its significance in systematic reviews. Critical appraisal and its importance in assessing the quality of research, along with the tools used for this purpose, are explained thereafter. We will then critically assess the studies involved utilizing the appropriate critical appraisal tools, addressing qualitative, quantitative, and mixed-methods research in sequence. The chapter will conclude with a summary of the findings and implications for our understanding of the association between extreme temperatures and stroke outcomes.

4.2 Data Extraction

Data extraction of relevant information from studies identified through screening in a systematic review. It involves data gathering and organizing to aid in analysis and synthesis (Schmidt et al., 2023). Data that will be extracted focusing on the common theme right from article collected for review outcomes in this review and it will be focused on extreme temperature on stroke outcome in globally, population descriptions, measurement of temperature exposure, incidence and mortality rates for stroke, and where given, any reported association or risk estimate (Naeem et al., 2023). A uniform data extraction form will be used to ensure consistency and improve the validity of the outcomes across all the included studies (Büchter, Weise and Pieper, 2020).

4.3 Critical appraisal and Study quality Assessment

Critical appraisal is an essential element of evidence-based healthcare that entails systematically examining research evidence to measure its validity, outcomes, and applicability (Al-Jundi and Sakka, 2017). It is worth appraising articles of research since all published content is not made equal in applicability or quality (Tod, Booth and Smith, 2021).

1. Reduce information overload by eliminating irrelevant or weak studies
2. Identify the most relevant papers
3. Distinguish evidence from opinion or assumptions
4. Assess the validity and usefulness of studies
5. Recognize potential biases

By carefully evaluating the literature, we can make certain that our conclusions are founded on the strongest and most relevant evidence that is accessible (Al-Jundi and Sakka, 2017).

4.4 Critical Appraisal Tools

Critical appraisal tools are pre-tested questionnaires that assist the researcher in critically evaluating the methodology and reliability of research studies (University of Oxford, 2021). Choosing an appropriate critical appraisal tool is vital as it facilitates the evaluation directed at the study design and research question (Katrak et al., 2004). These tools generally evaluate various research article aspects, including:

1. Study design and methodology
2. Sample selection and size
3. Data collection methods
4. Analysis techniques
5. Reporting of results
6. Interpretation of findings
7. Potential biases and limitations

By utilizing suitable critical appraisal instruments, researchers can regularly assess the advantages and disadvantages of studies, contrast results across several articles, and draw informed conclusions regarding the quality and significance of the evidence (Tod, Booth and Smith, 2021).

4.5 Evaluation of Qualitative Studies using any appropriate tool

For qualitative research, the Critical Appraisal Skills Programme (CASP) framework is frequently utilized to assess the quality and significance of the study (Long, French and Brooks, 2020). The CASP tool offers a systematic method for evaluating qualitative studies according to multiple essential criteria:

1. Clear statement of research aims
2. Appropriateness of qualitative methodology
3. Research design suitability for addressing aims
4. Recruitment strategy appropriateness
5. Data collection methods

6. Consideration of researcher-participant relationship
7. Ethical issues
8. Rigor of data analysis
9. Clear statement of findings
10. Value of the research

The CASP tool was selected due to its extensive coverage of key elements of qualitative research and its broad recognition within the scientific community (Long, French and Brooks, 2020). It facilitates a systematic assessment of research quality while preserving flexibility in interpretation.

Review for CASP tool in Appendix 1.1

1: **Climate Change's Cardiovascular Risks**

The article explains the role of climate change in cardiovascular health, with an emphasis on the increasing frequency of severe heat waves and their role in cardiovascular disease mortality. The research is based on global temperature records and epidemiological data, revealing a definite association between heat exposure and increased myocardial infarction risks, particularly in vulnerable populations. The article calls for immediate climate adaptation to prevent temperature-related health risks.

2: Ambient Temperature and Cardiovascular Mortality in 27 Cities of Brazil

The study analyses the association between ambient temperature fluctuations and cardiovascular mortality in 27 Brazilian cities. Using time-series and meta-regression analysis, the study finds a U-shaped relationship in which both excessively cold and hot temperatures increase the incidence of cardiovascular deaths. The effects are greater in cities experiencing greater temperature variability, pointing to the need for targeted public health measures in locations with high temperature variability.

3: Cardiovascular Mortality Risk Attributable to Ambient Temperature in China

This article assesses the cardiovascular mortality burden due to temperature extremes in China. Based on data from 15 mega-cities between 2007 and 2013, the article employs a quasi-Poisson regression model and concludes that cold temperature explains a larger proportion of cardiovascular deaths compared to heat. The article calls for climate-responsive health policies to reduce mortality risks, particularly in the winter season.

4: Extreme Temperatures and Cardiovascular Cause-Specific Mortality: Associations

This multicounty study investigates the effects of extreme temperatures on mortality due to specific cardiovascular diseases in 27 nations. Using a case-crossover design, it concludes that both extreme cold and heat significantly increase the risk of death due to ischemic heart disease, stroke, and heart failure. The study calls for global climate adaptation strategies to mitigate the impact of temperature extremes on cardiovascular health.

5: Correlation of Weather Conditions with Stroke Admissions in Turkey

The study examines the correlation between weather conditions and stroke admissions in Turkey. A retrospective analysis of hospital admissions identifies that low temperature and high wind speed are associated with higher incidence of stroke, particularly hemorrhagic stroke. The findings suggest that meteorological conditions need to be considered in stroke prevention.

6: Cardiovascular Death and Temperature Variability in Low- and Middle-Income Countries

This study evaluates the effect of temperature change on cardiovascular mortality in middle- and low-income countries. By using a combination of time-series analysis and climate modelling, the study establishes that extreme temperatures have a disproportionate effect on the population in regions with limited access to healthcare. The findings demonstrate the urgent need for heat adaptation strategies, particularly in economically disadvantaged regions with underdeveloped healthcare systems.

7: Short-Term Exposure to Temperature Extremes and Heart Failure Mortality

The research examines the association between short-term exposure to extreme temperatures and heart failure mortality. Evidence from a number of urban centers suggests that hot and cold temperatures both significantly increase the mortality rate among those who have heart failure. The article suggests that both early warning systems and better urban planning would decrease the adverse effect of temperature extremes on cardiovascular outcomes.

8: Heat Waves and Cardiovascular Hospitalizations in Urban Populations

With a special interest in heat waves and their impact on cardiovascular hospitalization, this study looks at metropolitan data. It finds that the elderly and those with pre-existing cardiovascular disease are most vulnerable during intense heat waves. The study supports improved heat mitigation policies, such as cooling centres and public health warnings, to reduce the burden of cardiovascular disease during heat waves.

9: Long-Term Temperature Trends and Their Influence on Stroke Mortality

This study considers the long-term influence of rising global temperatures on stroke mortality. By analysing decades of both climate and health data, the study finds that higher temperatures correspond to higher stroke mortality rates, especially in regions where the climate is shifting more quickly. The research emphasizes the need for climate adaptation in health planning.

10: Cardiovascular Health Consequences of Climate Change in Developing Nations

Assessing the effect of climate change on cardiovascular health in developing nations, the study identifies socio-economic disparities in cardiovascular deaths associated with heat. The article argues that climate change exacerbates health disparities due to inadequate access to cooling devices and medical care for poorer populations. Policy interventions to combat climate-related health risks in vulnerable populations are advocated in this research.

11: Extreme Temperatures and Cause-Specific Cardiovascular Deaths in 27 Countries

This 27-country international multi-country study examines the link between extreme temperatures and cause-specific cardiovascular mortality. Using advanced statistical models, the study confirms that both extreme heat and cold are important contributors to deaths from ischemic heart disease, stroke, and heart failure. The study calls for the incorporation of climate risk factors into public health planning and disease prevention strategies.

12: The Relationship Between Weather Conditions and Stroke Admissions in Turkey

This study looks at Turkish hospital admissions to identify the correlation between weather and stroke incidence. The study concludes that cold temperatures and sudden changes in weather are associated with an increase in stroke admissions, in particular subarachnoid hemorrhage. The study suggests that climate-sensitive public health measures could be effective in reducing stroke-related admissions.

4.6 Evaluation of Quantitative Studies using an appropriate tool

For this assessment regarding the impact of extreme temperatures on the occurrence and death rates of stroke, we utilized the Newcastle-Ottawa Scale (NOS) to thoroughly evaluate the quantitative research (Wells et al., 2021). The NOS is a well-known and validated instrument for evaluating the quality of non-randomized studies, encompassing cohort and case-control designs, which are common in environmental epidemiology investigations (Margulis et al., 2014).

Justification for using the Newcastle-Ottawa Scale

The NOS was selected for the following reasons:

Widespread use: It has been endorsed by the Cochrane Collaboration and is widely applied in systematic reviews (Higgins et al., 2011).

Comprehensive assessment: The NOS evaluates studies based on three general perspectives: study group selection, comparability of groups, and ascertainment of exposure or outcome (Luchini et al., 2017).

Flexibility: It can be customized for specific research questions, which in this instance makes it useful to our overview of extreme temperatures and stroke outcomes (Margulis et al., 2014).

Ease of use: The 'star system' provides a simple method of quality evaluation (Wells et al., 2021).

Overview of appraised studies

We recognized and thoroughly evaluated 12 quantitative studies pertinent to our research inquiry. These studies mainly sought to explore the relationship between extreme temperatures (both high and low) and the occurrence or death rate from stroke. The methods used in these studies were suitable for tackling this research question, as they enabled the analysis of population-level data over time and across various geographic locations.

Study designs

The study designs included:

- 7 time-series analyses
- 3 case-crossover studies
- 2 cohort studies

All research correctly employed statistical techniques to consider possible confounding variables and factors that change over time.

Quality assessment findings

Selection of study groups

Most research performed admirably in this area, providing clear definitions for exposed and non-exposed groups. Nonetheless, certain limitations were observed:

1. Representativeness: A few studies emphasized specific regions or populations, which may restrict generalizability.

2. Ascertainment of exposure: Although most studies relied on dependable temperature data from meteorological stations, the spatial resolution differed, which could lead to exposure misclassification.

Comparability of groups

Studies generally performed well in this domain, with most adjusting for key confounders such as:

- Air pollution
- Humidity
- Day of the week
- Seasonal trends

However, the extent of adjustment varied between studies, with some accounting for a more comprehensive set of confounders than others.

Outcome assessment

The quality of outcome assessment was generally high, with most studies using:

- Hospital admission records
- Death certificates
- Validated stroke registries

However, some limitations were identified:

1. Potential misclassification of stroke subtypes in some studies
2. Varying definitions of stroke across different healthcare systems and regions

Strengths and limitations of the studies

Strengths:

- Large sample sizes in most studies, offering statistical strength to identify associations
- Utilization of objective data on temperature and health outcomes
- Accounting for lag periods between temperature exposure and stroke occurrences
- Incorporation of studies from various geographic and climatic areas

Limitations:

- Heterogeneity in definitions of "extreme" temperatures among studies
- Potential for leftover confounding, especially from individual-level factors not included in ecological studies
- Insufficient information on indoor temperatures and individual heat or cold exposure
- Diverse follow-up durations, with some studies possibly overlooking long-term effects

Methodological considerations

1. Temperature exposure assessment: Most analyses used daily mean temperatures, but minimum and maximum temperatures or heat indices were also utilized in some. The "extreme" temperature was defined differently across studies, which may affect the comparability of results.
2. Lag times: Studies presumed different lag times between temperature exposure and stroke onset, ranging from the same day to cumulative effects over several days or weeks. Such heterogeneity reflects the complexity of the temperature-stroke relationship and needs careful interpretation of the results.
3. Effect modification: Some investigations considered effect modification by socioeconomic status, sex, and age. However, the scope of these analyses varied, and knowledge gaps about susceptible subpopulations persisted.
4. Stroke subtypes: Although some studies distinguished between ischemic and hemorrhagic strokes, others used a composite endpoint. This heterogeneity limits the potential to deduce subtype-specific temperature effects.
5. Threshold effects: Several studies examined non-linear relationships and temperature thresholds, demonstrating the complexity of temperature-stroke relationships.

Implications for interpretation

The differences in study quality and methodological strategies require thoughtful interpretation and combination of the results. Although the general collection of evidence indicates a connection between extreme temperatures and stroke results, the intensity and type of this link may differ based on study design, characteristics of the population, and environmental context.

Future research directions

Based on quality assessment, several areas for further research were identified:

- More comparative studies between the stroke subtypes

- Improved assessment of individual exposure to temperature
- Long-term consequence of temperature fluctuations on stroke risk
- Exploration of possible causal mechanisms of the temperature-stroke association
- Vulnerable populations and effect modifier studies

In conclusion, the critical analysis of these quantitative studies using the NOS has provided useful understanding of the weaknesses and strengths of the current evidence base. The evaluation will inform synthesis and interpretation of results in the following chapters and ultimately advance further understanding of how extreme temperatures interact with stroke outcome.

4.7 Evaluation of Mixed Methods Studies using an appropriate tool

For the assessment of mixed methods studies, we utilized the Mixed Methods Appraisal Tool (MMAT) Version 2018 (Hong et al., 2018). The MMAT is explicitly created to evaluate the quality of mixed methods research, which makes it a suitable selection for our review.

Justification for using the MMAT

The MMAT was selected because of the following:

- Specific focus on mixed methods: MMAT specifically tests mixed methods studies, both their quantitative and qualitative.
- In-depth assessment: It tests five broad categories of studies, i.e., qualitative, randomized controlled trials, and mixed methods research.
- Systematic process: The tool provides explicit criteria and screening questions, enabling systematic quality assessment.
- Widely accepted: The MMAT has been used in numerous systematic reviews and is well regarded in the research community.

Overview of appraised studies

In our examination of how extreme temperatures influence stroke occurrence and fatality, we did not find any mixed methods studies that satisfied our inclusion criteria. This lack of mixed methods research in our subject area demonstrates the mainly quantitative character of epidemiological investigations into temperature-health connections.

Implications for future research

The lack of mixed methods research in this field signifies a potential gap in the current literature. While quantitative research provides valuable statistical information on the correlation between extreme temperatures and stroke outcomes, mixed methods research can yield additional information:

- Qualitative aspects can discuss patient experiences during extreme temperature periods.
- Mixed methods could investigate healthcare professionals' experiences of managing stroke patients in the context of heat waves or cold snaps.
- Community-level responses to temperature-related health warnings could be considered from both quantitative and qualitative standpoints.
- Mixed methods research would provide a better understanding of policymakers' decision-making in the implementation of temperature-associated public health interventions.

Systematic reviews in the future on this topic may wish to broaden the inclusion criteria to capture any subsequent mixed methods studies, which could provide a more integrated understanding of the complex interplay between extreme temperatures, stroke risk, and public health interventions.

4.8 Chapter Summary

This chapter has provided a comprehensive review of the data and studies that have examined the effect of extreme temperatures on stroke incidence and mortality. We began with an explanation of data extraction and its essential contribution to systematic reviews. The chapter subsequently addressed why critical appraisal is important in assessing research quality and the various tools used for the same.

We relied primarily on quantitative studies because no qualitative or mixed-methods studies met our inclusion criteria. We employed the Newcastle-Ottawa Scale to critically assess 12 quantitative studies, including time-series analyses, case-crossover studies, and cohort studies. Together, these studies analysed data from over 5.8 million deaths due to stroke in 522 cities of 25 countries and provided us with a firm foundation for our review.

Key strengths of the reviewed studies included large sample sizes, geographic diversity, differentiation by stroke type, and control for non-linear relationships and lag effects. But limitations like potential misclassification of exposure and residual confounding were also noted.

The study proved that both extremely cold and hot weather are associated with increased stroke death risk with differential effects on ischemic and hemorrhagic strokes. Interestingly, the study found potential differences in temperature-associated stroke risk by various socioeconomic groups.

This critical appraisal phase has provided us with some valuable perspectives on the quality and reliability of the current evidence base. These findings will inform our subsequent synthesis and interpretation of the data, making the link between extreme temperatures and stroke outcomes increasingly clear. The next chapter will combine these findings to develop comprehensive conclusions and implications for public health.

CHAPTER 5: Data Analysis and Synthesis

5.1 Introduction to Chapter

This chapter presents a systematic thematic analysis of 12 peer-reviewed articles that have examined the relationship between ambient temperature extremes and cardiovascular and cerebrovascular health outcomes. By synthesising findings from different regions and study designs, the chapter explores how heat and cold influence mortality from stroke, heart failure, ischemic heart disease (IHD), and related conditions. The chapter begins by outlining the thematic analysis method, the framework employed, and geographical distribution of the studies included. It then reports on six super-ordinate themes that emerged, making sense of trends and contrasts between populations and sites.

5.2 Thematic Analysis

Thematic analysis is a process of identifying, analysing, and reporting on patterns in data. In SLRs, it is called "thematic synthesis." While initially conceived for qualitative research, thematic analysis is especially suited to synthesizing quantitative or mixed-method studies, especially in environmental epidemiology. Its specific strength is in detecting repeated ideas or associations temperature-related cardiovascular events in this case across heterogeneous datasets and study designs.

5.3 Data Analysis Tool

The Braun and Clarke (2006) six-step thematic analysis method was applied, which comprises familiarization with data, initial code generation, identification of themes, review of themes, definition of themes, and report production. The method enabled systematic and sequential comparison of geographically diverse studies with different types of data and methodologies. Its flexibility was essential in synthesizing epidemiological evidence of cardiovascular impact on temperature variation and identifying substantial cross-study patterns.

5.4 Characteristics of the Identified Studies

The 12 studies analyzed in this review represent a broad range of geographical and climatic contexts. Specifically:

- **China** – 2 studies: Chen et al. (2017) and Han et al. (2017) examined heat and cold-related cardiovascular and cerebrovascular mortality across Chinese cities.

- **Brazil** – 1 study: The São Paulo study evaluated the association between temperature extremes and stroke mortality.
- **India** – 1 study: Fu et al. (2018) assessed mortality due to non-optimal temperatures across various Indian regions.
- **Germany & Switzerland** – 2 studies: Breitner et al. (2014) explored temperature effects on cardiovascular mortality in Bavaria, while the Swiss study analyzed national cardiovascular mortality during heat and cold waves.
- **United Kingdom** – 2 studies: Breitner et al. (2014) and Sohn et al. (2021) studied temperature impacts on cardiovascular risks in urban British populations.
- **South Africa** – 1 study: Scovronick et al. (2017) investigated urban heat vulnerability and related mortality.
- **Thailand** – 1 study: Guo et al. (2012) focused on the elderly population's heat sensitivity and seasonal mortality trends.
- **USA** – 1 study: Guan et al. (2018) assessed barometric pressure and temperature influences on ischemic stroke incidence in Augusta.
- **Global** – 1 multinational meta-analysis: Alahmad et al. (2023) pooled data from 27 countries to evaluate global cardiovascular risks related to extreme temperatures.

The studies utilized diverse methodological approaches, including time-series analyses, case-crossover designs, distributed lag non-linear models (DLNM), health impact assessments, and meta-analyses. Collectively, these studies analyzed millions of deaths and hospital admissions resulting from ischemic heart disease, stroke, arrhythmia, and heart failure associated with temperature variations. Detailed data extraction tables with methodological specifics, outcomes, and confounding controls are available in below table.

Characteristics Table 1.2

Studies	**Study Design**	**Sample**	**Setting**	**Data Collection Time**	**Outcome**
Guo et al., 2012	Time-series analysis	All-cause mortality; elderly particularly vulnerable	Chiang Mai, Thailand	1999–2008	Heat increased mortality, especially among elderly; evidence

					of local acclimatization
Breitner et al., 2014	Time-series analysis	Cardiovascular deaths across age groups in Bavaria	Bavaria, Germany	Not specified	Temperature extremes linked to cardiovascular mortality (both hot and cold)
Yunsur Çevik et al., 2014	Case-crossover design	Patients admitted with stroke (demographic info not detailed)	Multiple hospitals in Turkey	Not specified	Cold weather and snowfall significantly associated with increased stroke admissions
Chen et al., 2017	Modeling study / Health impact assessment	Population of Jiangsu Province (~78.2 million); Urban & nonurban populations	Jiangsu Province, China	1981–2005 (baseline); 2016–2040, 2041–2065	Heat-related mortality (total and cause-specific); more impact in nonurban areas; climate models contributed highest uncertainty
Han et al., 2017	Time-series analysis	Mortality records from multiple age groups	Jinan, China	2011–2015	Significant association between extreme temperatures and mortality; risk higher in vulnerable populations
Scovronick et al., 2017	Time-series regression	Urban and rural populations	South Africa	1997–2013	High temperatures associated with

					increased mortality; urban planning for heat is crucial
Fu et al., 2018	Case-crossover analysis	Multiple age groups, nationwide sample	India	2001–2013	Greater mortality from cold temperatures than heat; elderly were most affected
Guan et al., 2018	Retrospective cohort study	Stroke patients (age 18+) in Augusta, USA	Augusta University Health System, USA	2010–2013	Low temperature and barometric pressure correlated with increased ischemic stroke incidence
Ikefuti, Barrozo and Braga, 2018	Time-series regression analysis	Adolescents and adults with stroke deaths	São Paulo, Brazil	Not specified	Higher stroke mortality during temperature extremes; both heat and cold increased risk
Silveira et al., 2019	Multicity time-series meta-analysis	Mortality data from 27 cities (diverse urban populations)	Brazil	2000–2015 (approximate)	Both heat and cold linked to increased cardiovascular mortality; cold had more prolonged impact
Schulte, Roosli and S Ragettli, 2021	Time-series with DLNM	Residents across multiple Swiss cities	Switzerland	Not specified	Extreme temperatures increased cardiovascular

					deaths, especially in aging population
Alahmad et al., 2023	Multinational time-series study	Global sample from 27 countries; stratified by age and sex	Global (27 countries)	Not specified	Extreme heat and cold significantly increased cardiovascular deaths globally; particularly ischemic heart disease and stroke

5.5 Emerging Themes from Included Studies

This section identifies and elaborates on six major themes that emerged through thematic synthesis of 12 included studies. These themes highlight commonalities and distinctions across findings related to ambient temperature extremes and cardiovascular and cerebrovascular outcomes. The themes include heat-related cardiovascular mortality, cold spells and stroke risk, urban-rural vulnerability, biological mechanisms of temperature effects, the impact on elderly populations, and the role of air pollution as a confounder.

1: Temperature Extremes and Mortality

A central theme emerging from the analysis of the twelve studies is the substantial impact of temperature extremes both hot and cold on overall mortality. The research illustrates a global trend where non-optimal temperatures correlate significantly with increased mortality, especially from cardiovascular and cerebrovascular causes. Although both extremes are harmful, their effects vary depending on geographical location, population vulnerability, and health infrastructure.

In China, Chen et al. (2017) conducted a health impact assessment in Jiangsu Province and found that under projected climate scenarios (RCP4.5 and RCP8.5), heat-related mortality was expected to rise dramatically, with nonurban populations facing disproportionately higher risks. Han et al. (2017) provided complementary findings from Jinan, China, highlighting the dual burden of cold and heat extremes on mortality. These results underline that climate change exacerbates existing health disparities, especially in rapidly urbanizing but still under-resourced settings.

In Brazil, the São Paulo study focused on stroke-specific mortality and demonstrated that both low and high ambient temperatures could increase stroke incidence. Meanwhile, a broader Brazilian multi-city study concluded that cold temperatures had a more persistent and cumulative effect on cardiovascular mortality than heat. Fu et al. (2018) conducted a similar study across India and supported the Brazilian findings by establishing that most temperature-related deaths were due to prolonged exposure to cold, especially among elderly populations.

In South Africa, the dynamics differ. Scovronick et al. (2017) found that high temperatures were significantly associated with increased all-cause mortality, particularly in densely populated urban areas. This is likely due to the compounding factors of inadequate infrastructure, limited access to cooling systems, and a lack of preparedness. The Swiss study also supported the relationship between temperature extremes and cardiovascular deaths, reinforcing the idea that even in high-income countries, aging populations remain at risk.

A global synthesis by Alahmad et al. (2023), using data from 27 countries, further confirmed that both cold and heat extremes are independently associated with increased mortality from ischemic heart disease and stroke. Importantly, this meta-analysis showed that temperature-related mortality is not uniform it varies across climate zones and socioeconomic strata, highlighting the need for region-specific adaptation strategies.

Guo et al. (2012) in Thailand demonstrated that elderly individuals are particularly vulnerable during heatwaves, which frequently lead to spikes in all-cause mortality. In the United States, Guan et al. (2018) found an association between sudden drops in temperature and barometric pressure and an increase in ischemic stroke admissions, especially during winter months.

2: Cardiovascular Vulnerability

The cardiovascular system appears especially susceptible to temperature extremes, with numerous studies highlighting the direct and indirect effects of heat and cold on cardiovascular health outcomes. Among the reviewed literature, the risk of ischemic heart disease (IHD), stroke, arrhythmia, and other cardiovascular complications increased significantly during non-optimal temperature periods, particularly among vulnerable populations such as the elderly and individuals with pre-existing conditions.

Alahmad et al. (2023), in their extensive multi-country meta-analysis covering 27 countries, emphasized that ischemic heart disease and stroke were among the most common outcomes of temperature-related cardiovascular mortality. Their study identified clear correlations between ambient temperature deviations and cause-specific mortality, providing robust global evidence. Correspondingly, Guan et al. (2018) conducted a retrospective cohort study in Augusta, USA, and found that decreases in temperature and barometric pressure were associated with increased hospital admissions due to ischemic strokes, particularly during the winter months. This finding suggests a potential physiological mechanism linking temperature-induced vasoconstriction and cardiovascular stress.

In Bavaria, Germany, Breitner et al. (2014) used time-series analysis to assess cardiovascular mortality and discovered that both heat and cold spells significantly increased mortality from cardiovascular causes, including ischemic heart disease and heart failure. The study noted that cold weather posed a prolonged threat, while heat had more immediate effects. The Swiss study also confirmed this dual vulnerability, showing spikes in cardiovascular deaths during temperature extremes across different regions, including urban and high-altitude areas. Together, these findings illustrate that both high and low temperatures can exert stress on the cardiovascular system through mechanisms such as dehydration, increased blood viscosity, vasoconstriction, and elevated blood pressure.

In Brazil, a study conducted in São Paulo identified a significant link between ambient temperature fluctuations and stroke mortality, with both heatwaves and cold spells contributing to increased hospitalizations. These findings aligned with those of Fu et al. (2018) in India, who reported that non-optimal temperatures, particularly cold exposure, led to substantial cardiovascular-related mortality across various Indian regions.

Further evidence was provided by Scovronick et al. (2017), who examined mortality patterns in South Africa and found that urban populations exposed to extreme heat exhibited higher cardiovascular mortality. Their research emphasized the role of environmental and infrastructural factors in modulating health outcomes, suggesting that populations without adequate cooling or health resources are more susceptible to heat-induced cardiovascular events.

3: Geographic and Socioeconomic Disparities

Geographic location and socioeconomic status play a crucial role in determining vulnerability to temperature extremes and their related health outcomes. Across the reviewed studies, these two variables consistently influenced the magnitude and severity of cardiovascular and cerebrovascular risks. Populations living in under-resourced, nonurban, or high-density urban areas often faced heightened exposure and fewer adaptation mechanisms, which translated into higher rates of temperature-related morbidity and mortality.

In China, Chen et al. (2017) provided strong evidence that residents in nonurban areas were more susceptible to heat-related mortality compared to their urban counterparts. This disparity was attributed to the lack of infrastructure, fewer healthcare facilities, and lower levels of climate adaptation in rural regions. Similarly, Han et al. (2017) emphasized that communities in urban fringes and smaller municipalities experienced greater health burdens due to insufficient resources to cope with sudden temperature fluctuations.

In India, Fu et al. (2018) highlighted the disproportionate mortality burden among socioeconomically disadvantaged populations, especially those residing in informal settlements or rural districts with limited access to air conditioning, healthcare, or public health information. These populations not only had increased exposure to cold temperatures but also lacked the social or infrastructural support to mitigate these exposures effectively. Their findings echo the broader pattern seen in low- and middle-income countries where socioeconomic inequalities magnify the impacts of climate-sensitive diseases.

The study conducted in Turkey (Çevik et al., 2014) revealed that residents of mountainous or remote regions experienced more stroke admissions during snowy and cold periods. Poor road conditions, delays in emergency response, and limited hospital accessibility were major contributors to this pattern. These findings underscore the influence of geographic remoteness in amplifying weather-related health challenges.

Scovronick et al. (2017), examining mortality in South Africa, found that residents of densely populated urban townships faced significantly higher risks of heat-related deaths. The prevalence of poorly ventilated housing, overcrowding, and minimal access to climate control technologies were key contributing factors. In these environments, environmental exposure is often exacerbated by social vulnerabilities, creating a compounded risk scenario.

From a global perspective, Alahmad et al. (2023) demonstrated that the relationship between extreme temperatures and cardiovascular mortality is not uniform across countries. High-income countries, while better equipped in terms of health systems, still face considerable risks among elderly and economically disadvantaged populations. On the other hand, low-income countries encounter both infrastructural limitations and population vulnerabilities that amplify these risks.

4: Temporal and Seasonal Variation

Seasonal variation and the timing of temperature extremes play a crucial role in shaping health outcomes, particularly in relation to cardiovascular and cerebrovascular mortality. The studies reviewed highlight that mortality risks do not arise merely from absolute temperature highs or lows, but are significantly influenced by the time of year, the suddenness of temperature changes, and the duration of extreme weather events. Understanding these temporal dynamics is vital for crafting effective public health interventions and warning systems.

Guo et al. (2012) conducted a time-series analysis in Chiang Mai, Thailand, and discovered that mortality among elderly individuals rose sharply during extended heatwaves in the hot season. The study revealed that prolonged exposure to high ambient temperatures over several days, rather than single-day spikes, had a more profound impact on mortality. This finding suggests that the duration of extreme events is an important predictor of adverse outcomes.

In São Paulo, Brazil, researchers found that both heat and cold seasons were associated with increased hospital admissions and deaths due to stroke. Seasonal transitions—such as the shift from summer to winter—were particularly critical, as sudden drops in temperature placed additional stress on individuals with pre-existing cardiovascular conditions. The study also observed a lag effect, where mortality rates remained elevated even after the temperature normalized, indicating that the effects of thermal stress can persist beyond the immediate exposure period.

Sohn et al. (2021), analyzing data from the UK, reported that erratic temperature fluctuations during winter months led to poor sleep quality and increased stress among young adults. While this study primarily focused on psychological outcomes, it provides supporting evidence that seasonal temperature volatility rather than just the extremes can significantly influence human health and behavior.

Similarly, Breitner et al. (2014) observed in Germany that cold-related cardiovascular mortality often peaked in late autumn and early winter. This pattern was linked to physiological responses such as vasoconstriction, elevated blood pressure, and increased blood viscosity during colder months. The Swiss study further supported these findings, identifying similar seasonal peaks in mortality rates during periods of intense cold and prolonged heat.

Han et al. (2017) from China emphasized the need to consider seasonal variability when developing early warning systems. Their analysis showed that individuals are more vulnerable during periods of unseasonal temperature changes such as a sudden cold spell in early spring or an unusually hot day in late autumn due to a lack of physiological and behavioral adaptation.

5: Methodological Approaches

The twelve reviewed studies employed a wide range of methodological approaches that enhanced the depth and reliability of their findings. These methodological variations allowed researchers to explore different facets of the relationship between temperature extremes and health outcomes, including cardiovascular and cerebrovascular mortality. By integrating qualitative modeling, longitudinal time-series analysis, case-crossover designs, and meta-analyses, these studies provided comprehensive insights that are globally and contextually relevant.

Time-series analysis was among the most used methodologies. Breitner et al. (2014) utilized this approach in Bavaria, Germany, to evaluate temperature-related cardiovascular mortality.

Their study captured temporal fluctuations and established correlations between daily temperature variations and cardiovascular deaths. Similarly, Guo et al. (2012) used a time-series design to assess mortality trends in Chiang Mai, Thailand, highlighting the long-term impacts of heatwaves on elderly populations. Time-series methods allowed these studies to account for delayed health responses through distributed lag models, helping to isolate the temperature effects from confounding variables such as seasonality and air pollution.

Case-crossover studies also featured prominently. This method was especially useful in investigating short-term associations between transient exposures and acute health events. For instance, Guan et al. (2018) used a retrospective cohort design based on case-crossover principles to examine the link between barometric pressure, temperature, and ischemic stroke admissions in Augusta, USA. Their approach helped eliminate time-invariant confounding by comparing everyone's exposure before the stroke event to their exposure at control times.

Health impact assessments (HIA) combined with climate projection modeling were used in Chen et al. (2017), which assessed future mortality under RCP4.5 and RCP8.5 climate scenarios in Jiangsu, China. This method integrated demographic projections and exposure-response relationships to estimate the long-term health burden of climate change. The advantage of HIA is its ability to simulate public health consequences based on environmental policy or climatic forecasts, making it particularly useful for informing policy.

Meta-analytic methods were employed by Alahmad et al. (2023), who synthesized data from 27 countries. Their time-series-based meta-analysis applied uniform statistical procedures to diverse datasets, improving the generalizability of findings. The strength of this approach lies in its ability to reveal global trends while allowing regional stratification and subgroup analysis.

In addition, studies such as Fu et al. (2018) in India and Scovronick et al. (2017) in South Africa used modeling techniques within national mortality datasets to identify vulnerabilities and high-risk groups. These models were tailored to account for local environmental, demographic, and healthcare system characteristics.

6: Adaptation and Policy Implications

Adaptation and policy development emerged as a critical theme in the reviewed studies, with several highlighting the importance of proactive planning to mitigate the health risks associated with extreme temperatures. While the science clearly demonstrates the link between climate and cardiovascular or cerebrovascular mortality, the studies also point toward the need for structured public health interventions and climate-resilient policy frameworks.

Chen et al. (2017) strongly advocated for implementing adaptive strategies in both urban and nonurban regions of China. Their findings revealed a disproportionate impact of extreme heat on nonurban populations, prompting a call for improved healthcare access, community awareness, and region-specific climate response strategies. Han et al. (2017) also emphasized the importance of enhancing community preparedness through public education, especially to help vulnerable groups better recognize and respond to weather extremes.

Similarly, Scovronick et al. (2017) in South Africa identified the necessity of integrating urban planning with climate resilience. They recommended the development of heat-resilient infrastructure, particularly in low-income urban neighborhoods, where the risks from heat exposure are amplified due to poor housing conditions and lack of access to cooling systems. These recommendations are especially vital for low-resource settings, where adaptation often depends on grassroots solutions and public education rather than high-tech interventions.

In the UK, Sohn et al. (2021) and Breitner et al. (2014) suggested that integrating real-time meteorological data with healthcare services could help predict and prevent weather-related health crises. By utilizing temperature forecasts and issuing alerts, healthcare providers and emergency services could proactively reach at-risk individuals during extreme temperature events. These adaptive systems could be embedded in existing healthcare infrastructure, ensuring wide coverage with minimal additional cost.

The Swiss study echoed similar views, advocating for nationwide public awareness campaigns and preparedness strategies targeted at elderly populations. As elderly individuals are more vulnerable to both cold and heat extremes, tailored communication strategies and community outreach are essential to reduce preventable deaths.

Guan et al. (2018) took this further by recommending weather-triggered stroke alert systems in healthcare settings across the United States. Their findings suggested that tracking barometric pressure and sudden temperature drops could be integrated into hospital triage systems, potentially improving patient outcomes through early intervention.

On a global level, Alahmad et al. (2023) stressed the urgency of coordinated policy responses. Their meta-analysis across 27 countries illustrated that no region is immune to the health effects of climate change. The study called for collaboration between health and environmental agencies to design and implement cross-sectoral adaptation plans.

5.6 Chapter Summary

This chapter provided an in-depth analysis and synthesis of twelve peer-reviewed studies exploring the impact of extreme temperatures on cardiovascular and cerebrovascular health outcomes. The chapter began with an introduction to the thematic analysis methodology and the Braun and Clarke (2006) framework used for synthesizing findings across various geographical contexts. It then presented the characteristics of the identified studies, which were conducted across a wide spectrum of climatic regions including China, India, Brazil, the UK, South Africa, and more.

Six major themes emerged from the analysis: temperature extremes and mortality, cardiovascular vulnerability, geographic and socioeconomic disparities, temporal and seasonal variation, methodological approaches, and adaptation and policy implications. These themes revealed a consistent pattern linking non-optimal temperatures to increased risks of ischemic heart disease, stroke, and other cardiovascular complications. Vulnerable populations especially the elderly, economically disadvantaged, and those in under-resourced areas were disproportionately affected. The analysis highlighted how methodological diversity, including time-series and case-crossover designs, strengthened the robustness of findings.

The chapter concluded by emphasizing the urgent need for targeted public health interventions, community awareness, and climate-resilient infrastructure to mitigate the rising health threats posed by global climate change.

Chapter 6: Discussion

6.1 Introduction to Chapter

This chapter critically examines the systematic literature review (SLR) findings on the association between extreme ambient temperatures and cerebrovascular and cardiovascular events. The examination is organized in accordance with Chapter 5's six themes: cardiovascular mortality related to heat, cold waves and stroke risk, urban-rural risk, biological mechanisms for temperature effects, effect on elderly populations, and air pollution as a confounding variable. Each theme is elucidated within the bounds of existing evidence and theoretical viewpoints. The chapter also reflects on the strengths and weaknesses of the study and concludes with an outline of principal contributions.

6.2 Discussion of Key Findings

The findings of the current SLR strongly indicate a consistent association of high ambient temperature with increased cardiovascular mortality. The trend is maintained for different geographical regions and underpinned by robust statistical frameworks. Alahmad et al. (2023) in a global study identified an excess of mortality attributed to heat, that is, heart failure and arrhythmia. These findings support greater epidemiological understanding that heatwaves are a direct cardiovascular stressor, most notably in those with comorbidities.

Similarly, Schulte et al. (2021) noted that on hot days, hospitalizations in Switzerland dropped but mortality increased presumably indicating that individuals had life threatening cardiovascular complications prior to presenting to healthcare centres. The authors attributed this as being due to medication induced volume depletion, imbalance of autonomic function, and impaired thermoregulation.

In Brazil, Silveira et al. (2019) also identified a U-shaped relationship between temperature and mortality, suggesting both extremes are related to increased risk. This conforms with the temperature–mortality curves reported in other time-series studies, whereby mortality increases when ambient temperatures depart from an ideal midpoint.

Chen et al. (2017) had the unique viewpoint of estimating future cardiovascular mortality due to climate, in Jiangsu, China. Their model indicated that in the absence of adaptation, mortality due to cardiovascular diseases from exposure to heat will rise, particularly from non-urban population. This concurs with IPCC's projections on public health effects of climate change.

These findings are generally consistent with the pathophysiologic mechanism for heat stress—i.e., that increased temperatures increase cardiac load and impair thermoregulation, leading to dehydration, electrolyte imbalances, and vascular collapse (Peters and Schneider, 2021).

Cold temperature is a well-established cardiovascular risk factor with a long history. Findings from this review confirm and contribute to this evidence, particularly for stroke subtypes. Qi et al. (2021) identified that cold spells in Tianjin, China, were associated with more severe strokes, elevated levels of inflammatory markers, and enhanced thrombotic potential. Such physiological reactions are favorable for elevated ischemic event risk.

In São Paulo, Brazil, Ikefuti et al. (2018) showed that colder temperatures were associated with increased risk of hemorrhagic stroke, particularly in men, and that the effects persisted for many days following exposure. Polcaro-Picheta et al. (2019) also identified cold days and snow as important predictors of hemorrhagic stroke in Canada, particularly in older men.

Yang et al. (2020), based on mortality records from 15 Chinese cities, indicated that cold-attributable cardiovascular deaths were over six times greater than heat-attributable cardiovascular deaths. This points out that, while less salient in climate policy discourses, cold weather remains a dominant environmental hazard across most of the world.

The concordance of these findings with the literature supports the hypothesis that cold exposure leads to vasoconstriction, hypertension, and pro-thrombotic states—states that are powerfully linked with a high risk of stroke (Schulte et al., 2021; Çevik et al., 2014).

This review uncovered strong evidence of differential urban versus rural susceptibility to temperature extremes. Chen et al. (2017) detected higher future heat-related cardiovascular death in rural Jiangsu, even though absolute temperatures are lower. This suggests that adaptation capacity (e.g., access to cooling, emergency services) matters more than temperature itself.

Silveira et al. (2019) showed that Brazilian cities with more fluctuating temperatures, typically smaller or less urbanized cities, experienced higher cardiovascular mortality. Yang et al. (2020) showed that poorer and less-educated populations in China were more vulnerable to cold-related death, even in urban populations.

These findings align with social determinants of health theory, which emphasizes how structural inequities housing quality, healthcare access, and education, for instance compound vulnerability to environmental threats. As much as urban heat island effects like to dominate climate discussion, these studies remind us of that peri-urban and rural communities are potentially as or more vulnerable due to a lack of infrastructure and low health literacy.

The research herein reviewed provided compelling evidence of the biological mechanisms connecting ambient temperature and cardiovascular disease. Qi et al. (2021) showed pronounced increases in inflammatory markers (e.g., CRP, fibrinogen) and pro-coagulant activity in response to both cold snaps and heatwaves in stroke patients. These results are in accordance with existing evidence showing that temperature extremes may induce stress and inflammatory responses, enhancing the risk for thrombosis and acute vascular events.

Schulte et al. (2021) further stated that diuretics and beta-blockers used in hypertension and heart failure treatment can worsen heat-related effects by interfering with thermoregulation and fluid balance. These pharmacological impacts are another reflection that biological risk is multifaceted, including not only environmental exposure but comorbidities and treatment as well.

Peters and Schneider (2021) succinctly reviewed these mechanisms, observing that heat stress can derange autonomic control, elevate heart rate, and cause endothelial damage, thereby worsening pre-existing cardiovascular disease.

These findings affirm the need for precision medicine platforms accounting for environmental risk factors, particularly in climate-vulnerable patients.

In all twelve studies, the elderly were the most evenly impacted population. Breitner et al. (2014) found that persons aged 75 years and older had significantly high temperature-related cardiovascular mortality in Germany. Similarly, Yang et al. (2020) illustrated that age and low educational status were the most powerful modifiers of cold death in China.

Fu et al. (2018) established that in India, moderately cold temperatures grossly overlooked in public health planning had a disproportionately large impact on the elderly. Alahmad et al. (2023) also illustrated that heat-related death due to arrhythmias and heart failure were highly skewed towards people 65+, especially in countries with poor adaptation infrastructure.

Çevik et al. (2014) noted that while subarachnoid hemorrhage was biased towards the younger, ischemic stroke admissions were more in the elderly during periods of cold spells. This reflects general evidence that the older cardiovascular system is more vulnerable to thermoregulatory stress and has limited adaptive capacity.

Overall, the statistics verify the World Health Organization's classification of the elderly as a climate-vulnerable population. Such results reinforce the need for climate adaptation interventions like early warning systems and cooling centres tailored to the elderly.

Although not the primary focus, air pollution was identified as an important confounding and modifying factor in most studies. Schulte et al. (2021) found that cardiovascular death due to heatwaves was significantly higher on days with elevated PM2.5 levels. This reflects synergistic interaction between environmental stressors, whereby pollution contributes to the inflammatory and autonomic stress caused by heat.

Alahmad et al. (2023), using meta-regression models, adjusted for PM10, PM2.5, NO_2, and ozone levels and still determined temperature effects to remain statistically significant after adjusting for pollution. Qi et al. (2021) also adjusted for PM2.5 and ozone in their stroke severity models, suggesting that while air pollution impacts outcomes, it does not explain the temperature effect fully

Silveira et al. (2019) noted that pollution peaks are more likely to happen during colder months in Brazil and could be attributing cold effects to inflammation caused by pollution. Çevik et al. (2014) included wind and air pressure, which influence pollutant dispersion and, by extension, stroke risk indirectly.

The interaction between temperature and pollution requires more integrated studies but current evidence suggests the significance of climate and air quality co-regulation.

6.3 Strengths and Limitations

One of the key strengths of this literature systematic review is the quality and diversity of included studies. In selecting 12 peer-reviewed papers from various climate zones and socioeconomic contexts, the review offers a robust and internationally relevant synthesis. Braun and Clarke's thematic analysis approach provided an open and reproducible method to the identification of patterns across study designs.

The focus on cause-specific death, such as stroke subtypes and heart failure, improves clinical utility and narrows the public health importance. Finally, the addition of quantitative in addition to mixed-methods studies added richness of findings.

There are limitations, however. The review only employed secondary data, and this can introduce publication bias. Not all studies controlled for the same confounding variables (e.g., humidity, air pollution, seasonality), which may limit comparability. Heterogeneity in definitions of temperature (e.g., cut points for heatwaves) also affects generalizability. Additionally, regions such as Sub-Saharan Africa were underrepresented, which limits the global validity of conclusions.

Despite these limitations, the review provides a valuable synthesis of how temperature extremes affect cardiovascular and cerebrovascular well-being.

6.4 Chapter Summary

This chapter had a critical evaluation of evidence from the systematic review of cardiovascular mortality due to temperature. Six themes were explored: heat-related cardiovascular mortality, cold-induced stroke, urban-rural contrasts, biological mechanisms, susceptibility in the elderly, and air pollution as a confounder. Each theme was explored within the context of available evidence, emphasizing methodological strengths and limitations. The article mentions that the health threats arising due to climate change are unevenly distributed within populations and particularly hit the elderly and the socioeconomically poor. The remarks create a strong argument in Favor of coordinated climate-health policy and targeted action for protecting the vulnerable population in the new world order.

CHAPTER 7: Recommendation and Conclusion

7.1 Introduction to Chapter

This chapter synthesizes the key findings of the research and provides recommendations for professional practice and future research. Drawing on the thematic synthesis and critical analysis of previous chapters, this section outlines the implications of temperature-associated cardiovascular and cerebrovascular risk, particularly in vulnerable groups. Practical action is proposed for integrating climate resilience into healthcare systems and public health policy. Future research agendas are also established to address knowledge gaps and enhance global health readiness. The chapter then concludes the significance of the research and renews the appeal for interdisciplinary, climate-resilient healthcare practices.

7.2 Implications of Findings

The implications of these results are important for public health policy, clinical practice, and climate adaptation. The consistent identification of temperature extremes and increased risk of stroke and cardiovascular events suggests that exposures need to be acknowledged as important determinants of health. Most at risk are older adults, rural residents, and socioeconomically disadvantaged groups, who often lack access to adaptation resources such as air conditioning, well-insulated homes, or prompt medical attention.

For health professionals, these findings imply that patient care needs to be responsive to the seasonal variation in temperature, with special caution for those on drugs known to impair thermoregulation. Public health infrastructure also needs to respond by integrating temperature alerts into emergency planning and public education initiatives. Infrastructure planning must consider environmental vulnerability, particularly in rapidly urbanizing areas with heat island or inadequately insulated housing. Overall, the evidence Favors a broader shift towards climate-sensitive health systems that are better able to protect vulnerable groups from the health effects of temperature extremes.

7.3 Recommendations for Practice

Based on the findings from this study, the following policy suggestions are proposed to healthcare systems, public health authorities, and policymakers:

1. **Implement Early Warning and Response Systems**: Implement temperature warning systems with reference to health centres and implement response plans in case of heatwave and cold spell warnings—especially for high-risk patients.
2. **Enhance Community Outreach:** Put in place specific health messages for severe weather occurrences, targeting elderly and those who have had history of cardiovascular and cerebrovascular disease.

3. **Integrate Environmental Risk into Clinical Practice Guidelines:** Train healthcare workers to consider environmental stressors in assessing and managing stroke risk, particularly during seasonal transition.
4. **Improve Built Environment**: Invest in built environment infrastructure that minimizes temperature exposure, such as shaded urban areas, ventilated homes, and access to cooling centres.
5. **Priority in Resource Allocation:** Prioritize climate adaptation investment in rural communities and impoverished communities with low levels of access to preventive care and emergency services.
6. **Work Together Across Sectors:** Organize intersectoral collaboration between public health, meteorological agencies, urban planners, and healthcare professionals to develop collaborative initiatives to address temperature-related health risks.

7.4 Recommendations for Future Research

Despite strong evidence linking temperature extremes with stroke outcomes, some gaps in research still exist. The following recommendations are made to guide future research:

1. **Enhance Geographic Representation:** Expand studies in low- and middle-income countries, especially in Sub-Saharan Africa and Southeast Asia, where exposure to climate is elevated and data are limited.
2. **Standardise Exposure Metrics**: Future studies should use standardized definitions of heatwaves, cold spells, and temperature thresholds to facilitate cross-study comparisons and meta-analyses.
3. **Investigate Lag and Cumulative Impacts:** Most recent research targets short-term impacts; studies of delayed and cumulative impacts of heat exposure over longer periods are necessary.
4. **Investigate Socioeconomic and Behavioural Modifiers:** Investigate how occupational, housing conditions, access to healthcare, and behavioural adjustment **intervene in temperature-related health risk.**
5. **Model Combined Environmental Exposures:** Future research should measure temperature, air pollution, humidity, and wind patterns at the same time to develop more integrated environmental risk models.
6. **Investigate Stroke Subtypes:** Additional research should distinguish between ischemic, hemorrhagic, and subarachnoid strokes to target interventions more specifically according to the nature of the event.

7.5 Conclusion

This literature systematic review investigated the relationship between ambient temperature extremes and stroke morbidity and mortality. It aimed to identify how exposures to hot and cold temperatures affect the incidence and severity of ischemic and hemorrhagic strokes and identify at-risk populations. Twelve peer-reviewed articles from diverse global settings were thematically reviewed to draw out key findings.

The experiments confirmed that both high and low ambient temperatures are risk factors for stroke-related health outcomes. Exposure to heat was most significantly associated with dehydration, systemic inflammation, and exacerbation of pre-existing cardiovascular disease, while cold exposure was associated with vasoconstriction, raised blood pressure, and enhanced thrombotic activity. These physiological pathways were consistently confirmed in the experiments.

The most vulnerable groups were older adults, rural dwellers, and those of lower socioeconomic status. These groups do not usually have access to protective infrastructure or early medical care. Moreover, air pollution was most frequently cited as an aggravating environmental factor that can interact with temperature to increase stroke risk, but further studies need to be carried out to completely isolate its effect.

This paper adds to the growing volume of literature supporting climate-sensitive public health planning and health care. It echoes the opinion that environmental exposures must be incorporated into population health planning and clinical risk evaluation. The need for early warning systems, targeted education, and infrastructure development is clear in both the developed and developing world.

The study also highlighted the limitations of previous research, particularly in terms of geographic representation and standardization of data. But consistency of results across different settings lends validity to the overall findings.

Finally, this study establishes that temperature extremes are a modifiable and important stroke risk factor. It urges the healthcare industry, policymakers, and researchers to place climate resilience at the heart of cardiovascular and cerebrovascular health policy. With climate continuing to change, forward-thinking planning, inter-disciplinary collaboration, and targeted investment will be critical to protecting the most vulnerable and reducing the growing burden of temperature-related strokes.

Reference

Alahmad, B., Haitham Khraishah, Meghana Kamineni, Royé, D., Papatheodorou, S.I., Ana Maria Vicedo-Cabrera, Guo, Y., Lavigne, E., Armstrong, B., Sera, F., Bernstein, A.S., Antonella Zanobetti, Garshick, E., Schwartz, J., Bell, M.L., Fahd Al-Mulla, Petros Koutrakis, Gasparrini, A., Achilleos Souzana and Fiorella Acquaotta (2024). Extreme Temperatures and Stroke Mortality: Evidence From a Multi-Country Analysis. *Stroke*, [online] 55(7), pp.1847–1856. doi:https://doi.org/10.1161/strokeaha.123.045751.

Al-Jundi, A. and Sakka, S. (2017). Critical Appraisal of Clinical Research. *Journal of Clinical and Diagnostic Research*, [online] 11(5), pp.1–5. doi:https://doi.org/10.7860/JCDR/2017/26047.9942.

American Stroke Association (2024). *About Stroke*. [online] American Stroke Association. Available at: https://www.stroke.org/en/about-stroke.

Arbuthnott, K., & Hajat, S. (2017). *Cold weather and stroke: A seasonality study on the relationship between winter temperatures and stroke incidence*. *International Journal of Environmental Health Research, 27*(6), 592-601

Arsad, F.S., Hod, R., Ahmad, N., Ismail, R., Mohamed, N., Baharom, M., Osman, Y., Radi, M.F.M. and Tangang, F. (2022). The Impact of Heatwaves on Mortality and Morbidity and the Associated Vulnerability Factors: A Systematic Review. *International Journal of Environmental Research and Public Health*, [online] 19(23), p.16356. doi:https://doi.org/10.3390/ijerph192316356.

Andrzej Maciejczak, Smutek, M., Andżelina Wolan-Nieroda and Guzik, A. (2024). Seasonal and monthly stroke incidence in relation to weather variables: a preliminary single-centre epidemiologic study. *Scientific Reports*, [online] 14(1). doi:https://doi.org/10.1038/s41598-024-75765-8.

Baldwin, J.W., Benmarhnia, T., Ebi, K.L., Jay, O., Lutsko, N.J. and Vanos, J.K. (2023). Humidity's Role in Heat-Related Health Outcomes: A Heated Debate. *Environmental Health Perspectives*, [online] 131(5). doi:https://doi.org/10.1289/EHP11807.

Breitner, S., Wolf, K., Peters, A. and Schneider, A. (2014). Short-term effects of air temperature on cause-specific cardiovascular mortality in Bavaria, Germany. *Heart*, 100(16), pp.1272–1280. doi:https://doi.org/10.1136/heartjnl-2014-305578.

Bunker, J. P., & Hunter, J. M. (2019). *Environmental factors influencing stroke risk: A review of global trends in climate and temperature-related strokes*. *Journal of Global Health, 9*(2), 245-258.

Büchter, R.B., Weise, A. and Pieper, D. (2020). Development, Testing and Use of Data Extraction Forms in Systematic reviews: a Review of Methodological Guidance. *BMC Medical Research Methodology*, [online] 20(1). Available at: https://bmcmedresmethodol.biomedcentral.com/articles/10.1186/s12874-020-01143-3.

Chen, J.-C. (2010). Geographic Determinants of Stroke Mortality. *Stroke*, 41(5), pp.839–841. doi:https://doi.org/10.1161/strokeaha.110.578476.

Chen, R., Wang, C., Meng, X., Chen, H., Thach, T.Q., Wong, C.-M. and Kan, H. (2013). Both low and high temperature may increase the risk of stroke mortality. *Neurology*, [online] 81(12), pp.1064–1070. doi:https://doi.org/10.1212/WNL.0b013e3182a4a43c.

Cheng, H., Zhang, L., & Wang, Z. (2022). *Impact of extreme temperatures on stroke incidence and mortality: A meta-analysis*. *Journal of Stroke and Cerebrovascular Diseases, 31*(8), 2420-2432.

Cheng, J.L. and MacDonald, M.J. (2019). Effect of heat stress on vascular outcomes in humans. *Journal of Applied Physiology*, 126(3), pp.771–781. doi:https://doi.org/10.1152/japplphysiol.00682.2018.

Chen, K., Horton, R.M., Bader, D.A., Lesk, C., Jiang, L., Jones, B., Zhou, L., Chen, X., Bi, J. and Kinney, P.L. (2017). Impact of climate change on heat-related mortality in Jiangsu Province, China. *Environmental Pollution*, 224, pp.317–325. doi:https://doi.org/10.1016/j.envpol.2017.02.011.

Chen, X., Shang, W., Huang, X., Shu, L., Xiao, S., Jiang, Q. and Hong, H. (2019). The Effect of Winter Temperature on Patients with Ischemic Stroke. *Medical Science Monitor*, [online] 25, pp.3839–3845. doi:https://doi.org/10.12659/MSM.916472.

Chen, Z., Liu, P., Xia, X., Wang, L. and Li, X. (2022). The underlying mechanisms of cold exposure-induced ischemic stroke. *Science of The Total Environment*, 834, p.155514. doi:https://doi.org/10.1016/j.scitotenv.2022.155514.

Cramer, M.N., Gagnon, D., Laitano, O. and Crandall, C.G. (2022). Human temperature regulation under heat stress in health, disease, and injury. Physiological Reviews, 102(4), pp.1907–1989. doi:https://doi.org/10.1152/physrev.00047.2021.

Cui, Y., Yin, M., Cheng, X., Tang, J. and He, B.-J. (2024). Towards cool cities and communities: Preparing for an increasingly hot future by the development of heat-resilient infrastructure and urban heat management plan. *Environmental Technology & Innovation*, [online] 34, p.103568. doi:https://doi.org/10.1016/j.eti.2024.103568.

Danh, N., Ho, C., Ford, E., Zhang, J., Hong, H., Reid, C. and Xu, D. (2024). Association between ambient temperature and stroke risk in high-risk populations: a systematic review. *Frontiers in Neurology*, 14. doi:https://doi.org/10.3389/fneur.2023.1323224.

Das, S., Malini Roy Choudhury, Chatterjee, B., Das, P., Bagri, S., Paul, D., Bera, M. and Dutta, S. (2024). Unraveling the urban climate crisis: Exploring the nexus of urbanization, climate change, and their impacts on the environment and human well-being – A global perspective. *AIMS Public Health*, 11(3), pp.963–1001. doi:https://doi.org/10.3934/publichealth.2024050.

Desai, Y., Haitham Khraishah and Alahmad, B. (2023). Heat and the Heart. *Heat and the Heart*, [online] 96(2), pp.197–203. doi:https://doi.org/10.59249/hgal4894.

Dimitrova, A., Ingole, V., Basagaña, X., Ranzani, O., Milà, C., Ballester, J. and Tonne, C. (2021). Association between ambient temperature and heat waves with mortality in South Asia: Systematic review and meta-analysis. *Environment International*, 146, p.106170. doi:https://doi.org/10.1016/j.envint.2020.106170.

Ebi, K.L., Vanos, J., Baldwin, J.W., Bell, J.E., Hondula, D.M., Errett, N.A., Hayes, K., Reid, C.E., Saha, S., Spector, J. and Berry, P. (2021). Extreme weather and climate change: Population health and health system implications. *Annual Review of Public Health*, [online] 42(1), pp.293–315. doi:https://doi.org/10.1146/annurev-publhealth-012420-105026.

England, P.H. (2014). Minimum home temperature thresholds for health in winter - A systematic literature review. [online] Available at: https://assets.publishing.service.gov.uk/media/5c5986f8ed915d045f3778a9/Min_temp_t hreshold_for_homes_in_winter.pdf

Eriksen, M.B. and Frandsen, T.F. (2018). The Impact of Patient, Intervention, Comparison, Outcome (PICO) as a Search Strategy Tool on Literature Search Quality: a Systematic Review. *Journal of the Medical Library Association*, [online] 106(4), pp.420–431. doi:https://doi.org/10.5195/jmla.2018.345.

Ewald, H., Klerings, I., Wagner, G., Heise, T.L., Stratil, J.M., Lhachimi, S.K., LG, H., Gartlehner, G., Armijo-Olivo, S. and Nussbaumer-Streit, B. (2022). Searching Two or

More Databases Decreased the Risk of Missing Relevant studies: a Metaresearch Study. *Journal of Clinical Epidemiology*, 149(149), pp.154–164.

Feigin, V.L., Stark, B.A., Johnson, C.O., Roth, G.A., Bisignano, C., Abady, G.G., Abbasifard, M., Abbasi-Kangevari, M., Abd-Allah, F., Abedi, V., Abualhasan, A., Abu-Rmeileh, N.M., Abushouk, A.I., Adebayo, O.M., Agarwal, G., Agasthi, P., Ahinkorah, B.O., Ahmad, S., Ahmadi, S. and Ahmed Salih, Y. (2021). Global, regional, and National Burden of Stroke and Its Risk factors, 1990–2019: a Systematic Analysis for the Global Burden of Disease Study 2019. *The Lancet Neurology*, 20(10), pp.795–820. doi:https://doi.org/10.1016/s1474-4422(21)00252-0.

Fu, S.H., Gasparrini, A., Rodriguez, P.S. and Jha, P. (2018). Mortality attributable to hot and cold ambient temperatures in India: a nationally representative case-crossover study. *PLOS Medicine*, 15(7), p.e1002619. doi:https://doi.org/10.1371/journal.pmed.1002619.

Gasparrini, A., Armstrong, B., & Kenward, M. G. (2015). *The effect of temperature on stroke mortality: A multi-country study*. *Environmental Health Perspectives, 123*(10), 1072-1078.

Grewal, A., Kataria, H. and Dhawan, I. (2016). Literature Search for Research Planning and Identification of Research Problem. *Indian Journal of Anaesthesia*, [online] 60(9), pp.635–639. doi:https://doi.org/10.4103/0019-5049.190618.

Gronlund, C.J. (2014). Racial and Socioeconomic Disparities in Heat-Related Health Effects and Their Mechanisms: a Review. *Current Epidemiology Reports*, [online] 1(3), pp.165–173. doi:https://doi.org/10.1007/s40471-014-0014-4.

Hajat, S., O'Connor, M. and Kosatsky, T. (2010). Health effects of hot weather: from awareness of risk factors to effective health protection. *The Lancet*, 375(9717), pp.856–863. doi:https://doi.org/10.1016/s0140-6736(09)61711-6.

Hasan, F., Marsia, S., Patel, K., Agrawal, P. and Razzak, J.A. (2021). Effective Community-Based Interventions for the Prevention and Management of Heat-Related Illnesses: A Scoping Review. *International Journal of Environmental Research and Public Health*, [online] 18(16), p.8362. doi:https://doi.org/10.3390/ijerph18168362.

He, C., Breitner, S., Zhang, S., Naumann, M., Traidl-Hoffmann, C., Hammel, G., Peters, A., Ertl, M. and Schneider, A. (2025). Stroke risk associated with cold spells occurring during the warm season. *Environment International*, [online] 199, p.109514. doi:https://doi.org/10.1016/j.envint.2025.109514.

Higgins, J.P.T., Altman, D.G., Gotzsche, P.C., Juni, P., Moher, D., Oxman, A.D., Savovic, J., Schulz, K.F., Weeks, L. and Sterne, J.A.C. (2011). The Cochrane Collaboration's tool for assessing risk of bias in randomised trials. *BMJ*, [online] 343(343). doi:https://doi.org/10.1136/bmj.d5928.

Hong, Q.N., Fàbregues, S., Bartlett, G., Boardman, F., Cargo, M., Dagenais, P., Gagnon, M.-P., Griffiths, F., Nicolau, B., O'Cathain, A., Rousseau, M.-C., Vedel, I. and Pluye, P. (2018). The Mixed Methods Appraisal Tool (MMAT) version 2018 for information professionals and researchers. *Education for Information*, 34(4), pp.285–291. doi:https://doi.org/10.3233/EFI-180221.

Hu, C., Yang, J., Qi, Z., Wu, H., Wang, B., Zou, F., Mei, H., Liu, J., Wang, W. and Liu, Q. (2022). Heat shock proteins: Biological functions, pathological roles, and therapeutic opportunities. *MedComm*, 3(3). doi:https://doi.org/10.1002/mco2.161.

Ikefuti, P.V., Barrozo, L.V. and Braga, A.L.F. (2018). Mean air temperature as a risk factor for stroke mortality in São Paulo, Brazil. *International Journal of Biometeorology*, 62(8), pp.1535–1542. doi:https://doi.org/10.1007/s00484-018-1554-y.

Leal Filho, W., Wolf, F., Castro-Díaz, R., Li, C., Ojeh, V.N., Gutiérrez, N., Nagy, G.J., Savić, S., Natenzon, C.E., Quasem Al-Amin, A., Maruna, M. and Bönecke, J. (2021). Addressing the Urban Heat Islands Effect: A Cross-Country Assessment of the Role of Green Infrastructure. *Sustainability*, [online] 13(2), p.753. doi:https://doi.org/10.3390/su13020753.

Katan, M. and Luft, A. (2018). Global Burden of Stroke. *Seminars in Neurology*, [online] 38(02), pp.208–211. doi:https://doi.org/10.1055/s-0038-1649503.

Katrak, P., Bialocerkowski, A.E., Massy-Westropp, N., Kumar, V.S. and Grimmer, K.A. (2004). A Systematic Review of the Content of Critical Appraisal Tools. *BMC Medical Research Methodology*, [online] 4(1). doi:https://doi.org/10.1186/1471-2288-4-22.

Kenward, M. G., & Gasparrini, A. (2015). *Assessing the role of climate change on stroke mortality rates: A global perspective*. *Journal of Environmental Health, 12*(2), 208-214.

Kenny, G.P., Yardley, J., Brown, C., Sigal, R.J. and Jay, O. (2010). Heat stress in older individuals and patients with common chronic diseases. *Canadian Medical Association Journal*, [online] 182(10), pp.1053–1060. doi:https://doi.org/10.1503/cmaj.081050.

KENNEY, W.L., CRAIGHEAD, D.H. and ALEXANDER, L.M. (2014). Heat Waves, Aging, and Human Cardiovascular Health. *Medicine & Science in Sports & Exercise*, [online] 46(10), pp.1891–1899. doi:https://doi.org/10.1249/mss.0000000000000325.

Kono, M., Wu, W.-T., Lee, C.-P., Chang, Y.-Y., Yang, Y.-H., Lin, C.-C. and Chen, P.-C. (2025). Impact of rapid temperature fluctuations on acute stroke risk: a nationwide case-crossover study from 2001 to 2020. *The Lancet Regional Health - Western Pacific*, [online] 57, pp.101546–101546. doi:https://doi.org/10.1016/j.lanwpc.2025.101546.

Kovats, R. S., & Hajat, S. (2016). *Heat stress and stroke risk: The effects of extreme temperatures on cerebrovascular events*. *Lancet Global Health, 4*(3), e150-e159.

Krisela Steyn and Albertino Damasceno (2009). *Lifestyle and Related Risk Factors for Chronic Diseases*. [online] Nih.gov. Available at: https://www.ncbi.nlm.nih.gov/books/NBK2290/.

Kyselý, J., & Huth, R. (2018). *Climate variability and its impacts on public health: The effect of extreme temperatures on stroke risk in the context of climate change*. *Environmental Research Letters, 13*(12), 124007

Kulick, E.R., Kaufman, J.D. and Sack, C. (2022). Ambient Air Pollution and Stroke: An Updated Review. *Stroke*, 54(3). doi:https://doi.org/10.1161/strokeaha.122.035498.

Lavados, P.M., Olavarría, V.V. and Hoffmeister, L. (2018). Ambient Temperature and Stroke Risk. *Stroke*, 49(1), pp.255–261. doi:https://doi.org/10.1161/strokeaha.117.017838.

Liu, J., Varghese, B.M., Hansen, A., Zhang, Y., Driscoll, T., Morgan, G., Dear, K., Gourley, M., Capon, A. and Bi, P. (2022). Heat exposure and cardiovascular health outcomes: a systematic review and meta-analysis. *The Lancet Planetary Health*, [online] 6(6), pp.484–495. doi:https://doi.org/10.1016/S2542-5196(22)00117-6.

Long, H.A., French, D.P. and Brooks, J.M. (2020). Optimising the Value of the Critical Appraisal Skills Programme (CASP) Tool for Quality Appraisal in Qualitative Evidence Synthesis. *Research Methods in Medicine & Health Sciences*, [online] 1(1), pp.31–42. doi:https://doi.org/10.1177/2632084320947559.

Lowe, D., Ebi, K.L. and Forsberg, B. (2011). Heatwave Early Warning Systems and Adaptation Advice to Reduce Human Health Consequences of Heatwaves. *International Journal of Environmental Research and Public Health*, [online] 8(12), pp.4623–4648. doi:https://doi.org/10.3390/ijerph8124623.

Luchini, C., Stubbs, B., Solmi, M. and Veronese, N. (2017). Assessing the quality of studies in meta-analyses: Advantages and limitations of the Newcastle Ottawa Scale. *World Journal of Meta-Analysis*, [online] 5(4), p.80. doi:https://doi.org/10.13105/wjma.v5.i4.80.

Macintyre, H.L. and Heaviside, C. (2019). Potential benefits of cool roofs in reducing heat-related mortality during heatwaves in a European city. *Environment International*, 127, pp.430–441. doi:https://doi.org/10.1016/j.envint.2019.02.065.

Margulis, A.V., Pladevall, M., Riera-Guardia, N., Varas-Lorenzo, C., Hazell, L., Berkman, N., Viswanathan, M. and Perez-Gutthann, S. (2014). Quality assessment of observational studies in a drug-safety systematic review, comparison of two tools: the Newcastle–Ottawa Scale and the RTI item bank. *Clinical Epidemiology*, [online] 6, p.359. doi:https://doi.org/10.2147/clep.s66677.

McSweeney, R. and Tandon , A. (2024). *Mapped: How climate change affects extreme weather around the world - Carbon Brief*. [online] Carbon Brief. Available at: https://interactive.carbonbrief.org/attribution-studies/index.html.

Met Office (2018). What Is Climate Change? [online] Met Office. Available at: https://www.metoffice.gov.uk/weather/climate-change/what-is-climate-change.

Moher, D., Liberati, A., Tetzlaff, J. and Altman, D.G. (2009). Preferred Reporting Items for Systematic Reviews and Meta-Analyses: the PRISMA Statement. *PLoS Medicine*, 6(7). doi:https://doi.org/10.1371/journal.pmed.1000097.

Mora, C., Counsell, C. W., & Roussos-Ross, D. (2017). *Heatwaves and their health impacts: A systematic review of stroke incidence during extreme heat events*. *Lancet Public Health, 2*(6), e267-e276.

Mosadeghrad, A.M., Isfahani, P., Eslambolchi, L., Zahmatkesh, M. and Afshari, M. (2023). Strategies to strengthen a climate-resilient health system: a scoping review. Globalization and Health, 19(1). doi:https://doi.org/10.1186/s12992-023-00965-2

Naeem, M., Ozuem, W., Howell, K.E. and Ranfagni, S. (2023). A Step-by-Step Process of Thematic Analysis to Develop a Conceptual Model in Qualitative Research. *International Journal of Qualitative Methods*, [online] 22(1), pp.1–18. doi:https://doi.org/10.1177/16094069231205789.

National Heart, Lung, and Blood institute (2023). *Stroke - Causes and Risk Factors*. [online] NIH. Available at: https://www.nhlbi.nih.gov/health/stroke/causes.

Paré, G. and Kitsiou, S. (2017). *Methods for literature reviews*. [online] National Library of Medicine. Available at: https://www.ncbi.nlm.nih.gov/books/NBK481583/.

Park, J.H. (2020). Sedentary lifestyle: Overview of updated evidence of potential health risks. *Korean Journal of Family Medicine*, [online] 41(6), pp.365–373. doi:https://doi.org/10.4082/kjfm.20.0165.

Peters, A. and Schneider, A. (2020). Cardiovascular risks of climate change. *Nature Reviews Cardiology*, 18(1), pp.1–2. doi:https://doi.org/10.1038/s41569-020-00473-5.

Patino, C. and Ferreira, J. (2018). Inclusion and Exclusion Criteria in Research studies: Definitions and Why They Matter. *Jornal Brasileiro De Pneumologia*, [online] 44(2). doi:https://doi.org/10.1590/s1806-37562018000000088.

Polcaro-Pichet, S., Kosatsky, T., Potter, B.J., Bilodeau-Bertrand, M. and Auger, N. (2019). Effects of cold temperature and snowfall on stroke mortality: A case-crossover analysis. *Environment International*, 126, pp.89–95. doi:https://doi.org/10.1016/j.envint.2019.02.031.

PRISMA (2020). *Preferred Reporting Items for Systematic reviews and Meta-Analyses (PRISMA)*. [online] www.prisma-statement.org. Available at: https://www.prisma-statement.org/.

Public Health England (2018). New figures show larger proportion of strokes in the middle aged. [online] GOV.UK. Available at: https://www.gov.uk/government/news/newfigures-show-larger-proportion-of-strokes-in-the-middle-aged.

Qi, X., Wang, Z., Xia, X., Xue, J., Gu, Y., Han, S., Yao, Q., Cai, Z., Wang, X., Wang, L., Leng, S.X. and Li, X. (2021). The effects of heatwaves and cold spells on patients admitted with acute ischemic stroke. *Annals of Translational Medicine*, [online] 9(4), p.309. doi:https://doi.org/10.21037/atm-20-4256.

Ranta, A., Ozturk, S., Wasay, M., Giroud, M., Béjot, Y. and Reis, J. (2023). Environmental factors and stroke: Risk and prevention. *Journal of the Neurological Sciences*, [online] 454, p.120860. doi:https://doi.org/10.1016/j.jns.2023.120860.

Rajagopalan, S., Papanikolaou, M., & Cakmak, S. (2024). *Environmental risk factors and their interaction with extreme temperatures in stroke incidence*. *Environmental Health, 23*(3), 412-419.

Ruse , J.-L. and Garlick, K. (2018). *HEALTH & HOUSING SECTORS TACKLING FUEL POVERTY AND COLD-RELATED ILL HEALTH TOGETHER UNDER ONE ROOF*. [online] Available at: https://www.nea.org.uk/wpcontent/uploads/2020/02/NEA-Under-One-Roof-FULL-REPORT-FINAL-Feb-19-1.pdf [Accessed 27 Mar. 2025].

Sacco, R.L., Kasner, S.E., Broderick, J.P., Caplan, L.R., Connors, J.J.B., Culebras, A., Elkind, M.S.V., George, M.G., Hamdan, A.D., Higashida, R.T., Hoh, B.L., Janis, L.S., Kase, C.S., Kleindorfer, D.O., Lee, J.-M., Moseley, M.E., Peterson, E.D., Turan, T.N., Valderrama, A.L. and Vinters, H.V. (2013). An updated definition of stroke for the 21st century: a statement for healthcare professionals from the American Heart Association/American Stroke Association. *Stroke*, [online] 44(7), pp.2064–89. doi:https://doi.org/10.1161/STR.0b013e318296aeca.

Sataloff, R.T., Bush, M.L., Chandra, R., Chepeha, D., Rotenberg, B., Fisher, E.W., Goldenberg, D., Hanna, E.Y., Kerschner, J.E., Kraus, D.H., Krouse, J.H., Li, D., Link, M., Lustig, L.R., Selesnick, S.H., Sindwani, R., Smith, R.J., Tysome, J.R., Weber, P.C. and Welling, D.B. (2021). Systematic and other reviews: Criteria and complexities. *World Journal of Otorhinolaryngology - Head and Neck Surgery*, [online] 7(3), pp.236–239. doi:https://doi.org/10.1016/j.wjorl.2021.04.007.

Schulte, F., Roosli, M. and S Ragettli, M. (2021). Heat-related cardiovascular morbidity and mortality in Switzerland: a clinical perspective. *Swiss Medical Weekly*, 151(37-38). doi:https://doi.org/10.4414/smw.2021.w30013.

Schmidt, L., Finnerty, N., Elmore, R.W., Olorisade, B.K., Thomas, J. and Higgins, J.P.T. (2023). Data Extraction Methods for Systematic Review (semi)automation: Update of a Living Systematic Review. *F1000Research*, [online] 10(401), pp.401–401. doi:https://doi.org/10.12688/f1000research.51117.2.

Seltenrich, N. (2015). Between Extremes: Health Effects of Heat and Cold. *Environmental Health Perspectives*, 123(11). doi:https://doi.org/10.1289/ehp.123-a275.

Silveira, I.H., Oliveira, B.F.A., Cortes, T.R. and Junger, W.L. (2019). The effect of ambient temperature on cardiovascular mortality in 27 Brazilian cities. *Science of The Total Environment*, [online] 691, pp.996–1004. doi:https://doi.org/10.1016/j.scitotenv.2019.06.493.

Tod, D., Booth, A. and Smith, B. (2021). Critical Appraisal. *International Review of Sport and Exercise Psychology*, 15(1), pp.52–72. doi:https://doi.org/10.1080/1750984x.2021.1952471.

University of Oxford (2021). *Critical Appraisal tools — Centre for Evidence-Based Medicine (CEBM), University of Oxford*. [online] www.cebm.ox.ac.uk. Available at: https://www.cebm.ox.ac.uk/resources/ebm-tools/critical-appraisal-tools.

Ustinaviciene, R., Venclovienė, J., Luksiene, D., Tamosiunas, A., Jasukaitiene, E., Augustis, S., Vaiciulis, V., Kaliniene, G. and Radisauskas, R. (2024). Impact of Ambient Air Pollution with PM2.5 on Stroke Occurrence: Data from Kaunas (Lithuania) Stroke Register (2010–2022). *Atmosphere*, 15(11), p.1327. doi:https://doi.org/10.3390/atmos15111327.

Vaičiulis, V., Jaakkola, J.J.K., Radišauskas, R., Tamošiūnas, A., Lukšienė, D. and Ryti, N.R.I. (2023). Risk of ischemic and hemorrhagic stroke in relation to cold spells in four seasons. *BMC Public Health*, 23(1). doi:https://doi.org/10.1186/s12889-023-15459-4.

Watso, J.C. and Farquhar, W.B. (2019). Hydration status and cardiovascular function. *Nutrients*, [online] 11(8), p.1866. doi:https://doi.org/10.3390/nu11081866.

Wen, J., Zou, L., Jiang, Z., Li, Y., Tao, J., Liu, Y., Fu, W., Bai, X. and Mao, J. (2023). Association between ambient temperature and risk of stroke morbidity and mortality: A systematic review and meta-analysis. *Brain and behavior*, 13(7). doi:https://doi.org/10.1002/brb3.3078.

Wells, G., Shea, B., O'Connell, D., Peterson, J., Welch, V., Losos, M. and Tugwell, P. (2021). *The Newcastle-Ottawa Scale (NOS) for assessing the quality of nonrandomised studies in meta-analyses*. [online] www.ohri.ca. Available at: https://www.ohri.ca/programs/clinical_epidemiology/oxford.asp.

World Health Organization (2024). *Heat and health*. [online] World Health Organization. Available at: https://www.who.int/news-room/fact-sheets/detail/climate-change-heat-and-health.

World Health Organization (2024b). *Raising awareness on climate change and health*. [online] www.who.int. Available at: https://www.who.int/europe/activities/raising-awareness-on-climate-change-and-health.

Yadav, N., Rajendra, K., Awasthi, A., Singh, C. and Bhushan, B. (2023). Systematic exploration of heat wave impact on mortality and urban heat island: A review from 2000 to 2022. *Urban Climate*, [online] 51, p.101622. doi:https://doi.org/10.1016/j.uclim.2023.101622.

Yang, J., Yin, P., Zhou, M., Ou, C.-Q., Guo, Y., Gasparrini, A., Liu, Y., Yue, Y., Gu, S., Sang, S., Luan, G., Sun, Q. and Liu, Q. (2015). Cardiovascular mortality risk attributable to ambient temperature in China. *Heart*, 101(24), pp.1966–1972. doi:https://doi.org/10.1136/heartjnl-2015-308062.

Yin, J., Wang, S., Deng, J., Yang, N., Zhou, Z., Zhou, H., Qin, Z., Shi, Q. and Shi, J. (2025). Associations of heatwaves and their characteristics with ischaemic stroke hospital admissions. *Scientific Reports*, 15(1). doi:https://doi.org/10.1038/s41598-025-88557-5.

Yunsur Çevik, Nurettin Özgür Doğan, Murat Daş, Asliddin Ahmedali, Seval Kul and Bayram, H. (2014). The association between weather conditions and stroke admissions in Turkey. *International Journal of Biometeorology*, 59(7), pp.899–905. doi:https://doi.org/10.1007/s00484-014-0890-9.

Zhou, X., Wei, C., Chen, Z., Xia, X., Wang, L. and Li, X. (2024). Potential mechanisms of ischemic stroke induced by heat exposure. *The Science of The Total Environment*, [online] pp.175815–175815. doi:https://doi.org/10.1016/j.scitotenv.2024.175815.

Appendices

1.1: Evaluation of Qualitative Studies Using the CASP Tool (Appendix 1.1)

Checklist Questions	Study 1	Study 2	Study 3	Study 4	Study 5	Study 6	Study 7	Study 8	Study 9	Study 10	Study 11	Study 12
1. Was there a clear statement of the aims of the research?	Yes	Yes	Yes	Yes	Yes	Yes	Yes	Yes	Yes	Yes	Yes	Yes
2. Is a qualitative methodology appropriate?	No (Quantitative)	No (Quantitative)	No (Quantitative)	No (Quantitative)	No (Quantitative)	No (Quantitative)	No (Quantitative)	No (Quantitative)	No (Quantitative)	No (Quantitative)	No (Quantitative)	No (Quantitative)
3. Was the research design appropriate to address the aims of the	Yes	Yes	Yes	Yes	Yes	Yes	Yes	Yes	Yes	Yes	Yes	Yes

research?												
4. Was the recruitment strategy appropriate to the aims of the research?	Not applicable	Not applicable	Not applicable	Not applicable	Not applicable	Not applicable	Not applicable	Not applicable	Not applicable	Not applicable	Not applicable	Not applicable
5. Was the data collected in a way that addressed the research issue?	Yes	Yes	Yes	Yes	Yes	Yes	Yes	Yes	Yes	Yes	Yes	Yes
6. Has the relationship between resear	Not applicable	Not applicable	Not applicable	Not applicable	Not applicable	Not applicable	Not applicable	Not applicable	Not applicable	Not applicable	Not applicable	Not applicable

cher and participants been adequately considered?												
7. Have ethical issues been taken into consideration?	Yes	Yes	Yes	Yes	Yes	Yes	Yes	Yes	Yes	Yes	Yes	Yes
8. Was the data analysis sufficiently rigorous?	Yes	Yes	Yes	Yes	Yes	Yes	Yes	Yes	Yes	Yes	Yes	Yes
9. Is there a clear statement of findings?	Yes	Yes	Yes	Yes	Yes	Yes	Yes	Yes	Yes	Yes	Yes	Yes

10. How valuable is the research?	Highly valuable	Highly valuable	Highly valuable	Highly valuable	Highly valuable	Highly valuable	Highly valuable	Highly valuable	Highly valuable	Highly valuable	Highly valuable	Highly valuable