

UNIVERSITY FOR DEVELOPMENT STUDIES

**IMPACT OF CLIMATE VARIABILITY AND AIR QUALITY ON HUMAN
HEALTH: A CASE OF TMALE METROPOLIS IN THE NORTHERN
REGION OF GHANA**

ABU IDDRISU

2025



UNIVERSITY FOR DEVELOPMENT STUDIES
FACULTY OF NATURAL RESOURCES AND ENVIRONMENT
DEPARTMENT OF ENVIRONMENT AND SUSTAINABILITY SCIENCES

**IMPACT OF CLIMATE VARIABILITY AND AIR QUALITY ON HUMAN
HEALTH: A CASE OF TAMALE METROPOLIS IN THE NORTHERN
REGION OF GHANA**

BY

ABU IDDRISU (Dip. BSc. MSc)

(UIN: 21000931)

**A THESIS SUBMITTED TO THE DEPARTMENT OF ENVIRONMENT
AND SUSTAINABILITY SCIENCES, FACULTY OF ENVIRONMENT
AND NATURAL RESOURCES, UNIVERSITY FOR DEVELOPMENT
STUDIES IN PARTIAL FULFILLMENT OF THE REQUIREMENTS FOR
THE AWARD OF DOCTOR OF PHILOSOPHY DEGREE IN
ENVIRONMENTAL MANAGEMENT AND SUSTAINABILITY**

JULY, 2025



DECLARATION

Student

I hereby declare that this thesis is the result of my own original work, and that no part of it has been submitted for another degree in this University or elsewhere.

Abu Iddrisu



18/08/25

(Student's name)

(Signature)

(Date)

Supervisor

We hereby declare that the preparation and presentation of the thesis was supervised in accordance with the guidelines on supervision of thesis laid down by the University for Development Studies.

Prof. Ibrahim Yakubu Seini



18/8/25

(Main Supervisor)

(Signature)

(Date)

Dr. Wilhemina Asare



18/08/2025

(Co-Supervisor)

(Signature)

(Date)

Prof. Ebenezer Owusu Sekyere



18/08/2025

(Head of Department)

(Signature)

(Date)

DEDICATION

I dedicate this thesis to the loving memory of my late parents; Mrs. Mariama Abu and Mr. Abu Imoro. May their souls rest in peace.



ACKNOWLEDGEMENTS

I wish to acknowledge the untiring efforts of my supervisors; Prof. Ibrahim Yakubu Seini and Dr. Welhemina Asare for their guidance and encouragement throughout the course of my research. Their critical comments provided me with different perspectives. I equally acknowledge Prof. Jerry Samuel Cobinna, Prof. Bernard N. Baatuuwie, and Dr. D. A. Doke for the informative contributions and critique that helped strengthened the quality of the thesis. I also acknowledge the assistance of Dr. Ibrahim Issaka who was instrumental in organizing the thesis. His willingness to offer assistance made my task easier. To my wife, Ms. Nafisa Alhassan, I am grateful for the support and understanding. From the bottom of my heart, I thank all those who contributed directly or indirectly to the completion of this research.



ABSTRACT

This study investigated the relationship between poor air quality and climate variability on human health aimed at generating evidence-based strategies for mitigating adverse health outcomes and improving environmental resilience. The study adopted a convergent parallel mixed-method design with integrated quantitative analysis to study meteorological and air quality data spanning a period of 33 years (1990–2023). It drew qualitative insights from community stakeholders and healthcare practitioners using time-series analysis revealing significant climatic trends. These included an increase in temperature from February to November and a significant decline in rainfall during May ($p = 0.01$). The annual rainfall ranged from 878.96 mm to 1608.12 mm. Air quality assessments indicated high concentrations of PM_{10} (mean = $263.56 \mu\text{g}/\text{m}^3$) and $PM_{2.5}$ during the dry Harmattan season. Conversely, SO_4 levels were the lowest (mean = $0.52 \mu\text{g}/\text{m}^3$). Correlation and principal component analysis confirmed a strong relationship between climatic parameters and pollutant levels, as well as a notable influence on respiratory health outcomes. The health data revealed a high prevalence of respiratory conditions such as asthma, bronchitis, and cardiovascular disorders, with significant seasonal variation. Perceptions among residents and healthcare professionals corroborated statistical trends, linking poor air quality particularly during dry periods with increased health complications. The study concluded that climate variability exacerbates air pollution levels, which in turn significantly compromises public health in the Metropolis. Proposed adaptive strategies included afforestation initiatives, promotion of LPG usage over biomass fuels, and awareness campaigns on indoor air pollution. Furthermore, strengthening local air quality monitoring systems, mainstreaming environmental health into urban planning, and implementing targeted interventions such as clean energy adoption and community-based environmental stewardship would minimise the overall effect on human health.



TABLE OF CONTENTS

DECLARATION.....	i
DEDICATION.....	ii
ACKNOWLEDGEMENTS.....	iii
ABSTRACT.....	iv
TABLE OF CONTENTS.....	v
List of Figures.....	xii
List of Tables	xiii
ABBREVIATIONS	xv
CHAPTER ONE	1
INTRODUCTION	1
1.0 Introduction	1
1.1 Background of Study.....	1
1.2 Statement of the Problem	2
1.3 Study Questions.....	3
1.4 Aim and Objectives of study.....	3
1.4.1 Aim of Study	3
1.4.2 Specific Study Objectives.....	3
1.5 Research Hypothesis	4
1.6 Study Justification	4
1.7 Thesis Organization.....	5
CHAPTER TWO	6
LITERATURE REVIEW	6





2.0 Introduction	6
2.1 The Conceptual Framework for the Study	6
2.2 Causes of Poor Air Quality	8
2.2.1 Air Pollutants	8
2.2.2 Industrial Pollution	8
2.2.3 Transportation.....	9
2.2.4 Agricultural Practices	10
2.2.5 Residential Heating and Cooking	12
2.2.6 Power Generation	13
2.3 Atmospheric Aerosols	13
2.4 Combustion	15
2.4.1 Chemical Composition of Combustions.....	15
2.4.2 Particulate Matter (PM)	16
2.4.3 Heavy Metals	18
2.4.4 Black Carbon (BC)	19
2.5 Secondary Pollutants	20
2.6 Climate Variability and Air Quality	22
2.6.1 Overview of Climate Variability	22
2.6.2 Trend of Temperature	26
2.6.3 Trend of Rainfall	28
2.6.4 Humidity Trends.....	29
2.6.5 Global Climate Trends	30
2.6.6 Regional Trends.....	32



2.6.7. National Trends	33
2.7 Changes in Air Quality and Pollutant Levels.....	34
2.7.1 Particulate Matter Concentration.....	34
2.7.2 Carbon Monoxide (CO) Levels	34
2.7.3 Sulphur Dioxide (SO ₂) Concentrations	34
2.7.4 Nitrogen Dioxide (NO ₂) Levels.....	34
2.8 Health Hazards of Air Pollution.....	35
2.9 Relationship between Air Quality and Disease Incidence	36
2.9.1 Respiratory and Cardiovascular Diseases.....	37
2.10 Adaptative Strategies.....	37
2.11 Methodical Approaches.....	38
2.11.1 Techniques for Analysing Climate Variability and Air Quality Data	38
2.11.2 Methods for Assessing Health Impacts of Air Quality.....	39
2.11.3 GIS and Remote Sensing in Environmental and Health Studies.....	40
2.11.4 Statistical and Computational Models for Climate-Health Impact Studies	40
2.12 Health Implications of Air Quality Due to Climate Change.....	41
CHAPTER THREE	42
METHODOLOGY	42
3.0 Introduction	42
3.1 The Study Area.....	42
3.2 Study Design	44
3.3 Research Philosophy	44
3.4 Data and Sources	45



3.5 Primary Data	45
3.5.1 Air Pollutant Data.....	45
3.5.2 Meteorological Data	47
3.5.3 Validation	48
3.5.4 Relationship between Air and Climate parameters	48
3.6 Secondary Data Analysis	49
3.6.1 Population.....	49
3.7 Sampling Procedure and Sample Size.....	49
3.7.1 Sampling.....	49
3.7.2 Sample Size	51
3.8 Data Analysis	52
3.8.1 Analysis of Air Pollutants	53
3.8.2 Respiratory Disease Prevalence.....	54
3.8.3 Analysis of Adaptation Strategies	54
CHAPTER FOUR.....	56
RESULTS	56
4.0 Introduction	56
4.1 Validation of PM _{2.5}	57
4.2 Trend Analysis of Meteorological Parameters.....	58
4.2.1 Mann Kendall Trend Analysis of Rainfall	60
4.2.2 Temperature.....	63
4.2.3 Mann Kendall Trend Analysis of Temperature (°C)	66
4.2.4 Relative Humidity (RH)	70



4.2.5 Mann Kendall Trend Analysis of Relative Humidity (%).....	72
4.3 Air Quality Parameters.....	75
4.3.1 Annual Variations.....	75
4.3.2 Monthly variations in air quality parameters.....	78
4.3.3 Trend Analysis of Air Quality Parameters	87
4.4 Effects of Air Quality on Climate Variability	87
4.4.1 Correlation Analysis of Climate and Air Quality Variables	87
4.4.2 Principal component analysis to indicate the sources of air pollutants	92
4.4.3 Influence of climatic factors on air Pollutants.....	95
4.5 Effects of Air Quality and Climate Variability on the Prevalence of Respiratory Illnesses, Cardiovascular Diseases, and Other Health Outcomes	98
4.6 Perceived Prevalence of Respiratory and Cardiovascular Diseases.....	101
4.6.2 Experience Respiratory Diseases (E.G., Asthma, Bronchitis) and Cardiovascular Diseases	103
4.6.3 Prevalence Rates of Respiratory Diseases and Cardiovascular Disorders .	103
4.6.4 Chi-Square Test Results for Association Between Demographics and Disease Prevalence.....	104
4.7 Adaptation Strategies Used by Residence to Enhance Air Quality in the Face of Climate Variability	106
CHAPTER FIVE	108
DISCUSSION OF RESULT.....	108
5.0 Introduction	108
5.1 Trend Analysis of Meteorological Parameters.....	108



5.2 Air Quality Parameters.....	110
5.3 Effects of Air Quality on Climate Variability.....	112
5.4 Effects of Air Quality and Climate Variability on the Prevalence of Respiratory Illnesses, Cardiovascular Diseases, and Other Health Outcomes	115
5.5 Perceived Prevalence of Respiratory and Cardiovascular Diseases.....	130
5.6 Adaptation Strategies Used by Residence to Enhance Air Quality in the Face of Climate Variability.....	140
CHAPTER SIX.....	147
CONCLUSION AND RECOMMENDATIONS	147
6.0 Conclusion.....	147
6.3.2 Concentrations of PM ₁₀ and PM _{2.5} , NO ₂ , SO ₂ , and CO	149
6.3.3 Effects of Climate Variability on the Prevalence of Respiratory and Cardiovascular Diseases	150
6.2.4 Socio-demographic Characteristics of Respondents	151
6.3.5 Prevalence of Respiratory Diseases and Cardiovascular Diseases.....	153
6.3.6 Adaptation Strategies to Enhance Air Quality in the Face of Climate Variability.....	154
6.4 Study Contribution to Knowledge.....	155
6.2 Recommendations	156
6.5.1 Concentrations of Particulate Matter, Nitrogen Dioxide, Sulphur Dioxide, and Carbon Monoxide	156
6.5.2 Pattern of Temperature, Humidity, and Rainfall	157
6.5.3 Effects of Air Quality and Climate Variability on Health.....	158

6.5.4 Perceived Prevalence of Respiratory and Cardiovascular Diseases	158
6.5.5 Adaptation Strategies for Enhancing Air Quality.....	159
6.6 Direction for Future Research	160
REFERENCES.....	161



LIST OF FIGURES

Figure 2.1: Conceptual framework (Source: Author's own construct (2024)	6
Figure 3.1: Map of Tamale Metropolitan	43
Figure 4.1: Annual and monthly average plot of rainfall (mm).....	58
Figure 4.2: Monthly Trend Plots of Rainfall from 1990 to 2023.....	62
Figure 4.3: Monthly Mean, minimum and maximum temperature (°C).....	65
Figure 4.4: Annual Minimum and Maximum temperature (°C).....	65
Figure 4.5: Monthly trend plot of $T_{\min}$ (°C)	68
Figure 4.6: Monthly Trend Plot for $T_{\max}$ (°C).....	70
Figure 4.7: Annual and monthly average plot of Relative Humidity (%)	72
K) Figure 4.8: Monthly Trend Plots of Relative Humidity (RH (%))	74
Figure 4.9: Annual Mean values of $PM_{2.5}$, PM_{10} , O_3 , CO and Dust.....	77
Figure 4.10: Annual mean values of SO_4 and BCC.....	77
Figure 4.11: Monthly distribution of PM_{10} , $PM_{2.5}$ and Rainfall	88
Figure 4.12: Correlation plot of climate and air quality variables	90
Figure 4.13: Plot of O_3 , CO_2 and Rainfall	90
Figure 4.14: Standard Deviation of SO_2 , NO_2 , CO and Temperature across the northern region between high and low concentrations.....	92
Figure 4.15: The PCA chart and loading vectors, indicate the distribution of variables of air pollutants in clusters along PC1 AND PC2.....	95

LIST OF TABLES

Table 3.1: Description of primary data set.....	45
Table 3.2: Sample communities and sample size	50
Table 3.3: Air Quality Index (AQI) results.....	53
Table 4.1: Evaluation Statistics of PM _{2.5}	57
Table 4.2: Monthly values of measures of central tendency for Rainfall (mm).....	59
Table 4.3: Monthly values of measures of central tendency for Temperature (°C) (Minimum and Maximum)	64
Table 4.4: Annual Mean, Maximum and Minimum Temperature (Minimum and Maximum).....	65
Table 4.5: Monthly values of measures of central tendency for Relative Humidity (RH (%))	71
Table 4.6: Trend analysis of temperature, rainfall and relative humidity	75
Table 4.7: Annual mean, maximum and minimum values of air quality parameter	76
Table 4.8: Monthly values of measures of central tendency for PM _{2.5}	79
Table 4.9: Monthly values of measures of central tendency for PM ₁₀	80
Table 4.10: Monthly values of measures of central tendency for SO ₄	82
Table 4.11: Monthly values of measures of central tendency for Dust	83
Table 4.12: Monthly values of measures of central tendency for Black Carbon.....	84
Table 4.13: Monthly values of measures of central tendency for CO	85
Table 4.14: Monthly values of measures of central tendency for O ₃	86
Table 4.15: Total Variance Explained	93
Table 4.16: The PCA loading matrix for the surface air pollutants.....	94





Table 4.17: Analysis of relationship between air quality, climate variability, and health outcomes	100
Table 4.18: Individuals experience of air population	102
Table 4.19: Experience respiratory diseases (e.g., asthma, bronchitis) and cardiovascular diseases	103
Table 4.20: Prevalence Rates of Respiratory Diseases and Cardiovascular Disorders	104
Table 4.21: Chi-Square test results for association between demographics and disease prevalence	105
Table 4.22: Adaptation strategies used by residence to enhance air quality in the face of climate variability	107

ABBREVIATIONS

IPCC	Intergovernmental Panel on Climate Change
GHG	Greenhouse Gas
CO ₂	Carbon Dioxide
O ₃	Ozone
AQI	Air Quality Index
PM _{2.5}	Particulate Matter (diameter $\leq 2.5 \mu\text{m}$)
PM ₁₀	Particulate Matter (diameter $\leq 10 \mu\text{m}$)
NO _x	Nitrogen Oxides
SO ₂	Sulphur Dioxide
CO	Carbon Monoxide
VOCs	Volatile Organic Compounds
WHO	World Health Organization
EPA	Environmental Protection Agency (USA)
ANOVA	Analysis of Variance
GIS	Geographic Information System
UN	United Nations
NASA	National Aeronautics and Space Administration



CHAPTER ONE

INTRODUCTION

1.0 Introduction

This chapter presents the introduction to the research. It gave the background to the study followed by the problem statement. The aim and specific objectives are outlined as well as the significance of the research.

1.1 Background of Study

Climate variability caused by human activities such as burning of fossil fuels is a serious challenge leading to long-term changes in climate patterns all over the world (Beniston, 2013; Reddy & Reddy, 2015). This causes increased temperatures along with changes in the pattern of precipitation, rising sea levels and increased extreme weather conditions with serious consequences for human health, ecosystems, and socioeconomic stability (Kumar et al., 2021; Rogers et al., 2020). Air pollution is a threats to life and the climate system (Bhandari & Bijlwan, 2019). Anthropogenic activities emit pollutants that degrades the quality of air (Boovarahan & Kurian, 2018). The World Health Organization (WHO, 2016) estimated that 92% of the world population is exposed to unhealthy air in regions such as South Asia. African countries face a huge challenge in severe air pollution coupled with vulnerability to climate change impacts (Ayeter et al., 2021; Busolo & Njabira, 2022).

The West African sub-region is recording increased levels of air pollution with important implications for human health and ecosystems (Islam et al., 2023; Sunjo & Fuanyi, 2022). The rise in sea levels and coastal erosion exposes inland areas to high levels of particulate matter and other pollutants (Adedolapo, 2022). These environmental stressors is worsened by the Saharan dust intrusions and extreme



weather events threatening livelihoods in the sub-region (Teye & Nikoi, 2022). Ghana is not exempt from the challenges of rising temperatures and changing rainfall patterns (Bhaga et al., 2020). Climate change-induced air pollution increases the risk of health problems (Kwakwa et al., 2022).

Understanding the relationship between climate change, air quality, and human health helps to develop effective policies and interventions that could reduce their impacts. While some measures have been adopted by Ghana to address air pollution and climate change, constant assessment of their effectiveness is needed in order to identify areas for improvement (Kwakwa et al., 2022).

1.2 Statement of the Problem

Greenhouse gas emissions have been noted to be increasing in the past decade (2010 to 2021) with varied contribution from various sectors including agriculture (8%), transportation and storage (10.7%), manufacturing (14.6%), power (14.8%), construction (14.4%), mining (7%), water supply, sewage, waste management, and remediation (20.6%), households (5.7%) and other service industries (11.7%) (Runde et al., 2022). The problem further get complicated due to the lack of standard diagnostic criteria and reporting methods for health outcomes related to air pollution (Service, 1991).

A critical challenge in Tamale is the absence of air quality monitoring and assessment and its impact on public health which is a disadvantage to communities in the Metropolis. It is for this reason that satellite-based air quality data become useful. Satellite data have large spatial coverage and may provide consistent long-term air quality measurements which are valuable in regions having poor or no



ground-based monitoring. The use of satellite-based data will provide information on air pollution patterns and help address the health challenges. This will ensure the achievement of the United Nations Sustainable Development Goals such as good health and well-being (SDG 3), clean water and sanitation (SDG 6), affordable and clean water (SDG 7) and climate action (SDG 13).

1.3 Study Questions

The following research questions are framed to address key objectives of the study:

1. What were the trends of climate variability in Tamale Metropolis from 1990 to 2023?
2. How has air quality changed over time and what are the dominant pollutants and their temporal-spatial distributions?
3. What relationship exist between air quality and the prevalence of respiratory and cardiovascular diseases in the Tamale metropolis?
4. What adaptation strategies are used to cope with polluted air exacerbated by climate variability?

1.4 Aim and Objectives of study

1.4.1 Aim of Study

The aim of the study is to analyse the impact of climate variability and air quality on human health in the Tamale Metropolis in Ghana.

1.4.2 Specific Study Objectives

The specific objectives of the study include:



1. To establish the relationship between climate variability and health outcomes in the Tamale Metropolis.
2. To identify the major air pollutants and their sources in the Tamale metropolis.
3. To establish the relationship between air quality and various pollutants.
4. To determine the mitigation strategies needed to reduce the effects of climate variability on human health.

1.5 Research Hypothesis

The hypothesis:

- Null hypothesis (H_0): There is no relationship between climate variability and air quality in Tamale.
- Alternative hypothesis (H_1): There is a relationship between climate variability and air quality in Tamale

1.6 Study Justification

Air quality is important to ensure a healthy nation and a public health concern among nations as highlighted in the sustainable development goals (SDG 3). Meteorological variables including temperature, humidity, wind characteristics, and vertical mixing bear upon the emission, transport, dispersion, chemical transformation, and deposition of pollutants are key in determining the quality of air (Kinney, 2008). It is projected that climate change will affect air quality in densely populated areas due to changes in atmospheric ventilation and dilution, precipitation, and other removal processes and atmospheric chemistry (Fiore et al., 2015). Air quality affects human health directly and the ecosystems with implications on



climate change due to feedback loops (Haase et al., 2014; World Health Organization, 2021).

Fang et al. (2013) observed that climate change resulted in a 5% global increase in population-weighted fine particle (PM_{2.5}) concentrations from 1860-2000 and near-surface ozone concentrations of 2% for the same period while Silva et al. (2013) found the change from pre-industrial time to the industrial period occasioned an additional 111,000 and 21,400 premature deaths attributed to fine particles and ozone respectively due to climate change. Thus for every degree of warming °F in the observed data, Ozone concentrations rose by approximately 1.2 ppb from 1997 through 2017 (Bloomer et al., 2009). The relationship between climate variability, air pollution, and human health is important to ensure that preventable deaths from diseases are avoided (Howse et al., 2021). It is further expected that this paper will contribute to literature on climate variability and air quality.

1.7 Thesis Organization

The thesis is organized into Six Chapters. Chapter One introduced the study with the background information and the objectives of the study. Chapter Two reviewed literature relevant to the study. In Chapter Three, the research methodology and techniques used of data collection and analysis is presented. Chapter Four presents the findings of the study followed by results and discussions in Chapter Five. Chapter Six concludes the thesis with recommendations for policy and future research.



CHAPTER TWO

LITERATURE REVIEW

2.0 Introduction

This chapter provides an overview of the theoretical framework and methodological approaches adopted to assess linkages among climate variability, air quality, and human health. It summarizes the main findings and identified gaps in the literature to inform research directions and policy formulation.

2.1 The Conceptual Framework for the Study

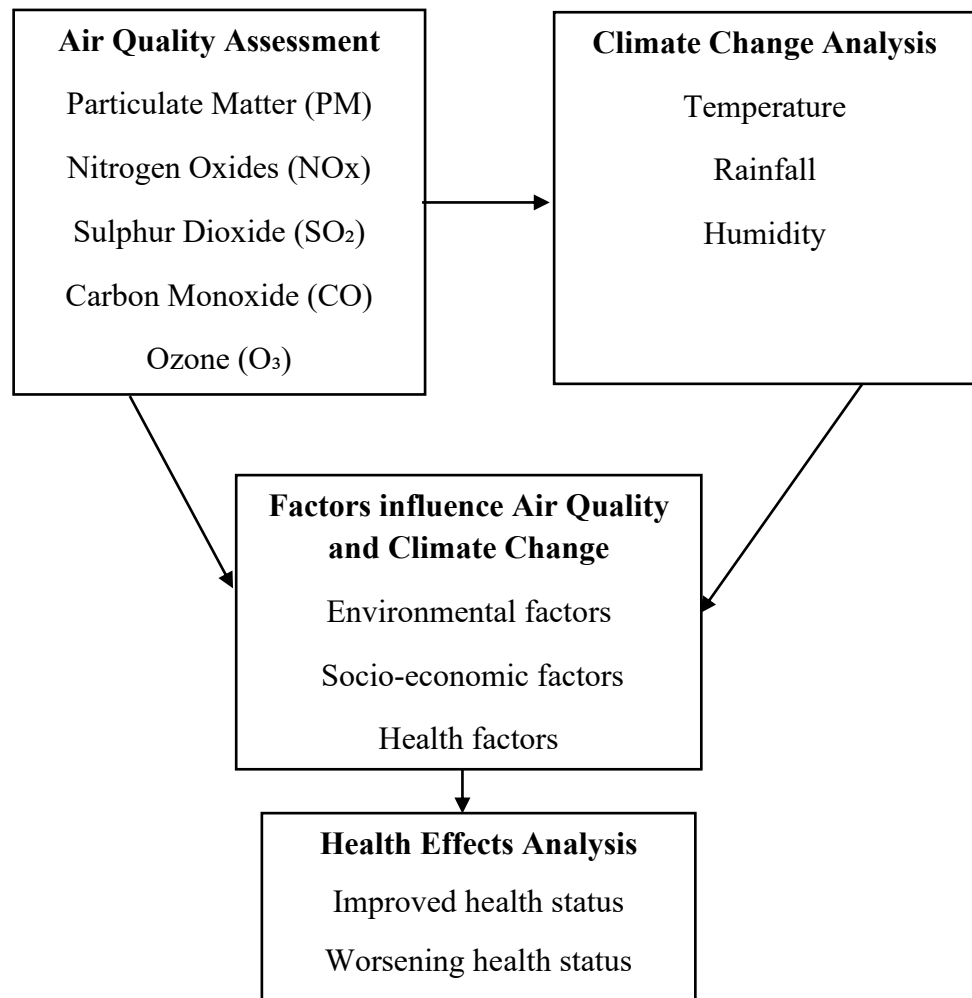


Figure 0.1: Conceptual framework (Source: Author's own construct (2024))



The conceptual framework for the analysis of the relationship between the different components, including air quality assessment, climate change analysis, factors influencing air quality and climate change, and health effects analysis is presented in Figure 2.1.

The measurements of air pollutant levels involving particulate matter (PM), nitrogen oxides (NO_x), sulphur dioxide (SO₂), carbon monoxide (CO) and ozone (O₃) is done with the help of air quality monitoring stations and sensors. Climate change analysis: Research on climate change patterns and trends dynamics puts attention on temperature variations together with precipitation patterns. The analysis can be done with climate data from various sources.

Environmental factors - such as weather conditions, wind direction, and temperature—behave as the most influential air-quality and climate-change determinants. Next are socio-economic factors: high population density, industrialization, transportation, etc. Health factors include respiratory and cardiovascular diseases, allergies, and other health conditions.

Health effects analysis is the research into the relationship that exists among air quality, climate change, and health outcomes. It may be presented through statistical methods, such as correlation analysis, in establishing a relationship between air pollutants, climate variables, and health outcomes.





2.2 Causes of Poor Air Quality

Air quality is the status of air and its impacts on the health of living and non-living things. The presence of pollutants in air influences its quality. It occurs when pernicious chemicals are released into the atmosphere changing its natural characteristics. The major sources of air pollution can be categorized under domestic and industrial. It may also be caused by man-made or natural disasters. The major pollutants that pose significant health risks to humans include particulate matter (PM), carbon monoxide (CO), ozone (O₃), nitrogen dioxide (NO₂), and sulphur dioxide (SO₂). The Air Quality Index (AQI) is a standardized metric used to report the daily status of ambient air, indicating the level of air pollution and its potential short-term health effects. The AQI is calculated based on five key pollutants regulated under the Clean Air Act including; ground-level ozone, particulate matter (PM_{2.5} and PM₁₀), carbon monoxide, sulphur dioxide, and nitrogen dioxide (World Health Organization, 2006).

2.2.1 Air Pollutants

Air pollutants are noxious compounds in the atmosphere that have adverse effects health and the environment. Pollutants are originated from various sources which may be natural sources or caused by human activities.

2.2.2 Industrial Pollution

Industrial operations such as manufacturing and mining constitute a major source of air pollutants such as particulate matter, sulphur dioxide, nitrogen oxides, and volatile organic compounds (Munsif et al., 2021). They are often a product of fossil fuels, chemical reactions, and exhaust from machinery. Fossil fuels are the major

source of pollutants including carbon dioxide, sulphur dioxide, nitrogen oxides, and particulate matter (Schauer, 2015).

Most industrial processes involve the use of chemicals that produce hazardous byproducts (Kanan & Samara, 2018). Smelters, refineries, and cement mills emit poisonous chemicals into the atmosphere. The pollutants contain toxic elements like lead and mercury that are injurious to human beings and other animals (Sankhla et al., 2016).

2.2.3 Transportation

The transport sector is one of the major contributors to air pollution, especially in urban areas. Petrol and diesel-powered vehicles emit a variety of pollutants including carbon monoxide, nitrogen oxides, volatile organic compounds, and particulate matter. In addition, aeroplanes and ships send out pollutants to the atmosphere (Adeyanju & Manohar, 2017). In addition, it is not a question of contributing to local air quality problems only; the use of fossil fuels in transportation contributes greatly to global climate change through the emission of greenhouse gases, including carbon dioxide. Petrol and diesel engines emit a mixture of pollutants, including carbon monoxide, nitrogen oxides, volatile organic compounds, and particulate matter. These emissions have serious health effects on both humans and the environment. Carbon monoxide (CO) is a toxic gas with no health benefits, especially in indoor environments. Nitrogen oxides (NO_x) contribute to the formation of ground-level ozone and smog; these have been linked with respiratory diseases (Manisalidis et al., 2020a). Volatile Organic Compounds (VOCs) substantially contribute to the formation of ground-level ozone and, thus, generate harmful air pollutants. Particulate matter, especially fine particles, can





penetrate into the lungs, and hence there lies the possibility of developing health complications. Emissions from transportation have a very big effect on the degradation of air quality in urban settings (Mac Kinnon et al., 2019). The burning of fuel in these automobiles results in the emission of pollutants, which then form smog, reducing the visibility and causing health hazards to the residents in these areas. Demographics that are more at risk from these pollutants include children, the elderly, and people suffering from respiratory diseases. The burning of fossil fuels by motor vehicles emits greenhouse gases, mainly carbon dioxide (CO₂), which is the major contributor to the enhanced greenhouse effect and the overall phenomenon of global warming. This has increased global atmospheric levels of CO₂, hence changing worldwide climatic patterns into rising temperatures, altered precipitation, and increased instances of extreme weather events (AghaKouchak et al., 2020).

2.2.4 Agricultural Practices

Agricultural activities cause air pollution. Fertilizers and pesticides release ammonia and other chemical compounds to the environment. Livestock and other animals excrete ammonia and methane compounds to the environment. Additionally, burning of crop leftovers sends particulate matter and other pollutants to the atmosphere.

Application of fertilizers and pesticides impinges on the quality of air. These chemicals get emitted into the atmosphere through some processes that contribute to the formulation of air pollutant (Abbasi et al., 2014). Nutrient fertilizers such as nitrogen, phosphorous and potassium gets applied to plants in solid and liquid form. Plants absorb those nutrients and afterward, release to the atmosphere in the form ammonia volatilization. This is attained through a mechanism by which ammonia,

the byproduct emanating from nitrogen metabolism taking place in plants, is converted to the gaseous ammonia released to the atmosphere. The chemicals making up smog are synthesized through photochemical degradation of nitrogen-containing fertilizer. Nitrogen oxides, which are responsible for the synthesis of ground-level ozone, are a major constituent of smog and a source of great concern for public health (Geddes & Murphy, 2012).

In addition, pesticides emit air pollutants in the form of volatile organic compounds (VOCs) that evaporate from the soil surface or plant into the atmosphere. Volatile organic compounds (VOCs) also react with other atmospheric substances to form secondary pollutants, including ground-level ozone and fine particles (Hien et al., 2022).

Livestock farming results in huge amounts of wastes that comprise manure, urine, and other organic materials. Animal husbandry is a contributor to air pollution. Animal excreta are sources of ammonia emission. Upon decomposition of the wastes, the produced ammonia goes to the atmosphere. Ammonia further reacts with other atmospheric compounds to form small particles that are harmful to human health as well as the environment (Behera et al., 2013).

Methane, a by-product of enteric fermentation in the gastrointestinal tracts of ruminant animals, is a potent greenhouse gas. It has 28 times greater global warming potential than carbon dioxide over a period of 100 years. An increased world population will therefore bring about increased emissions of methane by livestock husbandry and thereby aggravate climate change (McCormack, 2021).



Bush burning sends huge amounts of particulate matter, among other pollutants, into the atmosphere, including fine particles, carbon monoxide, nitrogen, and sulphur compounds (Chaudhary & Soni, 2020). Particulate matter is composed of very small-sized particles dispersed throughout the atmosphere and is harmful to the health of individuals, most particularly those with prior respiratory conditions. These particles can settle deep within the lungs and even enter the bloodstream, causing many diseases and early deaths. Second, particulate matter has hazardous environmental effects related to air quality deterioration and visibility degradation; it takes part in the formation of smog and acid rain (Anwar et al., 2021).

2.2.5 Residential Heating and Cooking

Emissions from the burning of wood and charcoal by traditional stoves and fireplaces emit particulate matter and carbon monoxide among other pollutants into the atmosphere. Poor ventilation of cooking stoves might, in addition, give rise to indoor air pollution- a source quite harmful to human health (Organization, 2014). Traditional stoves and fireplaces normally burn solid fuels and release harmful pollutants into the air: carbon monoxide, nitrogen oxides, sulphur dioxide, and volatile organic compounds. Particulate matter may be so fine that it could penetrate deep into the lungs, and some particles can even find their way into the bloodstream under certain conditions. Health problems possibly linked to particulate matter are, but are not limited to, respiratory ailments, cardiovascular ailments, and perhaps premature death. Further, poor ventilation can lead to high indoor air pollution levels with all their adverse health effects.



2.2.6 Power Generation

Coal, oil and natural gas power plants emit sulphur dioxide, nitrogen oxides, mercury, and other harmful substances. Power plants discharge varied pollutants to the atmosphere. These have very important consequences on human health and the environment (Seiyaboh & Izah, 2019). The sulphur dioxide and nitrogen oxides also cause acid rain that kills forests, aquatic life, and human-made structures. Particulate matter and other air pollutants directly challenge human health. One of the hazardous elements is mercury that bioaccumulates in the food chain and hence is a severe threat to humans and animals as it causes neurotoxicity (Kumari & Chand, 2023). Wind and solar power are the two most promising alternative sources of energy to the conventional power plants (Ellabban et al., 2014). Transition to the greener sources of energy is not without its challenges. Thus, there is an urgent requirement to expand and advance the infrastructure necessary for generation of renewable energy like wind turbines and solar panels to meet the growing need for power. In addition, the infrastructure of the integration of these green energy sources with already available power grids is complex and needs huge capital investment.

2.3 Atmospheric Aerosols

Atmospheric aerosols are created from gas-to-particle photochemical reactions and by the direct emission of solid particles and liquid droplets into the atmosphere.

They can also be defined as substances in a condensed phase that are dispersed in a gas as distinct units (Lamb & Verlinde, 2011). Aerosol particles have large variations in size, shape, chemical composition, and optical properties. These chemicals can negatively affect the world (Finlayson-Pitts & Hemminger, 2000). Some aerosols are able to undergo a set of physical and chemical processes and



transformations in the atmosphere and, thereby forming new particles, which are dissimilar in size, shape as well as composition. It occurs due to a chemical reaction, which basically is caused by the presence of water vapor and other particles present in the atmosphere. Aerosols can be primary or secondary. The secondary aerosols are formed through the local chemical reactions involving specific particles, and are not directly emitted into the sky like the primary aerosols are (Tomasi & Lupi, 2017). Some of the pollutants are formed from primary pollutants, which makes them both primary and secondary. These secondary pollutants can be emitted into the atmosphere directly (Huang et al., 2014). The major pollutants causing significant damage at high concentrations include carbon molecules including CO, CO₂, CH₄, and VOCs; nitrogen compounds including NO, N₂O, and NH₃; and sulphur compounds including H₂S and SO₂.

Some of the secondary pollutants, which also have been identified to be harmful at high concentrations, include: NO₂ and HNO₃, both formed from nitrous oxide; ozone (O₃) formed from photochemical reactions of nitrogen oxides and VOCs; sulphuric acid droplets formed from SO₂; and nitric acid droplets formed from NO₂. Sulphates and nitrates aerosols, e.g., (NH₄)₂SO₄ and NH₄NO₃ are formed from the reactions of sulphuric acids droplets and nitric acid droplets with NH₃ respectively. Thus, more focus was paid to organic aerosols from VOCs in gas-to-particle reactions (Dotse et al., 2012; Seinfeld & Pandis, 2016), whereby some of the newly formed particles can indeed survive for hours and even days - days and sometimes weeks - leaving emissions of the source region to move further away into the atmosphere by changing properties in line with prevailing meteorological conditions.



2.4 Combustion

Combustion is a chemical process phenomenon that occurs when fuel and oxidizer combined results in the production of smoke at high temperatures (Lackner et al., 2013). It comprises of a series of complex chemical reactions. Combustion has many sources but the atmosphere has been considered to be the major pathway for distribution of combustion related pollutants. These pollutants include organic compounds such as polycyclic aromatic hydrocarbons (PAHs) and heavy metals such as lead (Pb) (Abdel-Shafy & Mansour, 2016). Combustion sources are further classified as either area or point, permanent or transportable, and outdoor or interior sources. Outdoor and mobile sources include activities such as the incineration of gasoline in motor vehicles, aeroplanes, boats, and small machinery like lawn mowers (Mitchell & Sweeney, 2018). On the other side, outdoor and stationary sources include industrial plants, power plants, refineries, and the like. Indoor combustion sources include cooking, heating, and smoking. Rural combustion sources in developing countries are vastly different from most urban areas. Indoor air pollution at rural areas is greater than that coming from outside metropolitan areas (Spiru & Simona, 2017). Combustion is the source that emits, in large amounts, particulate and gaseous pollutants with serious health and environmental consequences. Other sources of combustion include industrial-related, vehicular emissions, and combustion from biomass and fossil fuels (Boreddy et al., 2021).

2.4.1 Chemical Composition of Combustions

The major chemical composition of combustion includes trace metallic elements such as: potassium (K), chlorine (Cl), sulphur (S), aluminium (Al), silicon (Si), phosphorus (P), zinc (Zn), lead (Pb), and iron (Fe), along with polycyclic aromatic



hydrocarbons (PAHs) and black carbon, which constitute particulate matter (Meka, 2020). Combustion will similarly emit other gases like carbon monoxide (CO), carbon dioxide (CO₂), nitrogen oxides (NO_x), sulphur dioxide (SO₂), hydrocarbons (HC) and water vapour, (Rahman et al., 2018). Metallic elements in dust or fine sprays in minute quantities if inhaled, irritate the eyes, nasal passages and the respiratory system which brings about sneezing coughing and throat discomfort, (Nemery, 2022). In larger quantities, it is even fatal. Nitrogen Oxides: NO_x triggers pulmonary inflammation and, in the same line of action, cripples the immunological protection mechanism of the human body, making it more vulnerable to various kinds of respiratory illnesses, including pneumonia and influenza (Schlesinger & Lippmann, 2020). NO_x contributes to atmospheric particulate matter by 33% (Pacheco et al., 2017).

Carbon monoxide: It is colourless, odorless gas from the burning of fossil fuels; it has contributed to about 66% of the pollution. The component, while inhaled, blocks the flow of oxygen to the brain, heart, and other major organs in a human body. The biggest victims of carbon monoxide are infants and those suffering from chronic diseases (Gozubuyuk et al., 2017). Sulphur dioxide (SO₂) is a damaging pollutant of combustion containing sulphur with prejudicial effects on the well-being of young children and asthmatic persons (Valavanidis et al., 2008).

2.4.2 Particulate Matter (PM)

Particulate matter is a complex mixture of solids and liquids having both organic and inorganic components (Gieré & Querol, 2010). It has suspended particulate matter together with other chemicals found in the atmosphere. The sources are natural and anthropogenic (Sonwani & Saxena, 2016). Certain particles are



sufficiently large or dark enough to be visible to the naked eye. Some are small enough to be viewed only on an electron microscope. Particulates can vary in size, between 0.01 and 100 μm in diameter (Conen et al., 2015).

Those with diameters less than 100 nm (0.1 μm) are in the ultra-fine or Aitken mode. Particulate matter, PM, designates solid or liquid particles found in the air. Particulate matter, PM, whose diameter is less than 2.5 μm is, therefore, known as a micro aerosol or, more commonly, PM_{2.5} (R. Zhang et al., 2015). On the other hand, particles with a size that ranges from 2.5 μm up to 10 μm are referred to as coarse particles and are sometimes considered as PM₁₀. Particles that have been emitted from the gas phase and afterwards coagulated formed the fine or accumulation mode that is sometimes regarded as respirable particulate matter (Feng et al., 2009). The coarse mode consists of particles that have been mechanically abraded or ground. Respirable particles are a synonymous term for small particulates. The residence time of particles in the atmosphere is a function of their aerodynamic size. Naturally occurring particles, such as dust and sea salt, are predominantly found in larger sizes and thus settle more rapidly than those aerosols produced by anthropogenic activities. Observations are made on how the concentration, composition, and size distribution of aerosol particles change over time and in space in the atmosphere. Finally, particulates are removed irreversibly from the atmosphere through two great mechanisms. The process by which particles are, under the force of gravity, deposited onto the ground, plant leaves, or bodies of water, is termed dry deposition (Kouznetsov & Sofiev, 2012). Alternatively, they can merge with cloud droplets during the process of raindrop formation, a process known as wet deposition. These usually occur over relatively short periods, from days to weeks, since their formation



and subsequent transport over distances ranging from a few meters to a few thousand kilometres are generally occurring (Caduff et al., 2015). Particles grow in size by collision and aggregation until they reach a settling state. Settling velocity in a quiescent atmosphere is a result of the equilibrium of two forces acting on a particle, which are the frictional force and the gravitational force. The biggest menace to human health is microscopic particles, which have the ability to invade the respiratory system massively. Examples of fine particles include asbestos fibres, cigarette smoke, car exhaust pollution, and biomass smoke (Brugge, 2018).

2.4.3 Heavy Metals

Heavy metals can be defined as chemical elements having high density and are toxic, even in minute quantities. Some transition metals, metalloids, lanthanides and actinides are included under heavy metals. The heavy metal elements, which are emitted from the exhaust of diesel engines, are Mercury (Hg), Arsenic (As), Lead (Pb), Cadmium (Cd), Chromium (Cr), Nickel (Ni) and Thallium (Tl). They hold quite an amount of environmental risk due to their toxicity and dispersion. In contrast to most organic pollutants, such as organochlorines, heavy metals are naturally occurring in the earth's crust. It is, therefore, present in soils and rocks, which results in a wide variability of naturally occurring concentrations in sediments and streams. Human activities can lead to high levels of metals compared to the normal background concentrations (Mikkonen et al., 2018).

Most heavy metals are toxic to organisms at relatively low concentrations. Metals such as iron, copper, manganese, and zinc are known to be important constituents. Generally, organisms exert homeostatic control over concentration levels of such essential elements and vary their uptake from the environment according to their



nutritional needs (Wood et al., 2012). Organisms experience harmful effects in cases where either the regulatory mechanism goes awry because too few or too many ions are there. Deficiency and excess may both be dangerous to the organisms, and may transport toxic metals, generally through air with water or attached in the form of chemicals or gases within the particulates. They bioaccumulate in organisms through direct absorption from the environment through the body wall, as well as via respiration and ingestion. Nutritional intake entails the assimilation of heavy metals, which although bound to particles on the leaf's surface, have not been taken up by the plant (Ofosu et al., 2012). Industrialization has increased the overall environmental burden of toxic heavy metals and made it very difficult for individuals to be out of reach with these hazardous compounds. However, individuals can take measures to learn about and minimize this threat by using preventive measures and therapies that will reduce the harmful effects on health.

2.4.4 Black Carbon (BC)

Black Carbon (BC) gets its name from its typical colour. Black carbon is, in itself, graphite-like in structure. It, however, includes functional groups composed of oxygen, sulphur, hydrogen, and nitrogen, which can also serve as a promoter for catalytic reactions. Soot is among the significant components of combustion residues. The black fraction of carbonaceous aerosol contains elemental carbon and highly polymerized organic molecules (Safo-Adu et al., 2014). It is a greenhouse gas, emitted from the incomplete combustion of fossil fuels, biofuel, and biomass; it is known to possibly change the climate. It is normally emitted into the atmosphere by means of both anthropogenic activity and naturally occurring soot. Mainly, higher concentrations of black carbon are able to reach indoor habitats, mainly coming from





cooking operations carried out with different biofuels such as wood, dung, and crop waste. The major contributors to outdoor air pollution are the combustion of fossil fuels. Soot aerosols can absorb and scatter solar radiation (Yang et al., 2016). Sources of black carbon emission can be distinguished into several types according to their high concentration. These include the use of diesel engines, the combustion of solid fuel for industrial and domestic purposes, and the general process of open material burning. Open burning of forests and savannas is considered among the larger sources of such emission at a global level. Emissions equally result from the combustion of coal and biomass by up to 60 to 80% through the whole continent of Asia to Africa (Bensch et al., 2021). In contrast, emissions in Europe, North America, and Latin America come mainly from on-road and off-road diesel engines that contribute to over 70% of the total emissions (Begum et al., 2011). Anthropogenic activities that lead to black carbon emission are concentrated within tropical regions having the largest sun radiation. Black carbon tends to be transported over long distances where it is mixed with other aerosols (Safo-Adu et al., 2014). Diesel emissions contribute a lot to the presence of elemental carbon, which is used as an indicator of urban pollution. The United Nations Development Programme (UNDP, 2014) (Organization, 2014), indicated that carbon emission per ton in Ghana was 0.4 in the year 2011. The major concern with black carbon concentrations in air particulate matter is its health effects.

2.5 Secondary Pollutants

Secondary pollutants are produced by the chemical reaction of primary pollutants with other chemicals. The secondary pollutants are divided as ground-level ozone and sources of ozone.



One example of secondary pollutant is tropospheric ozone, otherwise known as ground-level ozone. Photochemical smog results when nitrogen oxides (NO_x) and volatile organic compounds (VOCs) come in contact with sunshine at a higher temperature (Ibrahim, 2019). The production of ozone at the ground level goes up with most of the available compounds like nitrogen oxides, hydrocarbons, and many other pollutants present (Ibrahim, 2019).

Nitrogen oxides NO_x: These are a class of highly reactive gases made up of nitrogen and oxygen. They are released from the combustion of fossil fuels.

Volatile organic compounds-VOCs: These are carbon-containing chemicals that vaporize easily into the air (Yuan et al., 2010).

Both nitrogen oxides and volatile organic chemicals react in the presence of sunlight and higher temperature through a series of photochemical reactions. As a by-product of these processes, there is the production of ground-level ozone. Solar radiation supplies the energy that makes it possible for these reactions to occur; however, high temperatures raise the rates at which these reactions proceed (Roslan et al., 2018).

Apart from nitrogen oxides and volatile organic compounds, there are just a couple of other chemicals present in the atmosphere that also take part in forming ground-level ozone. The most important nitrogen oxides in this respect are nitrogen dioxide (NO₂) and nitric oxide (NO). Hydrocarbons play a part in the chemical processes leading to the production of ground-level ozone (Wu & Xie, 2017).

Ozone is a very reactive gas, and it has devastating effects on people, the ecosystem, and also the economy. When inhaled, ground-level ozone results in many respiratory problems. Moreover, ozone affects plant life, hence causing adverse effects on the ecosystem, and also it contributes to global warming (Emberson, 2020).



Ozone exposure causes severe respiratory problems, especially to the susceptible groups that include children, the elderly, and those with pre-existing diseases of the respiratory system. Exposure to ground-level ozone may cause pulmonary inflammation and damage by inhalation, producing symptoms such as breathlessness, wheezing, and respiratory distress. Long-term exposure has been associated with increased incidence of lung cancer, cardiovascular disease, and other severe health effects (Zhang et al., 2019).

Ozone is destructive to the ecosystem. The gas damages tissues in plants, which results in reduced growth rates, reduced crop yields, and, in extreme cases, death. Ozone-induced damage in forests contributes to ecosystem disturbances and climate change by reducing the potential of trees and plants to absorb carbon dioxide from the atmosphere (Agathokleous et al., 2022).

Economic impacts of ozone-pollutant effects: The negative effects of ozone have economic impacts on human health and the environment. Increased health care costs associated with diseases of the respiratory system and other health problems related to ozone exposure impose a heavy burden on individuals and the health care system. In addition, agricultural production losses and natural ecosystem degradation bring about financial loss (Organization, 2021).

2.6 Climate Variability and Air Quality

2.6.1 Overview of Climate Variability

Climate variability denotes deviations of features, that is, temperature and precipitation of climate from the average. It involves all changes in the climate that are longer than singular weather events and comes about because of natural and

periodic changes taking place in circulation in the atmosphere and ocean, volcanic eruptions, among others (UCAR, 2024a). In general terms, the climate variability takes place when the interaction of climate components leads to the movement of heat within the climate system (Core Writing Team, 2014).

The problems of climate variability and air quality are interlinked so that they can be solved at the same time through mitigation actions (Seinfeld & Pandis, 2016). Climate forcing can result from air pollution. For instance, ozone (O_3) in the lower part of the Earth's atmosphere can raise the temperature, while some aerosols, such as nitrate (NO_3^-) and sulphate (SO_4^{2-}), which are major components of fine particulate matter ($PM_{2.5}$), can lower the atmospheric temperature by reflecting the sun's radiation back to space (Sivakumar & Ramya, 2021). Apart from this, climate change can also influence the formation, loss, and transportation of $PM_{2.5}$ and O_3 (Chen et al., 2019). Climate change may influence the rates of photochemical processes as well as atmospheric degradation (Vione & Scozzaro, 2019). Apart from this, it may also impact air quality by changing the global circulation dynamics (Pausata et al., 2015). Groisman et al (Groisman et al., 2013) hypothesized that a reduction in the frequency of mid-latitude storms over southern Canada would result in more frequent midsummer pollution episodes over both the Midwest and Northeast regions of the United States. (Horton et al., 2014) estimated that both the frequency and persistence of atmospheric stagnation episodes would increase by the end of the twenty-first century. This forecast suggests that the air quality will become worse and human health problems due to it would increase tremendously in the future. The changing climate might impact the natural biogenic emission, which are



necessary for forming $PM_{2.5}$ and O_3 in the rural areas. The emissions can be influenced by changes in temperature, water vapour and CO_2 concentration.

(Jacob & Winner, 2009) applied global and regional chemical transport models to explore separately and together the impact of global and regional future temperature and emissions on air quality at the global and regional scale. Climate change is expected to lower O_3 levels in remote regions because of increased humidity and will raise the levels of O_3 in urban and polluted areas due to the rising temperatures, (Jacob & Winner, 2009). The effect of climate change on $PM_{2.5}$ is less clear, as the constituents in $PM_{2.5}$ respond diversely to the changes in climatic conditions (Fiore et al., 2015). The sources of GHG emissions and air pollutions are shared (Gao et al., 2018). More precisely, the combustion of fossil fuels is the major source of both GHGs and air pollution. Regulatory measures implemented for one may affect the other. Putting climate policies into practice to abate GHG emissions not only helps to reduce climate change but also improves air quality and human health.

This will result in greater indoor air pollution with health-hazardous implications and contribute to climate change through the emission of soot particles (Corsini et al., 2019). More importantly, unsustainable wood harvesting for fuel purposes leads to forest destruction, degradation of forest ecosystems, loss of habitats, and depletion of biodiversity (Abanikannda & Dantani, 2021).

Africa has already experienced raised temperatures: the probability of it continuing to do so is very high. The most precise predictions of temperature increase, by far, hover between $1.3-3.2^{\circ}C$ 125. The vast uncertainty range also goes with uncertainties about the magnitude by which climate change will affect air pollution





and in what way it will affect it (Fankhauser, 1997). Climate change is expected to impact the formation and removal processes of atmospheric pollutants hence altering their timing and spatial distribution (Seinfeld & Pandis, 2016). Changes in precipitation patterns as projected for Africa (Davies et al., 2013) impact wet scavenging by depositing particulate matter, PM, and water-soluble trace gases such as sulphur dioxide, SO₂. Such changes result in increased levels of pollution in arid areas (D'Amato, Holgate, et al., 2015). Warmer temperatures result in higher productions of ozone (O₃) and particulate matter (PM) (Megaritis et al., 2013). Projections indicate that global O₃ concentrations will rise by 5% and PM_{2.5} concentrations over North America will rise by 2% by 2021 (Brunekreef et al., 2021). Thus, it is likely that PM (Zhang et al.) will increase over most of Africa due to increasing temperature but increase in O₃ (Pope 3rd) levels only in central and southeastern regions (Pommier et al., 2018). Most notably, due to increased urbanization, atmospheric levels of anthropogenic pollutants are expected to increase sharply for greenhouse gases over West Africa. By the year 2030, these pollutants are expected to become more important (Amann et al., 2013). Particulate matter coming from sources that are situated in the opposite direction of the wind, coming from urbanized areas, contributes to the pollution in the urban air. These sources are impacted by changes occurring in precipitation patterns, and these have the potential to carry more of the wind-borne dirt and dust from the deserts into the metro areas (Middleton, 2017). Climate change has the potential to impact both occurrence and intensity of wildfires (Jones et al., 2020).

However, a very small loss of air quality resulting from climate change translates to negligible health impacts compared to total exposure to air pollution and all the other

consequences of climate change, such as heatwaves and intense weather events (D'amato et al., 2016). While there were considerable differences comparing the mortality rate derivations derived worldwide using the earlier models of anthropogenic climate change. The mean number of fatalities as a result of exposure to O₃ was 1,500, and the mortality due to exposure to PM_{2.5} was at 2,200 (Silva, 2015). Mitigation of the short-lived climate forcers, namely soot, nitric oxide and methane are considered vital to keep warming below 1.5°C says the IPCC (Core Writing Team, 2014). Moreover, the reductions would amount to better air quality; further benefits would flow.

2.6.2 Trend of Temperature

The Inter-Governmental Planning on Climate Change (IPCC) (Core Writing Team, 2014) reported that the estimated rise in global temperatures during the 21st century would be lower than the rate of warming that has occurred in Africa. Several research works have established that temperature in West African could possibly rise by 3-60 C relative to the baseline of late 20th century. It included the CMIP3 General Circulation Models (GCMs) under the SRES A2 and A1B Scenarios and the CMIP5 GCMs under the RCP4.5 and RCP8.5 scenarios. There have been many temperature measurements made in Sub-Saharan Africa (SSA).

The Inter-Governmental Panel on Climate Change IPCC, said on its Core Writing Team (2014) (Core Writing Team, 2014), the temperature near the surface of West Africa and the Sahel has risen over the past half a century. (Dash & Mamgain, 2011) also reported that in a period running from 1980 to 2010 there is an upward trend in frequency of warm days and nights coupled with a decline in the number of cold



days and nights. Ghana has a tropical climate with variations of temperature according to the seasons and elevation.

However, there has been a steadily increasing trend in the mean temperature over time, with the annual mean temperature ranging between 24°C and 30°C. The warming trend in the temperatures of the northern sector of Ghana has been much faster and increased as compared to the southern sector. Moreover, the maximum temperatures in Accra, which is the capital city of Ghana, have been occurring closer together and follow a clear trend of warming. The temperature trends, as witnessed in Ghana, bring concerns to the fore about possible impacts on agriculture, health, and ecosystems. This has huge implications for rising temperatures: reduced agricultural production, increased water scarcity, and changes in the timing and spatial distribution of rainfall—all very pertinent to food security and livelihoods (Aggarwal & Singh, 2010). It can also exacerbate health conditions in relation to the diseases of heat stress, dehydration, and respiratory illnesses. This goes to another element of temperature in relation to ecological systems where its fluctuation negatively impacts biodiversity, ecological services, and natural resources. For instance, temperatures in Ghana have shown a continuing upward trend over the years since the average temperatures have been ranging between 27.3 to 28.3 degrees Celsius between 1901 and 2021. The climate of Ghana is basically tropical and highly dominated by the monsoon winds blowing from West Africa hence it varies with the seasons and height which at present time is at its ebb between 24 and 30 degrees Celsius (Berry, 2022).

The rate of rising in temperature in the northern part has been more than the south. From 1960 to 2001, the mean annual air temperature over the coastal part of Ghana



increased by 0.9 °C. The maximum temperature increased by 2.5 °C and the minimum by 2.2 °C. There has been a noted increase in the occurrence of the warmest months in Accra, which gives a clear indication of a warming pattern. Rising temperature trends in Ghana have raised concern about possible impacts on various sectors, including agriculture, health, and ecosystems. The effects of temperature variability have been experienced in the country with an increase of 1.0°C from 2022 to 2023 as indicated by (Amoak et al., 2023).

2.6.3 Trend of Rainfall

Projections of changes in rainfall patterns over SSA for the mid-to-late 21st century are highly uncertain (Core Writing Team, 2014). Downscaled projections under high-emission scenarios suggest that those regions with high elevation or complex topography, such as the Ethiopian Highlands, may generally experience more rainfall toward the end of the century.

Harrison et al., (2019) observed a decreasing tendency in annual rainfall over SSA and particularly over West Africa and the Sahel region. Similarly, Spinage & Spinage (2012) reported that between 1968 and 1997, the total rainfall in the semi-arid and sub-humid areas of West Africa was 15–40% less than it was during the period from 1931 to 1960. A major difficulty in estimating long-term trends in rainfall is the lack of good observational data on patterns of annual precipitation over Africa

The World Bank Climate Change Knowledge Portal puts it that northern Ghana has a single rainy season that usually runs from May to September, whereas southern Ghana has two distinct rainy periods: April–July and September–November (Atiah



et al., 2021). The annual rainfall in this northern region ranges from 500 mm to 1200 mm, with the highest amount falling between May and September (Asamoah & Ansah-Mensah, 2020). The changing rainfall patterns in Ghana are of concern for their potential impacts on agriculture, water resources, and ecosystems (Buxton, 2018). Poor rainfall may result in reduced yields in crops, while changes in seasonal distribution and spatial patterns of precipitation may impact food security and livelihoods substantially. Changes in the pattern of precipitation may also disrupt ecosystems through changed species composition, ecosystem functions, and availability of natural resources.

2.6.4 Humidity Trends

Humidity levels in Ghana vary regionally and seasonally, since the country is influenced by the West African monsoon winds. Generally, the climate is that much warmer throughout the country, with seasonal variations resulting from elevation. In Accra, mean relative humidity remains about 83% most times of the year, peaking to about 87% in August and falling as low as 78% in January. Relative humidity is highest in September (85%) and February (81%), which coincides with increased rainfall between March and May (30–134 mm) (Asante & Amuakwa-Mensah, 2014).

Accra's average daily high temperature is 31°C, which makes it feel humid and tropical. When the temperature reaches 25°C, the relative humidity is 40%, corresponding to 9.2 grams of water per cubic meter of air, which feels muggy. Comparatively, the northern sector of Ghana has an average absolute humidity of 13.5 grams (Wiru et al., 2020).



2.6.5 Global Climate Trends

Climate variability is caused by many factors, including natural fluctuations such as the El Niño–Southern Oscillation (ENSO). While natural variability is an important component in the patterns of climate, climate change has strengthened the frequency and intensity of extreme events. Scientists continue to study the interactions between climate change and natural variability to understand the dynamics.

Air pollution, whether in the short- or long-term, poses serious health risks, from contributing to cases of stroke to chronic obstructive pulmonary disease (European Environment Agency, 2023). Based on various complications related to its exposure, air pollution has been associated with health effects according to the World Health Organization. International Agency for Research on Cancer classifies PM_{2.5} as a group one carcinogen due to chronic exposure affecting several body organs, particularly exacerbating illnesses of prior causation.

Monitoring air quality is very critical for the protection of public health, environmental sustainability, and the enforcement of air quality legislation. Efficient air quality management requires an assessment of atmospheric composition and the detection of harmful pollutants for the implementation of necessary interventions.

Climate variability refers to changes in air quality, temperature, and precipitation within naturally occurring climatic conditions. This internal climate variability is induced by the atmosphere-ocean-land-ice system and is driven mainly by ENSO and volcanic eruptions. Human-induced climate change, being the cause of GHG emissions, change in land use, and aerosols, gives additional forcing to the climate



system. Researchers try to separate natural climate variability from anthropogenic climate change so as to understand long-term trends.

Climate variability has had direct impacts on environmental and social development, including food security, water availability, biodiversity conservation, and public health (Mishra et al., 2010; Patz et al., 2005; Willis & Bhagwat, 2009). Knowledge about climates and their patterns can help explain how some of the big challenges in the world, such as resource scarcity and ecological degradation, are addressed (Costello et al., 2009; Tang et al., 2015; Tuanmu et al., 2013).

Numerous analyses have been done on climate trends at different spatial and temporal scales. For example, (Hansen et al., 2006) analysed global temperature change and its possible consequences for sea-level rise and extinction of species. On the other hand, (Sinha et al., 2015) did an analysis of monsoon rainfall trends over the last two millennia in South Asia to evaluate the relative role of natural variability versus anthropogenic drivers in modulating this trend.

Recent research has focused on chaotic dynamics in climate systems, which are highly variable (Christiansen, 2003; Harrouni & Guessoum, 2009; Nunes et al., 2011). Trend analyses capture general climate changes, but they do not depict inherent variability, which impacts human health, agriculture, and ecosystems (Pelletier & Turcotte, 1999). Climate variability influences the fundamental conditions of farming-soil moisture, heat, and sunlight-thus directly impacting agricultural productivity and economic development (Alexandrov & Hoogenboom, 2000).





Long-term climate dynamics and quantification of variability have also been addressed by several studies, such as the use of dimensional analysis by (Xu et al., 2016) in the examination of rainfall variability in Xinjiang, China, which indicated a strong relation between daily variability and elevation. (Biondi et al., 2001) used tree-ring chronologies to examine decadal sea surface temperature variability in the North Pacific and showed that the variability started weakening in the late 1700s. (Morata et al., 2006) combined self-organizing maps and wavelet analysis to investigate precipitation variability over the Iberian Peninsula, reporting a declining trend. (Bodri, 1994) also used fractal analysis to analyse temperature fluctuations in Hungary. These studies have emphasized the complexity of climate variability and its deep implications for ecosystems, agriculture, and socio-economic development.

2.6.6 Regional Trends

Climate variability in West Africa and Ghana has strong impacts on livelihoods, food security, economic stability, and governance. From the 1970s to date, extreme climate variations have been associated with high losses in agriculture and environmental degradation. Its long coastline continues to experience a rise in sea levels, which is projected to increase further (UCAR, 2024b). Its transnational impact is felt on the quality and quantity of food and water (UCAR, 2024b). Coupled with the fact that most of their agriculture is rain-fed, it increases exposure to climate (Baker et al., 2016; Sherbinin et al., 2013; Walther, 2021).

Ghana, like most Sub-Saharan African countries, remains very exposed to climate change. The available records from the past show that there was quite an amount of rainfall during the 1960s but drastically dropped between the 1970s and 1980s, which up to date has remained the case (Cameron, 2011). Temperatures: According

to World Bank projections, temperatures across Ghana will rise from 2010 to 2050, with the largest increases found in the country's north (World Bank, 2010). In the northern areas of Ghana, temperature increases from 2010 to 2050 will be about 2.1–2.4°C. (Stanturf et al., 2011) also foresee an increase in sea surface temperatures. According to their study, increased sea surface temperatures may disrupt the timing and intensity of coastal upwelling, negatively impacting fishery productivity.

2.6.7. National Trends

Air pollution is one of the most pertinent public health concerns in Ghana. The 2020 World Health Organization report named Ghana among the African countries with the highest levels of air pollution, with a particulate matter of PM_{2.5} concentration higher than the WHO Interim Target 1 of 35 µg/m³ for annual averages. Despite the deteriorating air quality in Ghana and other Sub-Saharan African countries, efforts to address it have been inadequate, and data on atmospheric particulate matter remains scanty (Katoto et al., 2019).

The Environmental Protection Agency of Ghana (EPA-Ghana) has come up with routine monitoring programmes that measure levels of PM₁₀ in Accra (Mudu & Organization, 2021). However, the nation does not have an official air quality criterion for PM_{2.5}, and no official records are currently available at these levels (Mudu & Organization, 2021). From 2005 to 2008, the EPA-Ghana, in collaboration with USAID, the United States Environmental Protection Agency (USEPA), and the United Nations Environmental Programme (UNEP), conducted an urban air quality monitoring network in Accra (Pfotenhauer, 2021). This study measured air pollution levels and characteristics and, finally, recommended measures for the management of air quality (Kanhai et al., 2021). (A Kofi Amegah & Samuel Agyei-Mensah,



2017) also identified road traffic congestion as the prime source of air pollution in most metropolitan areas of Sub-Saharan Africa.

2.7 Changes in Air Quality and Pollutant Levels

2.7.1 Particulate Matter Concentration

Particulate matter concentration refers to the number of tiny airborne particles or droplets that, when inhaled, can be deposited in the lungs, hence causing health effects. The common key performance indicators used in measuring the PM concentrations are PM_1 , $PM_{2.5}$, and PM_{10} .

2.7.2 Carbon Monoxide (CO) Levels

Carbon monoxide (CO) is a colourless, odorless gas emitted from the incomplete combustion of carbon-containing fuels. Although chronic exposure to low levels of CO has long-term health effects, high levels are immediately dangerous. Therefore, measurements of CO concentrations allow for inferences to be drawn about the impact of traffic and combustion-generated emissions on air quality.

2.7.3 Sulphur Dioxide (SO₂) Concentrations

Emissions of SO₂ are mostly from the combustion of sulphur-rich fossil fuels. This gas can produce respiratory and cardiovascular complications. Measuring SO₂ concentrations will also prove value in establishing whether the industrial sectors and power efforts to reduce their emissions are indeed effective.

2.7.4 Nitrogen Dioxide (NO₂) Levels

Nitrogen dioxide, or NO₂, is a by-product of fuel combustion from vehicles and industrial processes. High levels of NO₂ contribute to respiratory problems and the



formation of smog. Environmental air quality dashboards monitor NO₂ concentrations with the idea of forming policies and strategies toward reduction in emissions from these sources.

2.8 Health Hazards of Air Pollution

The most prominent health effects of air pollution are respiratory problems. The secondary pollutants cause photochemical smog, which usually causes eye irritation (Naureen et al., 2022). In heavily populated urban areas, high carbon monoxide concentrations can displace oxygen in the blood. The body, therefore, needs to increase cardiovascular activity to overcome its effects. (Boyle et al., 2021) reported that emissions of lead can be responsible for lower Intelligence Quotient IQ levels in children. Particulate matter aggravates heart and lung conditions, which comprise asthma, chronic bronchitis, and chronic emphysema. According to (Childs et al., 2015), those groups of people at risk to air pollution are; patients with cardiovascular disease, chronic respiratory diseases, children under age, and elderly people.

Exposure to copper dust at the workplace may cause nausea and upper respiratory tract irritation (Cohen et al., 1974). Though manganese is a necessary chemical for immune function, blood sugar regulation, digestion, reproduction, and bone formation, the inhalation of airborne manganese may cause muscles stiffness, tremors and impairs mobility through the long contraction of muscles (Horváth, 2011).

Lead is a naturally occurring metallic element which is found both in the environment and manufactured products. The major sources of airborne lead include industrial activities such as lead smelting, waste incineration, and vehicular



emissions. When inhaled, lead enters the bloodstream and deposits in the skeletal system (Okamoto et al., 2017). Exposure to lead has been associated with serious health consequences (Atiemo et al., 2012), while blood lead levels above 80 µg/dL have been reported to cause convulsions, coma, and even death (Sowmya, 2014).

2.9 Relationship between Air Quality and Disease Incidence

Cardiovascular diseases (CVDs) are among the leading causes of death and disability globally (Bansilal et al., 2015). One of the significant environmental risk factors for CVDs is air pollution, contributing to approximately seven million pre-avoidable deaths annually, as well as 2.4 million and 1.4 million from heart diseases and stroke respectively (Cohen et al., 2017). Studies from epidemiology constantly suggest air pollution, with evidence pointing specifically to ischemic heart disease (IHD) (De Marchis et al., 2018; Xu et al., 2014).

While the longitudinal studies conducted in developed countries have focused mainly on the long-term effects of air pollution, the time-series studies pointed out the short-term effects, especially those from fine particulate matter (PM_{2.5}) (Beckerman et al., 2012; Beelen et al., 2014).

Hypertension is one of the major risk factors for cardiovascular diseases and has been reported to be the leading preventable cause of death worldwide, with a high prevalence in lower-middle-income countries like Ghana (Bloch, 2016; Mills et al., 2020). Several studies have indicated an increasing trend in the prevalence of hypertension over the last four decades in Ghana, which has serious implications for stroke-related morbidity and mortality (Li et al., 2020; Sanuade et al., 2018). Alarming, about 70% of the hypertensive population remains untreated while only



13% had their blood pressure adequately controlled (Agyemang et al., 2022). Some risk factors include unhealthy diet, sedentary life, obesity, and elevated blood pressure (Agyemang et al., 2022; Dai et al., 2022; Li et al., 2020).

2.9.1 Respiratory and Cardiovascular Diseases

The cardiovascular system (CVS) and the respiratory systems (RS) work in tandem to provide tissues of the body with oxygen and other nutrients, as well as removing carbon dioxide (Calderon, 2017). The CVS has global and local mechanisms for the regulation of blood flow that directly influence respiratory functioning. Cardiac output, blood flow, and the synchrony of systemic and pulmonary circulation all impact the effectiveness of oxygen and carbon dioxide exchange. Proper ventilation-perfusion coupling is important for maintaining an optimal blood-gas exchange, ensuring the body's physiological stability (Calderon, 2017).

2.10 Adaptative Strategies

The necessity to adapt to climate change is highly recognized (Nyantakyi-Frimpong & Bezner-Kerr, 2015). In addressing livelihood adjustments in respect to climate uncertainty, different adaptation approaches are put in place. These are large-scale changes, which individuals and communities undertake as a way of trying to reduce the adverse outcomes arising from climate fluctuations (Core Writing Team, 2014).

In recent years, climate change policies of both national and international levels have changed focus from mitigation to adaptation in consideration of sustainable development and reduction of poverty, which has been promoted by the failure of some mitigation programs. Adaptation is defined as the collective decision-making



process and actions taken to maintain resilience against current and future climate changes (Nelson et al., 2007).

Adaptation, according to (Aniah et al., 2019), is a process that goes along with decision-making, personal attributes, challenges of climate change, and innovation. Coping strategies, on the other hand, are short-term measures - usually lasting less than a year - taken to reduce immediate adverse effects on livelihoods and well-being (Gentle & Maraseni, 2012).

2.11 Methodical Approaches

2.11.1 Techniques for Analysing Climate Variability and Air Quality Data

Accurate climate variable prediction is very instrumental in water management, flood and drought mitigation, and disaster preparedness (Feng et al., 2016). Quite a number of parametric and non-parametric statistical techniques are in use toward the analysis of climate variability. While in the parametric approach - for example, t-tests and F-tests—assume normality in the data under study, in fact, most of the climate time series data is not normally distributed. Hence, non-parametric methods like the Mann–Kendall test, Kruskal - Wallis test, and Sen's slope estimator are in wide use (Burn et al., 2004), (Fu et al., 2010), (Oyerinde et al., 2015), (Tekleab et al., 2013) and (Wang et al., 2012). Non-parametric approaches are also more robust against outliers (Sonali & Kumar, 2013; Zhang et al., 2006).



2.11.2 Methods for Assessing Health Impacts of Air Quality

HRA for air pollution requires mathematical modelling of population exposures to pollutants and the burden of associated diseases (World Health Organization, 2021). Such assessments could need air pollution quality data, population distribution information, disease rate information, as well as coefficients (β) relating exposure and risks from selected epidemiological study designs.

There are key AP-HRA steps, which at the very basic level include the following:

1. Exposure Estimation: Identifies populations exposed—through census-based information and spatiotemporal resolution (Hoek et al., 2008)
2. Exposure Assessment: Estimating pollutant concentration, exposure duration, and population susceptibility. Ambient pollutant concentration is mostly used as surrogate for exposure (Hoek et al., 2008).
3. Health Risk Estimation: Connecting exposure levels with health outcome utilizing the concentration-response functions. WHO air quality guideline of 2005 provides acceptable limits to vital air pollutant like PM₁₀, PM_{2.5}, NO₂, SO₂ and O₃ (L. Hou et al., 2016).

Various analytical methodologies implemented for the analysis of air pollution exposure assessment involve:

- GMAPS: City-scale estimations of PM₁₀ concentrations (Katsouyanni et al., 1997)
- TM5 Chemistry Transport Model & Source-Receptor (SR) Models: Estimation of the air quality response to emissions (Kheirbek et al., 2013; Kim et al., 2019)
- GEOS-Chem, MOZART: ozone and PM_{2.5} (Lelieveld et al., 2015)



- Land-Use Regression Models: spatial modeling based on geographical characteristics to predict pollutant concentrations (Liao et al., 2018; Lim et al., 2012)
- Bayesian Statistical Models: Estimate multi-pollutant exposure (Liu et al., 2019; Maji et al., 2017). Health impacts of air pollution are summarized as:
 - Short-term exposure impacts: Enhanced mortality, hospital admission owing to respiratory and cardiovascular diseases, restricted activity days and absenteeism at work or school.
 - Long-term exposure impacts: Chronic respiratory and cardiovascular diseases, lung cancer and intrauterine growth restrictions (Q. Hou et al., 2016). Whereas some populations, like children, the elderly, and people with pre-existing conditions, are more susceptible to these health effects, statistical models for estimating mortality or morbidity rates caused by exposure to pollution often suffer from generalizability limitations (Q. Hou et al., 2016).

2.11.3 GIS and Remote Sensing in Environmental and Health Studies

Geographic Information Systems (GIS) In disease mapping and ecological analysis, GIS has a significant role to play. They greatly simplify the visualization of data and enable easier assessment of environmental factors impacting public health by allowing spatial interpolation and modelling. Integration of remote sensing and internet-based GIS applications further expanded their usefulness in environmental health research.

2.11.4 Statistical and Computational Models for Climate-Health Impact Studies

A variety of statistical approaches are used in analysing climate and health data:



- Empirical Statistical Models: Describe spatial and temporal distributions of diseases in relation to climatic variables, including outbreak detection.
- Mathematical Mechanistic Models: Simulate the dynamics of disease transmission related to climate drivers coupled with intrinsic disease processes.
- Machine Learning Techniques: Neural networks, expert systems are used for making predictions about the evolution of epidemic, usually not based on any explicit causal structure.

2.12 Health Implications of Air Quality Due to Climate Change

Ambient health effects are also portrayed by air pollution. For example, photochemical smog leads to eye irritation and respiratory distress (Naureen et al., 2022). The International Energy Agency noted in 2015 that almost three million out of the total 6.5 million annual deaths due to air pollution globally could be accredited to outdoor air pollution.



CHAPTER THREE

METHODOLOGY

3.0 Introduction

This chapter discusses the methods used in the study. It briefly describes the study area and elaborates on the instruments of data collection. It also looks at the research design, sampling procedure, and data analysis techniques.

3.1 The Study Area

The Northern Region is the northernmost region in Ghana. It was the largest in terms of land area, originally encompassing three: Northern, Savannah, and North East. However, the region now covers approximately 70,384 square kilometres and accounts for 31% of the total land area of Ghana. It has its capital as Tamale and is made up of sixteen (16) districts. According to the 2021 Population and Housing Census, the population is 2,310,934, of which 1,143,439 are males and 1,167,495 are females. The largest city in the region is Tamale, with a population of approximately 570,000. The city is known for its rich culture, and the architecture is a mix of the traditional with the modern. Because of its location, Tamale has been able to become an important hub for trade, commerce, and agricultural production within Ghana.

The city houses a number of major institutions, including the Tamale Teaching Hospital, the University for Development Studies, and the Tamale Airport. Its unique combination of Islamic and traditional African influences makes it an attractive location for tourism and investment. The Tamale township shares boundaries with Vittin, Datoyili, Dungu, and Changnayili (Figure 3.1). The North Region, therefore, happens



to be a dry climate considering it is proximate to the Sahel and the Sahara. Its dry season stretches from January through March, with its rainy season starting in July and running up to October; its annual rainfall measures between 750 mm and 1,050 mm. The temperatures found in this region are highly diversified, ranging up to a high of 40°C or 104°F to as low as 14°C or 59°F (GSS, 2021).

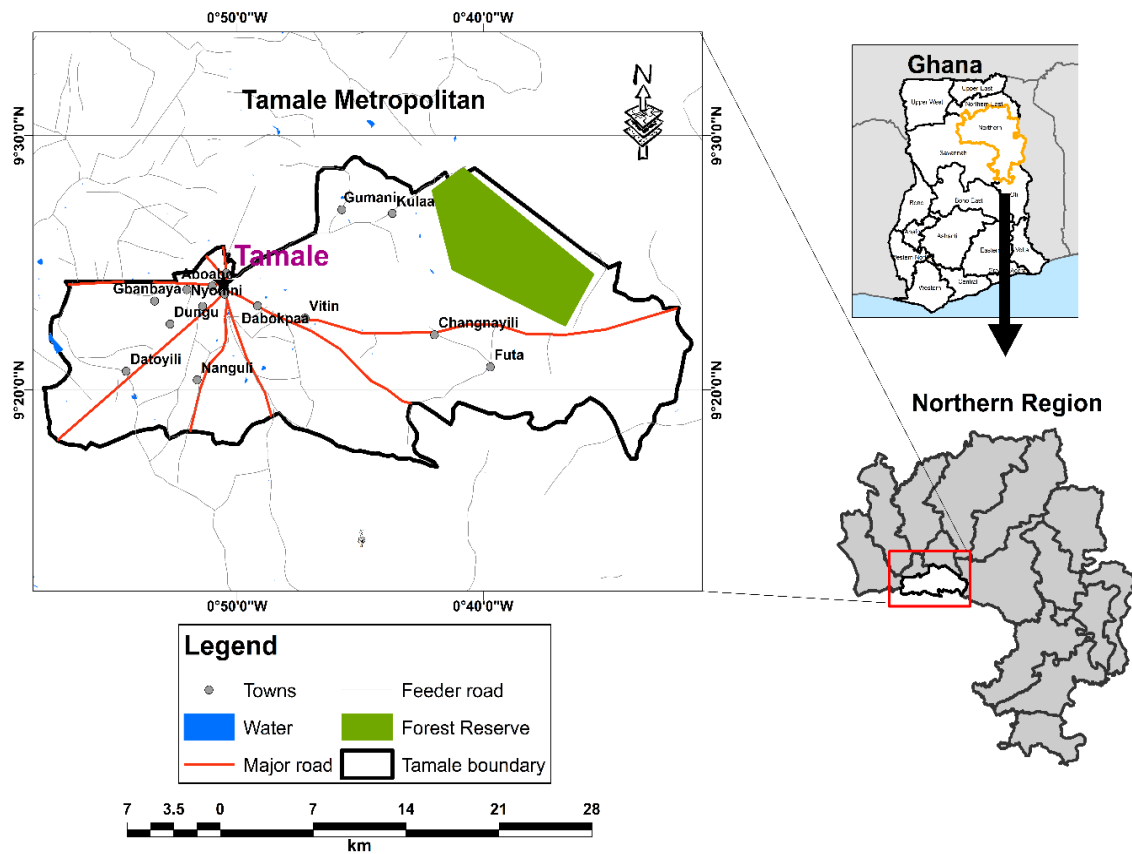


Figure 0.1: Map of Tamale Metropolitan

Source: Author Construct (2024)



3.2 Study Design

The study has adopted the descriptive method for a comprehensive and as-needed review of the status quo of air quality and climate conditions in this region. It thereby gives an all-over view, relating the pattern of climate change with air quality and its possible consequences on human health. In carrying out the descriptive study, data were gathered covering different aspects of climate and air quality in this region. It also covered temperature, precipitation, and humidity, among others, in relation to air pollutant concentrations such as particulate matter, nitrogen oxides, sulphur dioxide, and ozone.

3.3 Research Philosophy

Informed by the pragmatic research philosophy, this study realized that the influence of climate change on air quality and human health is a rather intricate issue due to being multi-causal in nature and hence requiring comprehensive consideration. To pragmatism, practicality, applicability, and collaboration are core factors that underpin the aim of this study in using its findings to inform policy and decision-making. This research also draws on elements of critical realism, which acknowledges the existence of an objective reality—climate change, air pollution, health impacts—while recognizing the subjective experiences and perceptions of individuals and communities. This philosophical stance allows the study to bring in diverse perspectives, methods, and data sources, hence giving a rich and nuanced understanding of the phenomena being researched and its implications for stakeholders. The study contributes to the fast-growing literature linking climate change with air quality and human health.

3.4 Data and Sources

The data used for the study included both primary and secondary data. The air pollutant parameter and climate parameters listed in Table 3.1 involved various spatial and temporal data types to be collected for monitoring. This served as the major dataset where secondary data was evaluated from literature.

Table 3.1: Description of primary data set

Platform/ Instrument	Sensor Acquisition	Format	Spatial Resolution	Date range	Download Website/ Organisation
M2TMNXAER	MERRA-2	.netcdf	0.5 ° x 0.625 °	1990 to 2021	https://disc.gsfc.nasa.gov/datasets
Meteorological data			Ground	1990 to 2023	Ghana Meteorological Agency

3.5 Primary Data

3.5.1 Air Pollutant Data

Time-averaged 2-dimensional monthly mean data collection of M2TMNXAER in Modern-Era Retrospective analysis for Research and Applications version 2, sourced from NASA GES DISC website (<https://disc.gsfc.nasa.gov/datasets>) for the years 1993-2021. The instrument is good for remotely-based pollutant discharge concentration studies because of its high noise-to-signal ratio and 0.5° x 0.625° spatial resolution. The



data was downloaded in a NETCDF format with over 50 variables of different air pollutant variables Appendix 1. The variables included are Black Carbon mass density, dust surface mass density, organic carbon mass, SO₄ surface mass and concentration, sea salt mass, etc. Using the Python programming interface, data masking to the study area was done, pre-processing and analysis was conducted. The QGIS and ArcGIS 10.7 was used to visualize spatial distributions. Organic Carbon Concentration, Black Carbon Concentration, Dust Concentration and SO₄ concentration from the M2TMNXAER data was taken out.

PM_{2.5} was obtained using the formular in equations 1 and 2, as described by (Buchard et al., 2017)

$$\text{PM}_{2.5}(\mu\text{gm}^3) = \text{DUSMASS25} + \text{OCSMASS} \times 1.8 + \text{BCSMASS} + \text{SSSMASS25} \times 1.375 + \text{SO4SMASS} \times 1\text{e}9 \quad (3.1)$$

$$\text{PM}_{10}(\mu\text{g m}^3) = (\text{SO4SMASS} \times 1.375 + \text{SSSMASS} + \text{DUSMASS} + \text{OCSMASS} \times 1.8 + \text{BCSMASS} \times 0.74 \times 1\text{e}9 \quad (3.2)$$

Where:

DUSMASS25 = Dust Column Mass Density - PM_{2.5}

OCSMASS = Organic Carbon Surface Mass Concentration

BCSMASS = Black Carbon Column Mass Density

SSSMASS25 = Sea Salt Column Mass Density - PM_{2.5}

SO4SMASS = SO₄ Column Mass Density



3.5.2 Meteorological Data

Rainfall, temperature and relative humidity data were obtained from the Ghana Meteorological Agency (GMeT), from 1990 to 2023.

The Mann-Kendall trend test is a non-parametric statistical method to detect trends in time-series data, mainly in the fields of environmental and hydrological studies. It is an extensively used method to test for the presence of a monotonic upward or downward trend in time-series data without making any assumption of the distribution of the data (Mann, 1945). The test evaluates the trend by comparing the ranks of all pairs of data in a dataset. The test statistic, S , is the result of a comparison of the ranks of all pairs of data points using equation (3).

$$S = \sum_{i=1}^{n-1} \sum_{j=i+1}^1 \text{sgn}(x_j - x_i) \quad (3.3)$$

where x_j and x_i represent data values at times i and j respectively, and $\text{sgn}(x_j - x_i)$ is the sign function:

$$\text{sgn}(x_j - x_i) = \begin{cases} 1 & \text{if } (x_j - x_i) > 0 \\ 0 & \text{if } (x_j - x_i) = 0 \\ -1 & \text{if } (x_j - x_i) < 0 \end{cases} \quad (3.4)$$

The Variance S for a larger dataset ($n > 10$) is calculated by

$$\text{Var}(S) = \frac{(n-1)(2n+5)}{18n} \quad (3.5)$$

The standardized test statistic Z is then computed as:

$$Z = \begin{cases} \frac{S-1}{\sqrt{\text{var}(S)}} & \text{if } S > 1 \\ 0 & \text{if } S = 0 \\ \frac{S+1}{\sqrt{\text{var}(S)}} & \text{if } S < -1 \end{cases} \quad (3.6)$$



A high positive value of Z suggests an increasing trend, while a low negative value of Z suggests a decreasing trend (Tabari et al., 2015). The Mann-Kendall test is also robust in the presence of missing data and can be adjusted to account for autocorrelation (Kumar et al., 2019).

3.5.3 Validation

Due to the limitation of access to the ground data, validation of a single station gauge monitoring from June 2023 to May 2024 was conducted. The validation was carried out by calculating the matching grid number and shape parameters of each object between MERRA-2 and observation. In this study, 3 evaluation metrics were applied to assess the accuracy of precipitation by GPM IMERG dataset and the rain gauge: r-squared, root mean square error (RMSE), and p-bias.

$$R^2 = \left(\frac{\sum_{i=1}^n (O_i - \underline{O})(P_i - \underline{P})}{\sqrt{\sum_{i=1}^n (O_i - \underline{O})^2} \sqrt{\sum_{i=1}^n (P_i - \underline{P})^2}} \right) \quad (3.7)$$

$$RMSE = \sqrt{\frac{\sum_{i=1}^n (P_i - O_i)^2}{n}} \quad (3.8)$$

$$BIAS = \frac{\sum_{i=1}^n P_i}{\sum_{i=1}^n G_i} \quad (3.9)$$

O_i = observed variable, P_i = predicted variable, $\underline{P}$ = mean of predicted variable, $\underline{O}$ = mean of observed variable.

3.5.4 Relationship between Air and Climate parameters

Correlations between pollutant concentrations and meteorological factors were analysed using Pearson's correlation coefficient. The correlation matrix is visualized below:

3.6 Secondary Data Analysis

3.6.1 Population

The target population involves those people who are either directly or indirectly affected by the incidence of poor air quality. In this study, the population under study refers to the number of people living within Tamale Metropolis and its environs. According to the Ghana Statistical Service (GSS, 2021), the total population within the study area is 730,000.

3.7 Sampling Procedure and Sample Size

3.7.1 Sampling

Sampling involves the selection of a small size of persons or objects from the whole population with the aim of making inferences about the entire population (Mujere, 2016).



Table 3.2: Sample communities and sample size

Zones	Communities	Number of respondents
Tamale North	Kalpohin	35
	Gumani	30
	Jisonayili	20
	Fuo	30
	Sognaayili	15
Tamale Central	Aboabo	50
	Ward K	60
	Kukuo	30
	Zogbeli	20
	Choggu	30
Tamale South	Kalariga	20
	Lamashegu	40
	Bamvim	60
	Dungu	30
	Vitting	50
Total		400

Since it is nearly impossible to study the entirety of a community, sampling techniques are applied in order to collect a sample that is representative and may be used to make inferences about the population as a whole. In this line of thought, the study area was divided into four zones based on emissions, land use, resource consumption, and





vulnerability so that the different factors contributing to air quality would be accurately represented. This helped in capturing the changes that occur concerning air quality throughout the different zones. In this research, Metropolis was zoned into three: Tamale South, Tamale Central, and Tamale North. From each Zone, five Communities were purposively selected. Employing simple random sampling and convenience sampling, a total of 400 respondents was randomly selected, as illustrated in Table 3.2 below:

3.7.2 Sample Size

The term sample size refers to the number of observations or individuals to be included in an experiment. It describes the number of individuals, items, or data points chosen from a larger population that are to be used in representing it statistically (Dattalo, 2008). Sample size is, therefore, very important in research works since it directly impacts the reliability and validity of the findings. This will provide a higher degree of precision in the estimates, and the statistical test's power. It reduces the margin of error—in other words, if the sample size is big, then one will have a close estimate of the real value. The number of observations and measurements of air quality parameters and climate change indicators referred to the sample size collected from the region (Arya et al., 2012). The sample size will be representative of the population and adequate in size to ensure reliable and valid results. The sample size was determined using Cochran's theory (Cochran & Banner, 1977). In applying the total population of the northern region, 2,310,939 people were obtained. This study adopted Cochran's theory (Cochran & Banner, 1977) sample size determination formula in calculating the

sample size. Using Cochran theory (Cochran & Banner, 1977), sample size (n) computation formula as:

$$n = \frac{N}{1 + Ne^2} \dots\dots\dots (3.10)$$

where n = sample size

N = Total population of respondents

e = marginal error (5%)

N = 17415

$$n = \frac{17415}{1 + 17415 (0.05)^2} = 399$$

For this study, a sample size of 400 respondents was deemed sufficient.

3.8 Data Analysis

Data analysis is the process of inspecting, cleaning, transforming, and interpreting data to discover valuable information, draw conclusions, and make informed decisions. It involves various techniques and tools to understand and extract meaningful information from data (Shmueli et al., 2017). This study used quantitative data analysis. Quantitative data analysis is the application of statistical techniques in organizing and summarizing data, and creating visualizations that give an overview of the dataset, including broad qualities. It is mainly used in analysing numerical data, where it helps in the discovery of trends, patterns, and relationships that exist within the data. In this paper, data were analyzed using descriptive statistics in the form of frequencies, percentages, and means. The inferential statistics used in the exploration of relationships among variables and to



determine the significance of findings included correlation analysis and analysis of variance (ANOVA).

3.8.1 Analysis of Air Pollutants

Analysis of concentrations of particulate matter (PM₁₀ and PM_{2.5}), nitrogen dioxide (NO₂), sulphur dioxide (SO₂) and carbon monoxide (CO), in selected locations within the Tamale Metropolis and its environs was reached by first developing Air Quality Index (AQI). The air quality is commonly measured using assorted parameters. The AQI is a commonly used scale that ranging from 0 to 500. The AQI is based on the density of pollutants in the air with specific focus on pollutants such as PM_{2.5}, PM₁₀, ground-level ozone, nitrogen dioxide, and sulphur dioxide (NASA, 2023). The level of density of each air pollutants was measured based on the scale in Table 3.3. The results are then illustrated using line graphs and satellite images.

Table 3.3: Air Quality Index (AQI) results

Level of AQI	Rate of AQI
Good	0 to 50
Moderate	51 to 100
Unhealthy for Sensitive Groups	101 to 150
Unhealthy	151 to 200
Very Unhealthy	201 to 300
Hazardous	301 and above

Source: NASA, (2023)





3.8.2 Respiratory Disease Prevalence

The prevalence of the diseases in the general population within the Tamale Metropolis and its environs was analysed using descriptive statistics. Prevalence is the proportion of people in a population that have a specific disease at a given point in time. It is mostly expressed as a percentage, per 1,000, or per 100,000 people.

Calculation of Prevalence Rates:

$$\text{Prevalence Rate} = \frac{\text{Number of existing cases}}{\text{Total population}} \times 100\% \quad (3.11)$$

A Chi-Square Test was used to determine the significant association between demographics (Age groups, Gender, income levels, education and occupation) and disease prevalence.

3.8.3 Analysis of Adaptation Strategies

Kandall's Coefficient of Concordance (Legendre, 2005) was used to analyse the adaptation strategies adopted by residence in improving air quality in the face of climate variability in Tamale and its environs. A list of adaptation strategies was, however, picked from the literature and presented to the respondents to rank in order of importance. Kendall coefficient of concordance was adopted for the purpose of testing the level of agreement among the ranked scores which the respondents assigned to the various adaptation strategies. Kendall's coefficient of concordance, W, according to Legendre, 2005, "is a measure of the agreement among several, p, judges who are assessing a given set of, n, objects".

W is an index that measures the ratio of the observed variance of the sum of the ranks to the maximum possible variance of the ranks. The Kendall's concordance coefficient (W) is therefore given by the equation

Analysis of the prevalence of respiratory and cardiovascular diseases among the residents within the Tamale Metropolis and its environs was achieved by using descriptive statistics. Prevalence refers to the proportion of individuals in a population who have a particular disease at a specified time. It is normally expressed as a percentage or per 1,000 or per 100,000 individuals:

$$W = \frac{12s}{p^2(n^3-n)} - pT \quad (3.12)$$

where W denotes Kendall's Concordance Coefficient, p denotes the number of adaptation strategies, n denotes the number of respondents, T denotes correlation factor for tied ranks and s denotes the sum of square statistics. The sum of a square statistic (S) is given as:

$$S = \sum (R_i - R)^2 \quad (3.13)$$

where: R_i = rows sums of ranks

R = the mean of R_i

The correlation factor for tied ranks (T) is also given as:

$$T = \sum (T_k^3 - T_k) \quad (3.14)$$

where: t_k = the number of ranks in each (k) of m groups of ties.

$$X_2 = P(n-1)W \quad (3.15)$$

where: p = number of adaptation strategies; W = Kendall's coefficients of concordance.

CHAPTER FOUR

RESULTS

4.0 Introduction

This chapter presents the empirical results of the study, organized according to the five specific objectives outlined in Chapter One. The findings shows trends, patterns, and interrelationships among climate variability, air quality, and human health in the Tamale Metropolis. The analyses drawn from both quantitative data sets and qualitative responses gathered from the field.

Objective 1: Trends in Climate Variability – This section outlines the temporal patterns and statistical trends in temperature, rainfall, and relative humidity observed over the 1990–2023 period, providing insight into how local climatic conditions have evolved.

Objective 2: Seasonal Variations in Air Quality – Here, results focus on the temporal and spatial fluctuations in air pollutants, including PM_{2.5}, PM₁₀, NO₂, SO₂, O₃, and CO, and how these vary across wet and dry seasons.

Objective 3: Correlation Between Air Quality and Health Outcomes – This section presents the statistical relationships between air quality indicators and the prevalence of respiratory and cardiovascular illnesses, using correlation and regression models to quantify health risks.

Objective 4: Adaptation Strategies to Improve Air Quality – Findings related to the adaptive measures employed by communities, households, and institutions to cope with declining air quality are discussed, including infrastructural and behavioural responses.

Objective 5: Mitigation Strategies to Protect Human Health – This section details the measures identified to reduce the adverse health impacts of climate-induced air pollution, such as early warning systems, public health education, and resilient healthcare interventions.





4.1 Validation of PM_{2.5}

The performance of the satellite data with respect to the gauge measurements was evaluated based on three statistical measures: Percent Bias (PBIAS), Root Mean Square Error (RMSE), and the Coefficient of Determination (R²). The value of PBIAS was calculated as 6.53, which means the satellite data underestimates the gauge measurements by 6.53%. This positive PBIAS value indicates a small but noticeable bias, such that the satellite data always yields values slightly lower than the gauge data. In general, a PBIAS value close to zero indicates a good fit, with a value of 6.53 suggesting that the satellite data are reasonably accurate, although with some underestimation. The RMSE was found to be 16.46, which indicated that the average error between the satellite and gauge data is approximately 16.46. While results of correlation showed a very poor correlation between the satellite data and gauge data. About 20% (0.2) of the variability in the gauge measurements could be explained by the satellite data.

Table 4.1: Evaluation Statistics of PM_{2.5}

Statistic	Value
PBias	6.53
RMSE	16.46
R ²	0.2



4.2 Trend Analysis of Meteorological Parameters

The monthly and annual analysis of the daily rainfall data is presented below. Table 4.2 summarises the monthly and annual central tendency rainfall. The annual total rainfall from the year 1990 to 2023 had a range from 878.96mm to 1608.12mm. The maximum value recorded was in the year 1991, while the minimum value recorded was in the year 1992.

Figure 4.1: Annual and monthly rainfall plot for the study period. Average monthly rainfall over the period observed low records of rainfall from November to April, while high rainfall was recorded from May to October with the peak being in August and September with a total of 207.01mm and 215.16mm respectively.

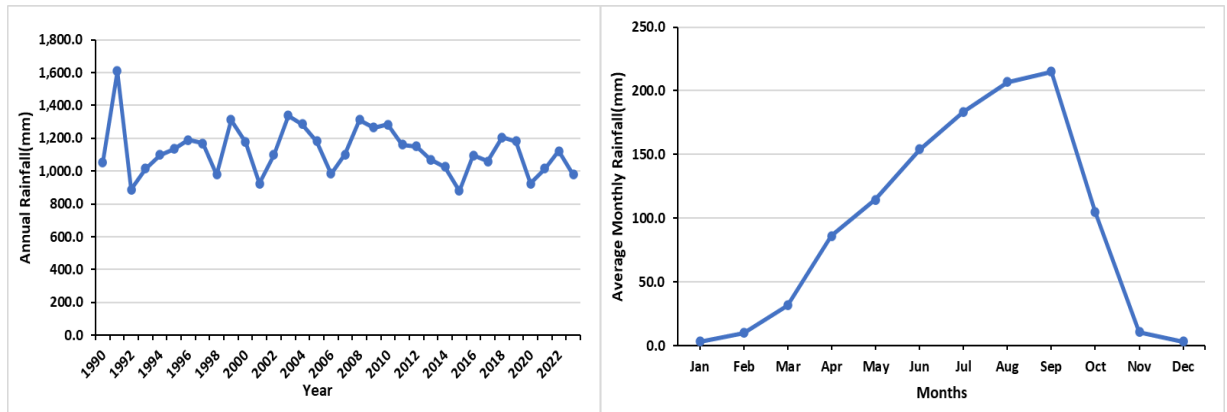


Figure 4.1: Annual and monthly average plot of rainfall (mm)

Table 4.2: Monthly values of measures of central tendency for Rainfall (mm)

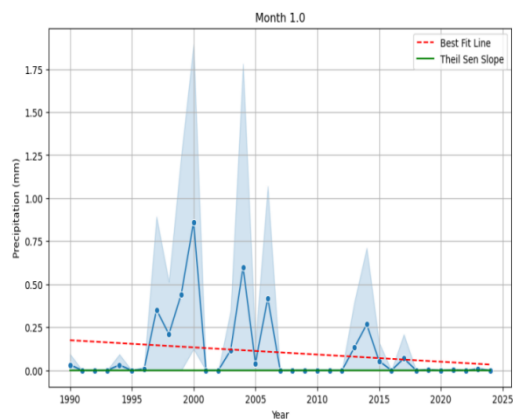
Parameter	Jan	Feb	Mar	Apr	May	Jun	Jul	Aug	Sept	Oct	Nov	Dec
Mount	34	34	34	34	34	34	34	34	34	34	34	34
Mean	19.96	23.03	25.41	25.52	24.64	23.46	22.92	22.69	22.57	22.70	21.55	19.61
Minimum	18.18	20.34	23.77	24.35	23.48	22.66	22.21	21.87	21.73	21.75	18.46	17.71
25 th Percentile	19.29	22.47	25.04	25.09	24.26	23.18	22.53	22.39	22.27	22.36	21.16	18.88
50 th Percentile	19.98	23.35	25.54	25.50	24.58	23.50	22.86	22.63	22.53	22.71	21.53	19.66
75 th Percentile	20.49	23.77	25.78	25.88	24.92	23.79	23.29	22.97	22.82	22.95	22.31	20.22
Maximum	21.85	24.93	26.78	26.91	25.62	24.55	24.03	24.00	23.83	23.91	23.69	22.32
Standard Deviation	0.86	1.07	0.70	0.60	0.53	0.49	0.47	0.45	0.50	0.52	1.10	1.03



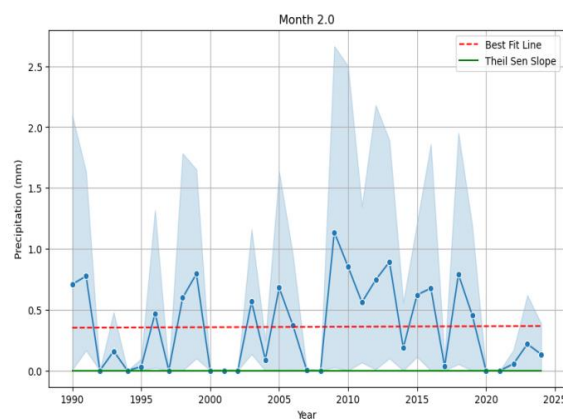
4.2.1 Mann Kendall Trend Analysis of Rainfall

Applied to the monthly trend analysis of the rainfall, the Mann-Kendall test shows that for most months, the series have a non-significant trend during the period under study since most of their p-values are greater than 0.05, which basically means no statistical evidence of a trend. Specifically, January ($p = 0.55$), February ($p = 0.63$), March ($p = 0.18$), April ($p = 0.57$), June ($p = 0.88$), July ($p = 0.55$), August ($p = 0.25$), September ($p = 0.48$), October ($p = 0.54$), November ($p = 0.55$), and December ($p = 0.41$) all show no identifiable increasing or decreasing trends in monthly rainfall (Table 4.2).

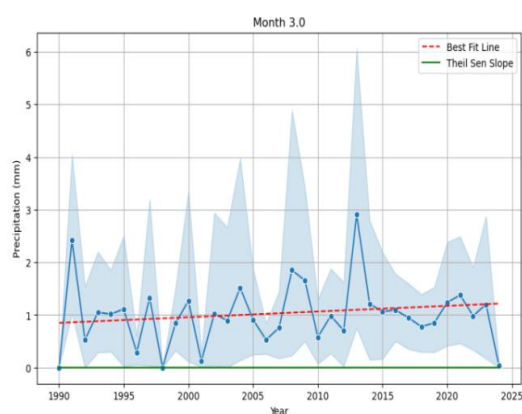
However, the month of May showed a highly significant declining trend at $p = 0.01$, supported by the negative Kendall's S value (-173), which designates a consistent downward pattern in the rainfall for that month. From these observations, the calculated slope for all months, including May, was 0.00, suggesting that even though there is a decreasing trend in May, the magnitude of change per year is very small. Figure 4.2 shows the monthly rainfall data for each month from 1990 to 2023. While some years, especially around the early 2000s, showed high peaks in rainfall, exceeding even 25 mm, the overall trend line shows a very gradual decline in the rainfall, which is however insignificant, and most of the recent years are showing lower levels of precipitation. This may indicate a possible shift in the rainfall pattern. In detail, the month of January, May, and August shows a slight decrease in the amount of rainfall with May being significant, while the months of February, September, and October showed relatively no trend.



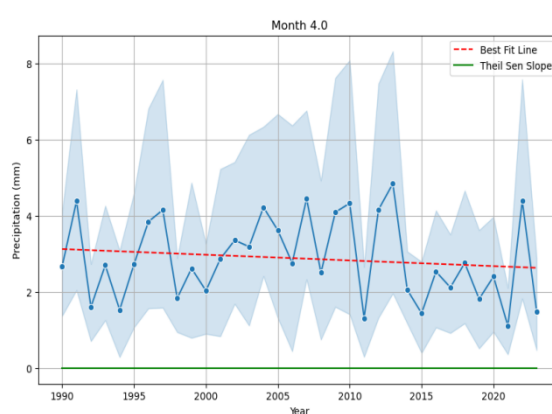
A) January



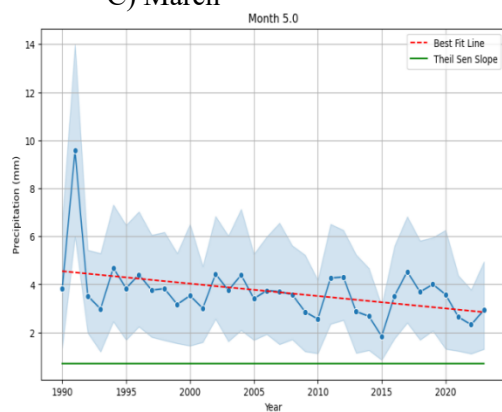
B) February



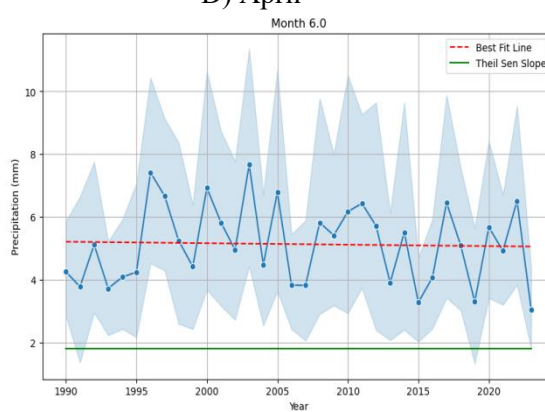
C) March



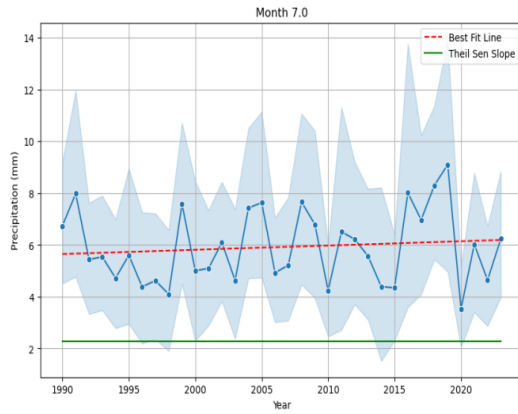
D) April



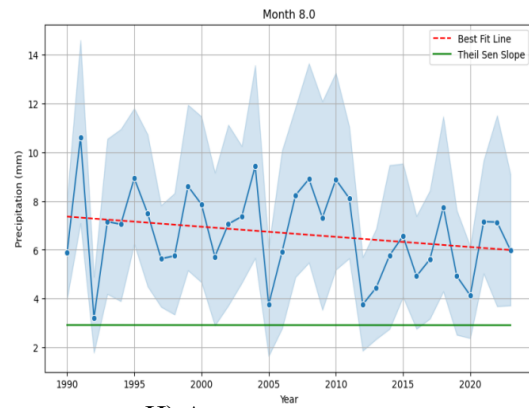
E) May



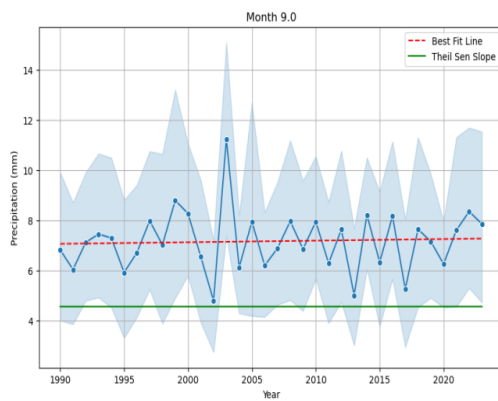
F) June



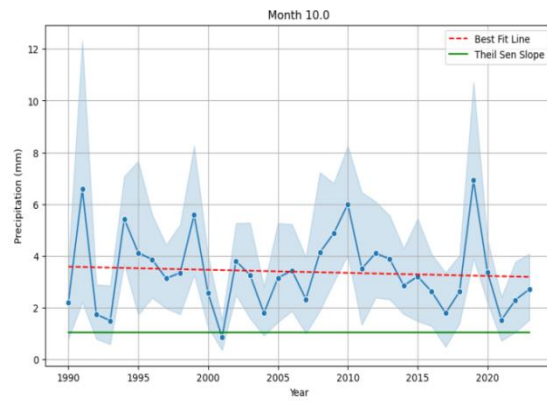
G) July



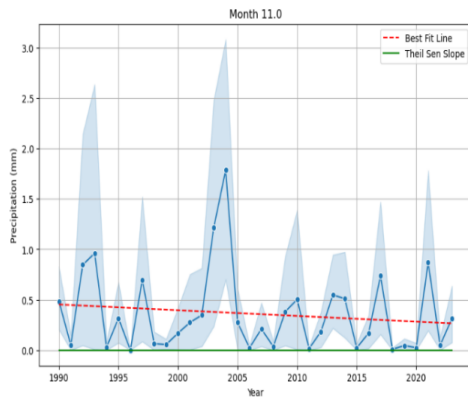
H) August



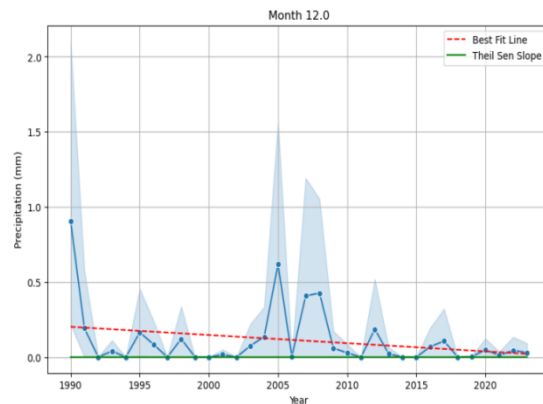
I) September



J) October



K) November



L) December

Figure 4.2: Monthly Trend Plots of Rainfall from 1990 to 2023

4.2.2 Temperature

Monthly Tmin over the period ranged between 29.2°C and 35.3°C. As summarized in tables 4.3 and 4.4, August showed the lowest Tmin of 29.2°C while the highest Tmin was noted in February with 35.3°C. Similarly, March showed the highest Tmax of 39.5 while the lowest Tmax was noted in August with 30.6°C. The mean Temperature ranges from 29°C to 37°C. However, annual mean Tmin and Tmax was 22.8°C and 34.5°C respectively. From the figure 4.3, highest temperatures were observed from November to March, while lowest temperatures were observed from May to October. The annual temperature plot showed variability in temperature with slight increase observed for both Tmin and Tmax in the late 2000s.



Table 4.3: Monthly values of measures of central tendency for Temperature (°C) (Minimum and Maximum)

Parameter	Jan	Feb	Mar	Apr	May	Jun	Jul	Aug	Sept	Oct	Nov	Dec
Count	34	34	34	34	34	34	34	34	34	34	34	34
Mean	35.52	37.44	37.92	36.29	34.30	32.02	30.45	29.94	30.78	32.90	35.34	35.39
Minimum	33.29	35.83	36.77	34.62	31.76	31.10	29.51	29.27	29.46	31.01	32.07	33.59
25 th Percentile	35.01	37.10	37.52	35.51	33.85	31.49	30.17	29.70	30.64	32.53	35.04	35.09
50 th Percentile	35.58	37.43	37.92	36.44	34.40	32.08	30.43	29.90	30.81	32.99	35.54	35.44
75 th Percentile	36.09	37.83	38.36	36.93	34.88	32.41	30.64	30.19	31.07	33.27	35.76	35.74
Maximum	37.30	38.46	39.57	37.97	35.95	33.61	31.76	30.67	31.65	34.47	36.62	36.78
Standard												
Deviation	0.88	0.61	0.69	0.91	0.79	0.60	0.51	0.32	0.48	0.67	0.86	0.75

Table 4.4: Annual Mean, Maximum and Minimum Temperature (Minimum and Maximum)

	Tmin (°C)			Tmax (°C)		
	Mean	Maximum	Minimum	Mean	Maximum	Minimum
Annual	22.84	26.2	17.7	34.02	39.5	29.3

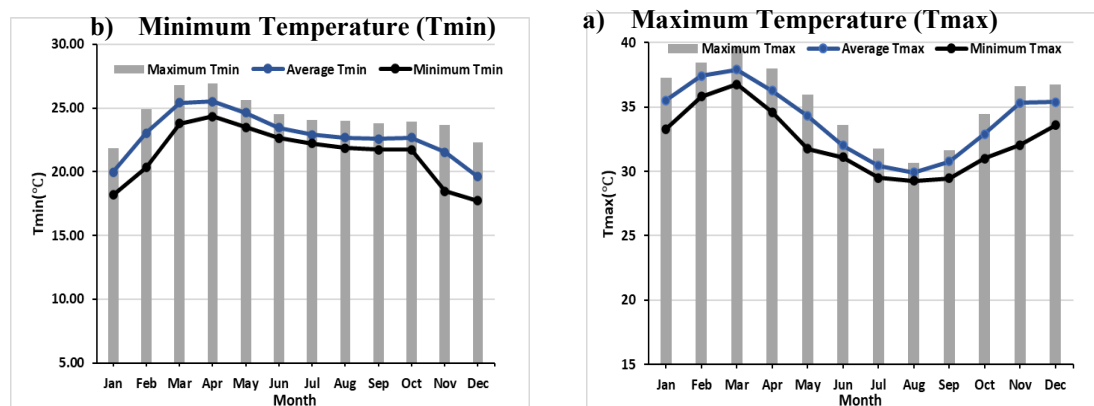


Figure 4.3: Monthly Mean, minimum and maximum temperature (°C)

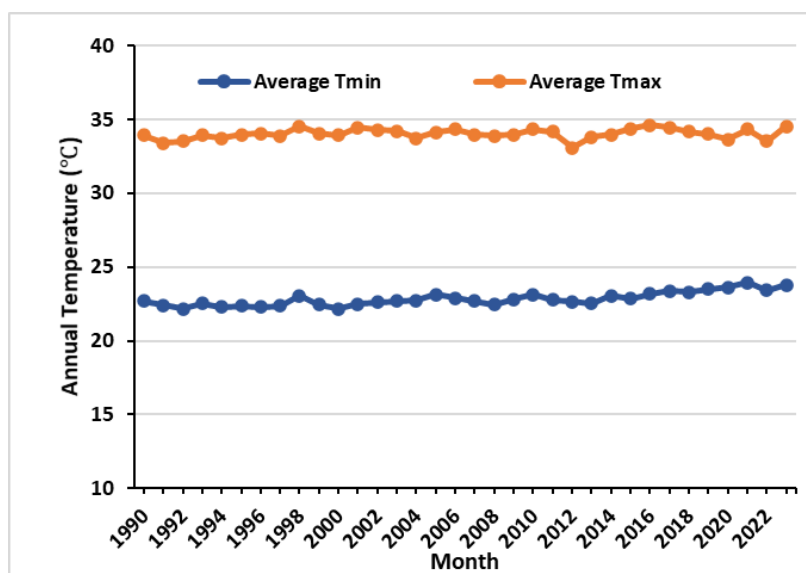


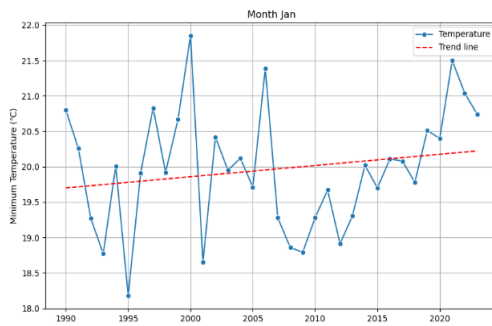
Figure 4.4: Annual Minimum and Maximum temperature (°C)



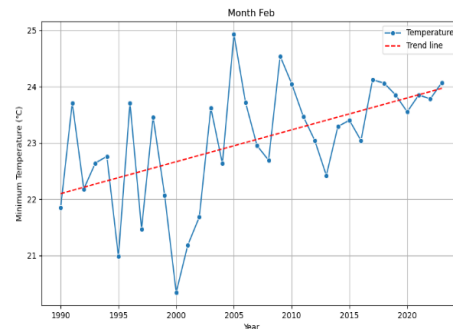


4.2.3 Mann Kendall Trend Analysis of Temperature (°C)

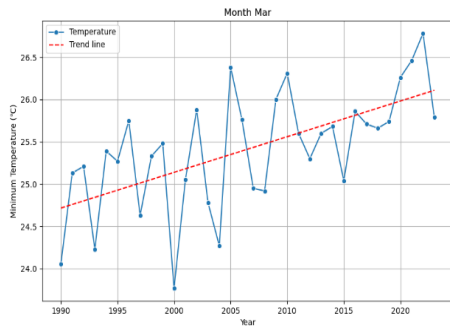
On a monthly scale, the Tmin trend analysis using Mann-Kendall test showed that most months gave significant increasing Tmin trends for the study period; precisely from February to November at $p < 0.00$. January and December showed no trend in Tmin as evidenced by its p-value equal to 0.22 and 0.12 respectively and the Kendall S-value of 84 and 107 respectively. However, Tmax observed a significant increase in temperature during December only p-value 0.05 with the rest of the months having no trend p-values > 0.05 . Figure 4.5 shows the monthly plot trends for Tmin over the years. High Tmin was observed during the period from 1990 to 2005. However, there was a sharp decrease in 2007 and continues to increase to 2023 for January. Over the years, a steady increase in Tmin can be seen starting from the late 2000s for all months.



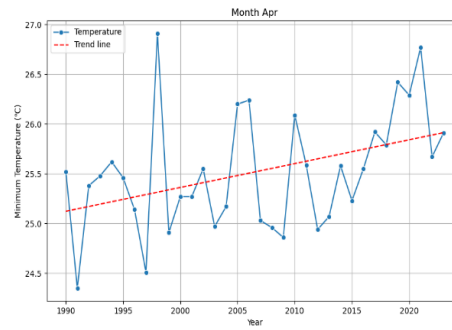
A) January



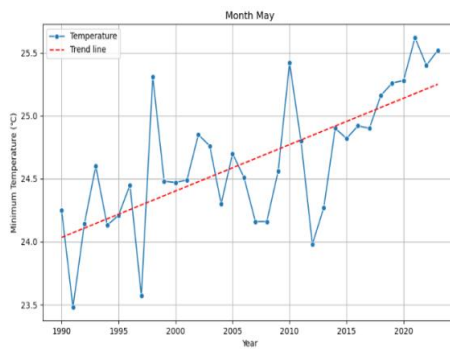
B) February



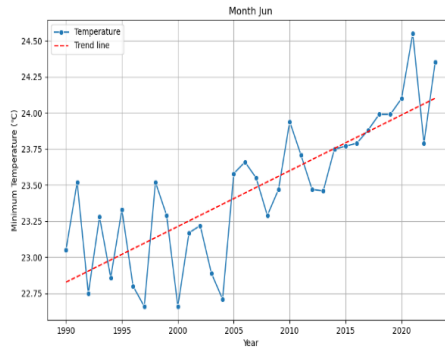
C) March



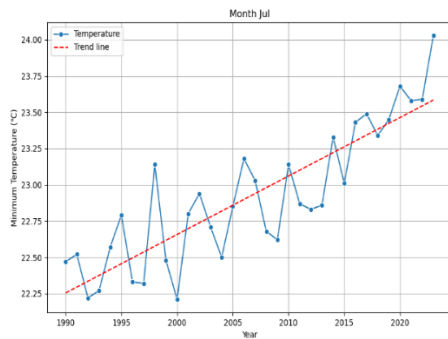
D) April



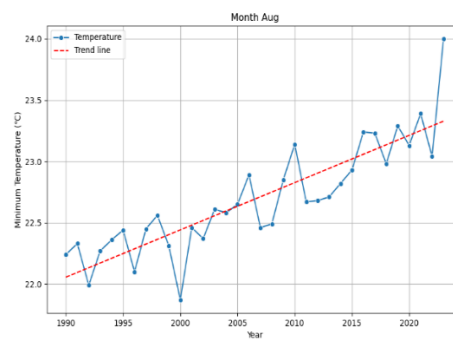
E) May



F) June

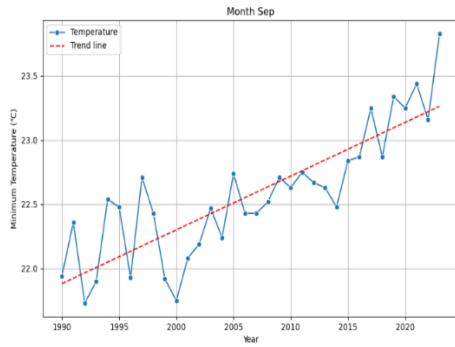


G) July

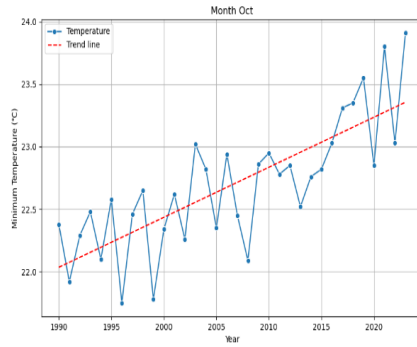


H) August

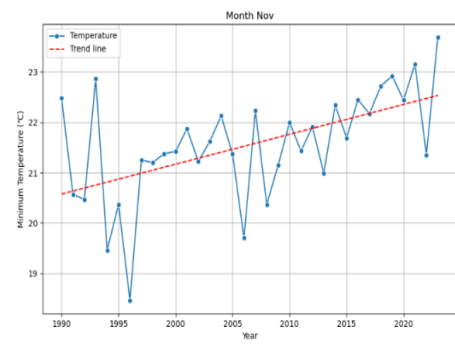




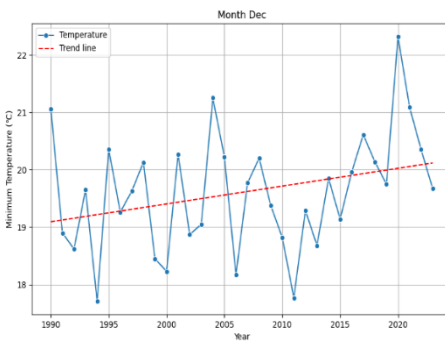
I) September



J) October

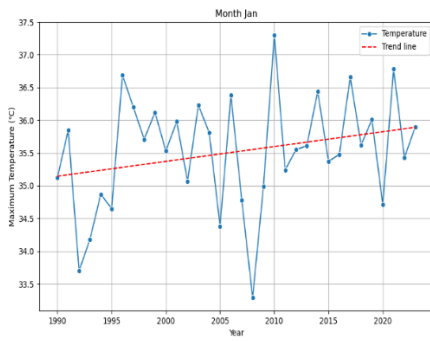


K) November

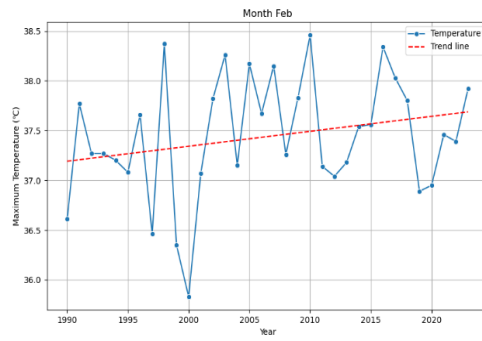


L) December

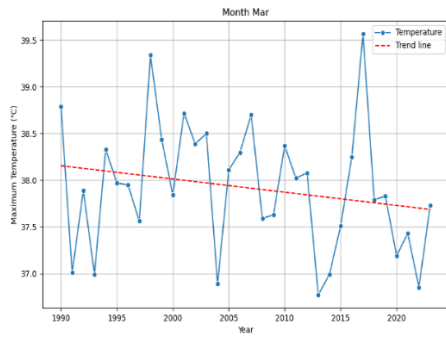
Figure 4.5: Monthly trend plot of $T_{\min}$ (°C)



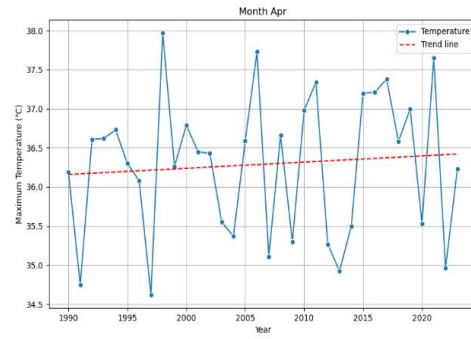
A) January



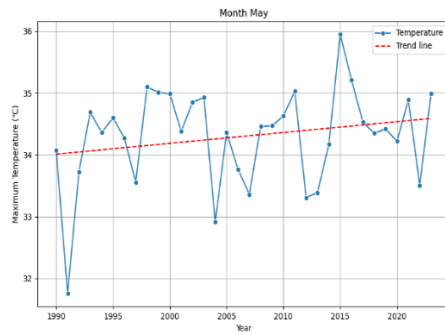
B) February



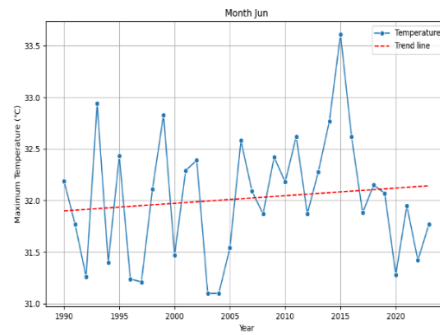
C) March



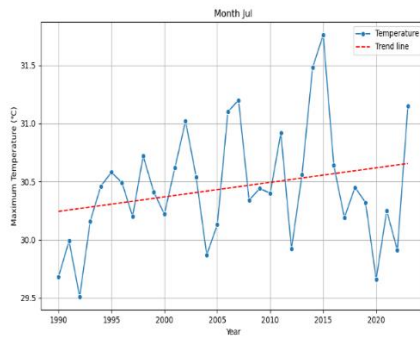
D) April



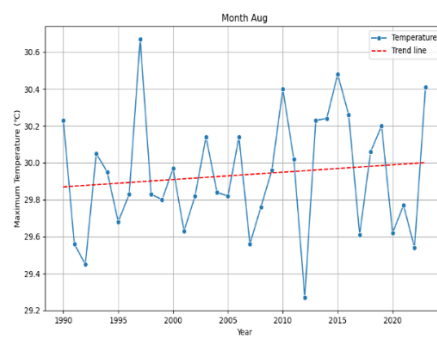
E) May



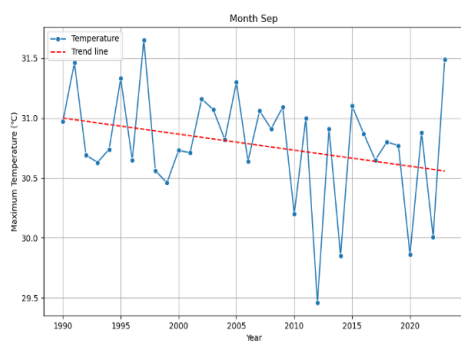
F) June



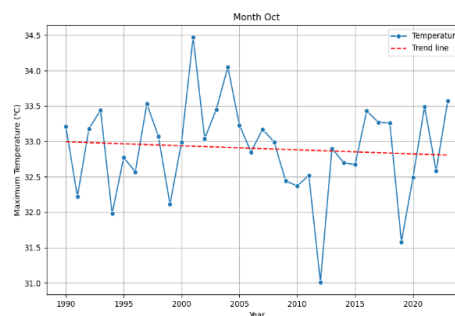
G) July



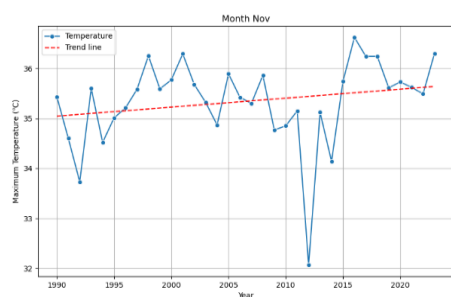
H) August



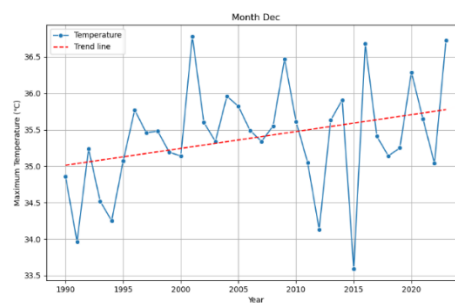
I) September



J) October



K) November



L) December

Figure 4.6: Monthly Trend Plot for $T_{\max}$ (°C)

4.2.4 Relative Humidity (RH)

Relative humidity observed over the period ranged between 27.2 to 171.0 with mean value of 118.4. Generally, from May to October had the highest humidity record with the lowest in January and February with mean values 66.24 and 76.70 respectively (Table 4.5).

Table 4.5: Monthly values of measures of central tendency for Relative Humidity (RH (%))

Parameter	Jan	Feb	Mar	Apr	May	Jun	Jul	Aug	Sept	Oct	Nov	Dec
Count	32	32	32	32	32	32	32	32	32	32	32	32
Mean	66.24	76.70	96.32	123.18	138.74	147.30	151.89	153.24	148.44	135.00	105.14	78.90
Minimum	27.25	44.44	62.90	81.37	63.38	63.73	63.07	65.48	32.47	29.50	46.35	31.18
25 th Percentile	57.17	65.17	84.43	115.36	137.80	145.86	152.11	150.57	134.79	117.73	86.46	60.88
50 th Percentile	67.29	75.60	99.44	125.31	141.47	153.32	161.75	165.05	162.78	151.67	118.75	85.65
75 th Percentile	75.78	89.69	105.59	133.92	145.77	158.36	163.43	166.79	163.91	153.93	126.12	94.06
Maximum	96.63	109.77	127.21	141.45	160.75	163.10	167.22	171.00	166.37	160.90	134.79	113.29
Standard												
Deviation	14.68	17.57	16.11	13.89	17.17	19.34	22.64	25.33	28.57	30.31	28.41	20.69

Annually, RH tend to decrease over from 2012 with slight increase to the later years. A sharp decline was observed in 1993 with a relative stability from 1994 to 2010 (Figure 4.7).

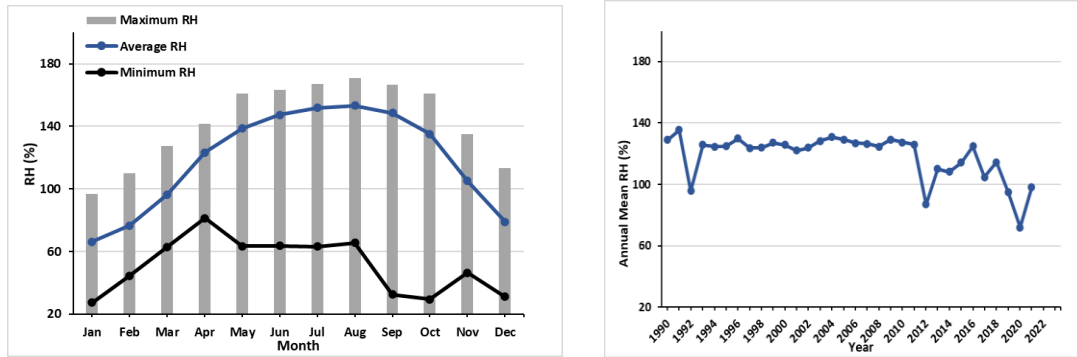


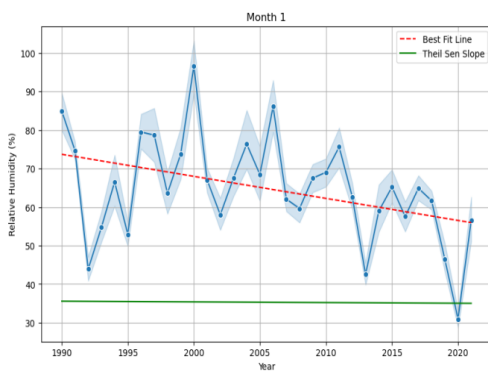
Figure 4.7: Annual and monthly average plot of Relative Humidity (%)

4.2.5 Mann Kendall Trend Analysis of Relative Humidity (%)

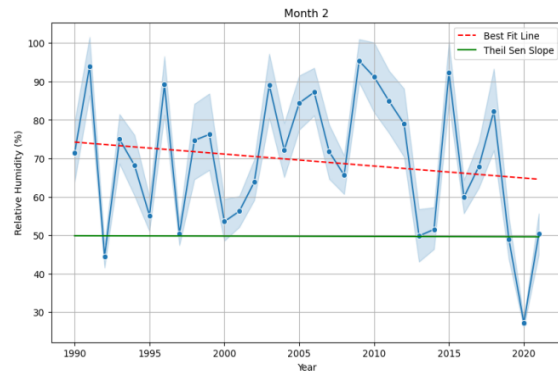
Monthly trend analysis of relative humidity shows that most of the months don't depict any significant trends throughout the study period. Most of the months have p-values greater than 0.05, meaning there is no statistically significant trend. Specifically, the months of January ($p = 0.19$), March ($p = 0.06$), April ($p = 0.57$), May ($p = 0.96$), August ($p = 0.00$), September ($p = 0.00$), October ($p = 0.00$), November ($p = 0.00$), and December ($p = 0.00$) all indicate no discernible increasing or decreasing trends about relative humidity (Table 4.6).

On the other hand, February has a statistically significant increasing trend at $p = 0.02$, which is supported by the Kendall's S value being positive at 0.94, meaning this month generally shows an upward consistently inclined pattern in relative humidity. All the other months in the declining group from June to December, on the contrary, have significant decreasing trends between $p = 0.01$ for June, $p = 0.00$ for July, and so forth, with the range of Kendall's S values between -0.38 to -1.86. The slope calculated for February is quite positive (0.94), which would suggest an increase in the relative humidity levels in February through the years.

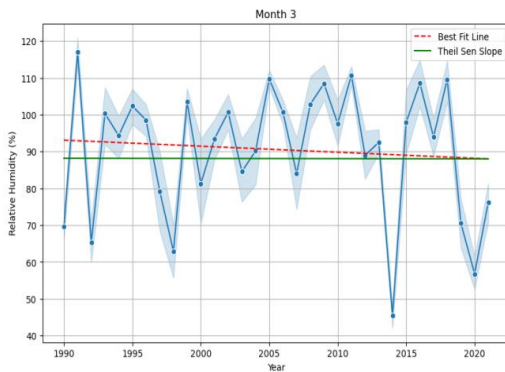
While considering the trends found in February, June, July, and the other months, the slope value of months showing a decreasing trend, especially November with -1.86, shows the falling of the relative humidity though in varying degrees. Figure 4.8: Monthly relative humidity from 1990 to 2023; while in some years, there are peaks in relative humidity, the recent trend is on a decline, especially in the later years, which may signal a change in relative humidity dynamics.



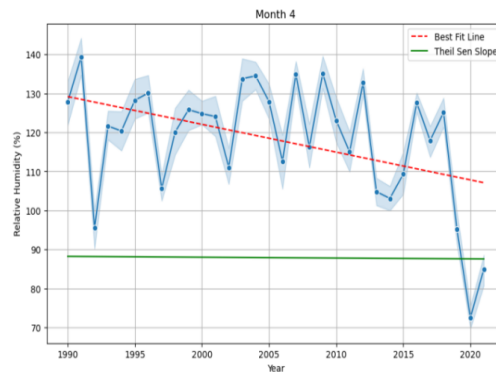
A) January



B) February

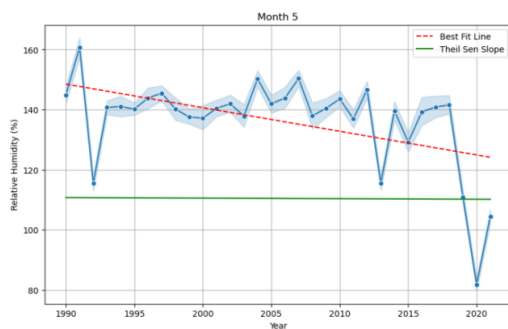


C) March

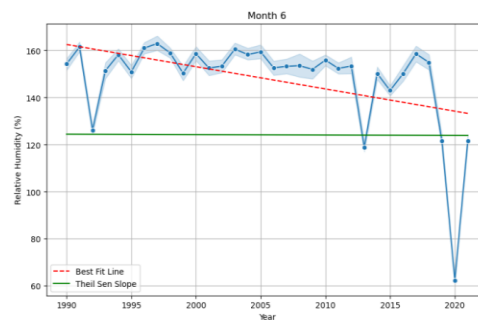


D) April

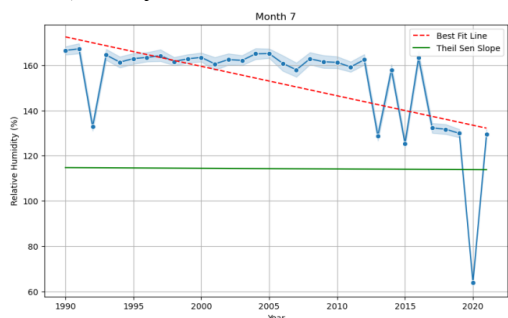




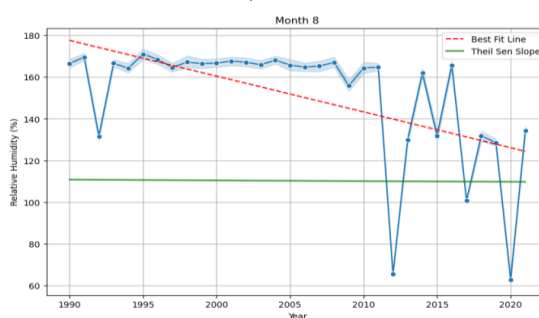
E) May



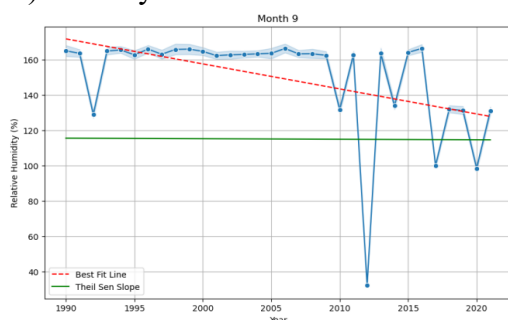
F) June



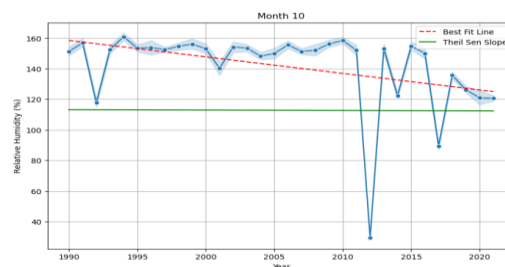
G) July



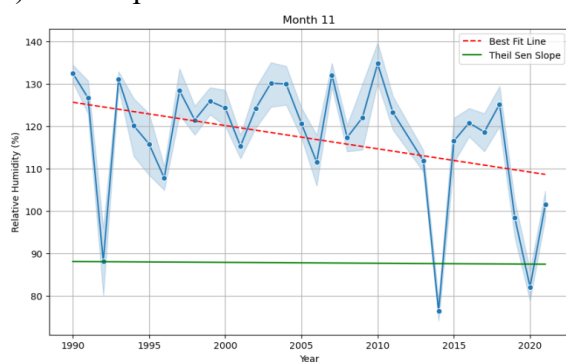
H) August



I) September



J) October



K) November

K) Figure 4.8: Monthly Trend Plots of Relative Humidity (RH (%))

Table 4.6: Trend analysis of temperature, rainfall and relative humidity

Month	Tmax			Tmin			Rainfall			Average Relative Humidity		
	M-K Test Value (S)	Theli Sen Slope	Trend	M-K Test Value (S)	Theli Sen Slope	Trend	M-K Test Value (S)	Theli Sen Slope	Trend	M-K Test Value (S)	Theli Sen Slope	Trend
Jan	93.00	0.00	+	84.00	0.00	+	-39.00	0.00	N	-82.00	0.00	-
Feb	62.00	0.00	+	218.00	0.00	+	33.00	0.00	N	140.00	0.00	-
Mar	- 112.00	0.00	N	246.00	0.00	+	91.00	0.00	+	118.00	0.00	N
Apr	45.00	0.00	N	155.00	0.00	+	-39.00	0.00	N	36.00	0.00	-
May	55.00	0.00	+	303.00	0.00	+	- 173.00	0.00	N	-4.00	0.00	-
Jun	25.00	0.00	N	351.00	0.00	+	-11.00	0.00	N	- 152.00	0.00	-
Jul	77.00	0.00	+	380.00	0.00	+	41.00	0.00	N	- 227.00	0.00	-
Aug	58.00	0.00	N	426.00	0.00	+	-79.00	0.00	-	- 248.00	0.00	-
Sept	-63.00	0.00	-	377.00	0.00	+	49.00	0.00	N	- 252.00	0.00	-
Oct	-14.00	0.00	N	330.00	0.00	+	-42.00	0.00	N	- 198.00	0.00	-
Nov	112.00	0.00	+	234.00	0.00	+	-41.00	0.00	N	- 212.00	0.00	-
Dec	135.00	0.00	+	107.00	0.00	+	-56.00	0.00	-	- 212.00	0.00	-

4.3 Air Quality Parameters

4.3.1 Annual Variations

The study period air quality parameters analysed included Particulate Matter 2.5 (PM2.5), Particulate Matter 10(PM10), Ozone (O3), Carbon monoxide (CO), Dust concentration (Dust), Black Carbon (BCC), and Sulphur dioxide (SO4). Annual mean values give average concentration, with the highest mean of PM10 with (263.56) and the lowest for SO4 (0.52). Max values point toward some extreme cases where dust and

PM_{2.5} reached a value of 618.75, and CO peaked at a value of 460.68. By contrast, minima are much more variable—e.g., the low of 3.00 for PM₁₀ and the low of 0.15 for BCC.

Table 4.7: Annual mean, maximum and minimum values of air quality parameter

Annual	Dust	PM _{2.5}	CO	PM ₁₀	O ₃	SO ₄	BCC
Mean	123.51	123.51	162.78	91.39	263.56	0.52	0.76
Maximum	618.75	618.75	460.68	457.87	287.43	1.33	4.16
Minimum	4.05	4.05	100.34	3.00	236.27	0.20	0.15

Figure 4.9: Mean annual concentration trend of some air pollutants from 1990 to 2022.

From the figure, one could note that dust concentrations are almost invariable at approximately 280 µg/m³ throughout these years; on the other side, PM_{2.5} has a slowly decreasing trend, whereas PM₁₀ starts the decreasing trend from around 2005 and becomes quite stable till the year 2022. CO and O₃ show fluctuations: the former is fairly stable, while the latter shows an increasing trend over recent years.



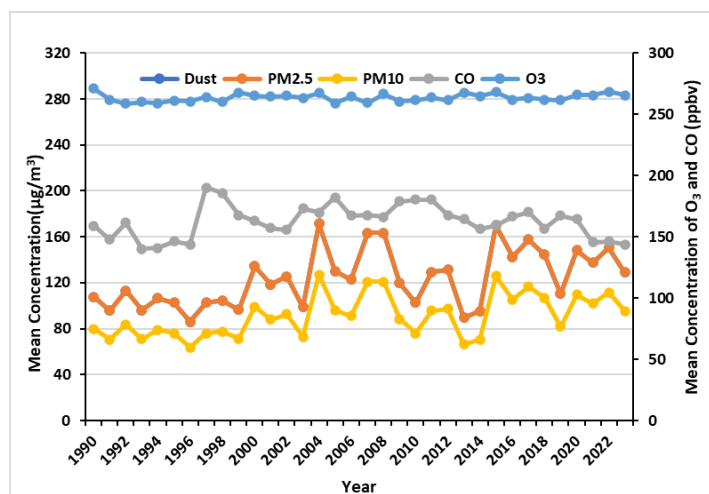


Figure 4.9: Annual Mean values of PM_{2.5}, PM₁₀, O₃, CO and Dust

Also, sulphate (SO₄) mean concentrations and black carbon concentration (BCC) from 1990 to 2022. SO₄ concentrations exhibit a visible peak in 1996, followed by a fluctuation but overall increase toward the end of the period, reaching about 0.8 µg/m³ (figure 4.10). In contrast, BCC shows stable trends; that is, it remains quite stable at about 0.6 µg/m³ over the years with minor fluctuations. The data indicates diverging trends of these pollutants over the given time frame.

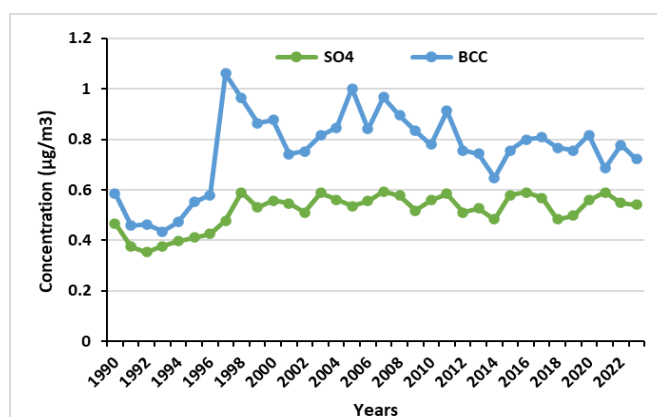


Figure 4.10: Annual mean values of SO₄ and BCC



4.3.2 Monthly variations in air quality parameters

Particulate matter (PM_{2.5} and PM₁₀)

The monthly statistics of PM_{2.5} concentrations exhibit big fluctuations all year round: the mean concentrations reach their maximum in February with 257.0 $\mu\text{g}/\text{m}^3$, while the minimum mean value is measured in August at 17.3 $\mu\text{g}/\text{m}^3$. February also witnesses the highest maximum value of 618.8 $\mu\text{g}/\text{m}^3$, reflecting serious air pollution, while the lowest minimum value of 4.1 $\mu\text{g}/\text{m}^3$ is detected in August. The highest variability is noted in February, with a standard deviation of 114.2 $\mu\text{g}/\text{m}^3$, while August shows the least variability (6.5 $\mu\text{g}/\text{m}^3$). These variations reflect seasonal influences on air quality, with the most polluted periods occurring in the dry months. Similarly, to PM_{2.5}, the monthly statistics of PM₁₀ concentrations also show significant seasonal fluctuations throughout the year. Mean concentrations peak in February (190.19 $\mu\text{g}/\text{m}^3$) and are lowest in August (12.82 $\mu\text{g}/\text{m}^3$). The highest recorded value occurs in February with a maximum of 457.87 $\mu\text{g}/\text{m}^3$, while August shows the lowest minimum value of 3.00 $\mu\text{g}/\text{m}^3$. February also has the largest variability with the largest standard deviation at 84.50 $\mu\text{g}/\text{m}^3$, while the smallest is observed for August with a standard deviation of 4.84 $\mu\text{g}/\text{m}^3$. These trends suggest that particulate matter is seasonal in nature, showing an increase in drier months (see Table 4.8 and Table 4.9).

Table 4.8: Monthly values of measures of central tendency for PM_{2.5}

Parameter	Jan	Feb	Mar	Apr	May	Jun	Jul	Aug	Sept	Oct	Nov	Dec
Count	34	34	34	34	34	34	34	34	34	34	34	34
Mean	245.6	257.0	216.7	130.1	69.7	43.6	25.5	17.3	36.6	89.4	142.2	208.3
Minimum	105.2	105.5	93.3	49.5	34.4	22.0	14.3	4.1	6.7	17.5	61.6	92.9
25 th Percentile	167.2	170.1	134.8	83.2	57.5	31.4	21.0	14.0	22.6	65.3	93.7	141.0
50 th Percentile	242.6	233.6	200.0	132.8	67.7	39.7	23.9	17.6	37.6	85.9	146.1	182.7
75 th Percentile	310.3	314.0	274.3	170.4	82.6	55.2	28.9	21.4	43.8	107.3	188.7	251.7
Maximum	499.1	618.8	549.4	285.4	134.3	83.7	42.8	34.7	85.9	185.9	248.8	570.7
Standard Deviation	95.4	114.2	105.6	50.4	22.0	15.1	7.2	6.5	16.7	36.3	54.0	97.4

Table 4.9: Monthly values of measures of central tendency for PM₁₀

Parameter	Jan	Feb	Mar	Apr	May	Jun	Jul	Aug	Sept	Oct	Nov	Dec
Count	34	34	34	34	34	34	34	34	34	34	34	34
Mean	181.72	190.19	160.36	96.28	51.60	32.27	18.90	12.82	27.05	66.18	105.21	154.13
Minimum	77.84	78.10	69.03	36.64	25.42	16.31	10.58	3.00	4.96	12.93	45.61	68.74
25 th Percentile	123.74	125.90	99.78	61.58	42.55	23.20	15.58	10.36	16.74	48.33	69.37	104.33
50 th Percentile	179.55	172.89	147.99	98.26	50.13	29.35	17.69	13.04	27.84	63.54	108.09	135.18
75 th Percentile	229.60	232.39	202.95	126.08	61.09	40.83	21.41	15.83	32.40	79.42	139.68	186.25
Maximum	369.35	457.87	406.56	211.18	99.40	61.97	31.65	25.68	63.56	137.56	184.13	422.28
Standard												
Deviation	70.62	84.50	78.18	37.28	16.27	11.15	5.34	4.84	12.36	26.88	39.98	72.05



SO₄, Black Carbon and Dust

The sulphate concentrations (SO₄) show a gradual decrease in mean values from January (0.66 mg/m³) to May (0.40 mg/m³), followed by a slight rise during the remaining months, which peaks at 0.62 mg/m³ in December. The maximum value of sulphate concentration is 1.33 mg/m³ in February; the lowest value recorded is 0.20 mg/m³ during the month of May. February has the highest variability, with a standard deviation of 0.18 mg/m³, which means concentrations in this month are most variable in magnitude. On the other hand, dust concentrations show a very strong pattern of seasonality, with maxima occurring in February (257.02 µg/m³) and a minimum of 17.33 µg/m³ during August. The maximum concentration of dust was 618.75 µg/m³ in February, and the lowest at 4.05 µg/m³ during August. The highest variability is in February, with a standard deviation of 114.19 µg/m³. Black Carbon Concentration (BCC) manifests a clear seasonal pattern, with mean concentrations peaking in January (1.93 µg/m³) and decreasing to a low of 0.29 µg/m³ in May. The maximum BCC is 3.99 µg/m³ in January, while the minimum value is 0.15 µg/m³ in August. Highest variability is registered for January when standard deviation attains a value of 0.64 µg/m³. This pinpoints greater concentration fluctuation during the beginning part of the year. See Table 4.10, 4.11 and 4.12 for the same.

Table 4.10: Monthly values of measures of central tendency for SO₄

Parameter	Jan	Feb	Mar	Apr	May	Jun	Jul	Aug	Sept	Oct	Nov	Dec
Count	34	34	34	34	34	34	34	34	34	34	34	34
Mean	0.66	0.57	0.47	0.41	0.40	0.44	0.46	0.46	0.52	0.61	0.60	0.62
Minimum	0.44	0.36	0.29	0.24	0.20	0.23	0.25	0.20	0.26	0.31	0.40	0.44
25 th Percentile	0.59	0.49	0.41	0.35	0.32	0.34	0.40	0.34	0.43	0.53	0.53	0.52
50 th Percentile	0.63	0.53	0.47	0.40	0.40	0.45	0.48	0.47	0.55	0.60	0.58	0.61
75 th Percentile	0.73	0.62	0.52	0.46	0.45	0.50	0.52	0.53	0.61	0.72	0.66	0.69
Maximum	0.99	1.33	0.80	0.88	0.87	0.69	0.63	0.79	0.73	1.00	1.09	0.91
Standard Deviation	0.12	0.18	0.10	0.12	0.13	0.10	0.09	0.14	0.13	0.15	0.14	0.12

Table 4.11: Monthly values of measures of central tendency for Dust

Parameter	Jan	Feb	Mar	Apr	May	Jun	Jul	Aug	Sept	Oct	Nov	Dec
Count	34	34	34	34	34	34	34	34	34	34	34	34
Mean	245.57	257.02	216.70	130.11	69.73	43.61	25.54	17.33	36.56	89.43	142.18	208.28
Minimum	105.19	105.54	93.28	49.52	34.36	22.04	14.29	4.05	6.71	17.47	61.64	92.89
25 th Percentile	167.22	170.14	134.84	83.21	57.50	31.35	21.04	14.00	22.63	65.30	93.74	140.99
50 th Percentile	242.64	233.64	199.98	132.78	67.75	39.66	23.91	17.63	37.62	85.87	146.07	182.67
75 th Percentile	310.27	314.04	274.27	170.37	82.56	55.17	28.92	21.40	43.78	107.33	188.75	251.68
Maximum	499.12	618.75	549.41	285.38	134.32	83.74	42.77	34.71	85.90	185.90	248.82	570.65
Standard Deviation	95.44	114.19	105.65	50.37	21.98	15.07	7.22	6.55	16.70	36.33	54.02	97.37

Table 4.12: Monthly values of measures of central tendency for Black Carbon

Parameter	Jan	Feb	Mar	Apr	May	Jun	Jul	Aug	Sept	Oct	Nov	Dec
Count	34	34	34	34	34	34	34	34	34	34	34	34
Mean	1.93	0.95	0.52	0.34	0.29	0.31	0.33	0.33	0.31	0.41	1.07	2.29
Minimum	0.74	0.39	0.26	0.20	0.18	0.17	0.17	0.15	0.19	0.24	0.59	1.49
25 th Percentile	1.56	0.78	0.40	0.28	0.25	0.27	0.29	0.28	0.27	0.36	0.78	1.74
50 th Percentile	1.95	0.96	0.50	0.36	0.31	0.33	0.34	0.35	0.33	0.42	0.96	2.19
75 th Percentile	2.14	1.17	0.58	0.40	0.32	0.36	0.40	0.38	0.37	0.46	1.37	2.51
Maximum	3.99	1.55	1.36	0.54	0.36	0.43	0.50	0.52	0.42	0.53	1.81	4.16
Standard Deviation	0.64	0.33	0.23	0.09	0.05	0.06	0.08	0.09	0.07	0.08	0.38	0.59

CO and O₃

Table 4.13: Monthly CO values, with mean concentrations varying considerably throughout the year. The highest mean concentration occurs in December at 279.69 $\mu\text{g}/\text{m}^3$, while the lowest is in May at 112.59 $\mu\text{g}/\text{m}^3$. Notably, the standard deviation peaks in December at 58.74, indicating greater variability in CO levels during that month. It also underlines a more general pattern, with lower values of CO between April and October and a sharp increase in November and December. This seasonal trend may indicate that factors such as heating during colder months might contribute to higher CO emissions.

Table 4.13: Monthly values of measures of central tendency for CO

Parameter	Jan	Feb	Mar	Apr	May	Jun	Jul	Aug	Sept	Oct	Nov	Dec
Count	34	34	34	34	34	34	34	34	34	34	34	34
Mean	225.11	149.73	121.63	115.58	112.59	135.69	168.92	163.91	138.25	139.07	203.20	279.69
Minimum	147.79	115.28	101.42	101.40	100.34	109.99	147.98	137.44	121.64	122.03	150.33	178.67
25 th Percentile	195.91	133.82	109.87	108.82	108.26	127.30	154.31	153.35	129.48	132.83	166.12	239.29
50 th Percentile	224.62	151.03	121.01	115.75	114.01	134.93	163.64	162.42	138.39	137.67	199.54	264.08
75 th Percentile	255.26	163.91	128.94	121.58	117.45	140.26	178.99	169.67	145.67	144.58	232.39	316.10
Maximum	303.38	196.48	176.85	140.12	123.72	169.70	233.39	227.51	157.69	155.79	285.25	460.68
Standard Deviation	40.40	19.62	14.88	8.61	5.77	13.05	18.93	16.12	10.60	8.25	38.53	58.74

By contrast, Table 4.14 gives the monthly averages for ozone (O₃) exhibiting a much rather stable concentration band through the year.

From this, mean values of ozone are seen increasing very gradually up to July—from January's 247.12 to 275.25 in July—then fall

back slightly, to 250.36 by December. Very low standard deviation values prevail in all instances at between 4 and 6, which confirms stable O₃ concentration levels. Unlike CO, ozone tends to peak in the summer months, which probably reflects both the greater flux of solar radiation and resulting photochemistry (see Table 4.13).

Table 4.14: Monthly values of measures of central tendency for O₃

Parameter	Jan	Feb	Mar	Apr	May	Jun	Jul	Aug	Sept	Oct	Nov	Dec
Count	34	34	34	34	34	34	34	34	34	34	34	34
Mean	247.12	249.78	256.96	264.93	270.46	274.95	275.25	274.14	272.71	267.33	258.72	250.36
Minimum	236.38	237.80	236.27	254.63	262.07	265.75	265.45	265.89	262.77	258.06	250.91	240.38
25 th Percentile	243.41	247.30	254.83	263.30	267.45	269.59	271.74	270.49	268.48	263.19	255.18	246.63
50 th Percentile	247.26	249.48	258.13	265.27	270.78	274.89	274.31	273.94	273.05	266.97	258.29	250.08
75 th Percentile	250.81	252.30	259.91	267.26	273.60	278.79	278.73	275.99	276.54	270.01	262.31	255.05
Maximum	257.33	261.77	264.83	273.85	282.37	286.11	287.43	284.93	284.19	278.19	268.44	258.75
Standard Deviation	4.74	4.69	5.46	4.06	4.55	6.00	5.43	5.25	5.65	5.25	4.92	5.27

4.3.3 Trend Analysis of Air Quality Parameters

The Mann-Kendall trend analysis of air quality parameters varies in the monthly trend. On the other hand, $PM_{2.5}$ presents a significant upwards trend for the months of February, April to July, September, and October with a p-value lower than 0.05. Among the months, February has the highest positive increase with a p-value equal to 0.04 with a slope equal to 3.46. Similarly, PM_{10} also has an increasing slope for February too similar to $PM_{2.5}$'s results that were reflected above; this being 0.04 p value with a 2.56 slope. And contrastingly the SO_4 sulphate values show April, July September, and October period to record significant increase period according to respective paired p – value <0.05 . Carbon monoxide (CO) remains stable from June to December with a rise in February, April, and May at p-values 0.00 and slopes 189.00, 170.00, and 157.00, respectively. On the other hand, black carbon (BCC) shows an increasing trend from February to October with p-values <0.005 . Dust levels show variations across months with a notable rise in August at a slope of 2.95 at p-value 0.00. Also, O_3 concentrations show a non-significant trend over the months with p-values >0.05 . Summary of the trend test is shown in table 4.14.

4.4 Effects of Air Quality on Climate Variability

This section present results on the effects of air quality on climate variability within Tamale and its environs.

4.4.1 Correlation Analysis of Climate and Air Quality Variables

Figure 4.11 The $PM_{2.5}$ concentrations are the highest from January to April, with its median above $200 \mu g/m^3$, and then it drops off considerably between May and

September below $100 \mu\text{g}/\text{m}^3$, where it stabilizes toward the lower part. Outliers, outlined by dots, show that in some months, especially January and March, the $\text{PM}_{2.5}$ values are very high. Similarly to $\text{PM}_{2.5}$, PM_{10} values are highest from January to April, when values often exceed $200 \mu\text{g}/\text{m}^3$. From May through September there is a significant decline, with levels falling below $50 \mu\text{g}/\text{m}^3$ for most months, as illustrated in Figure 4.11.

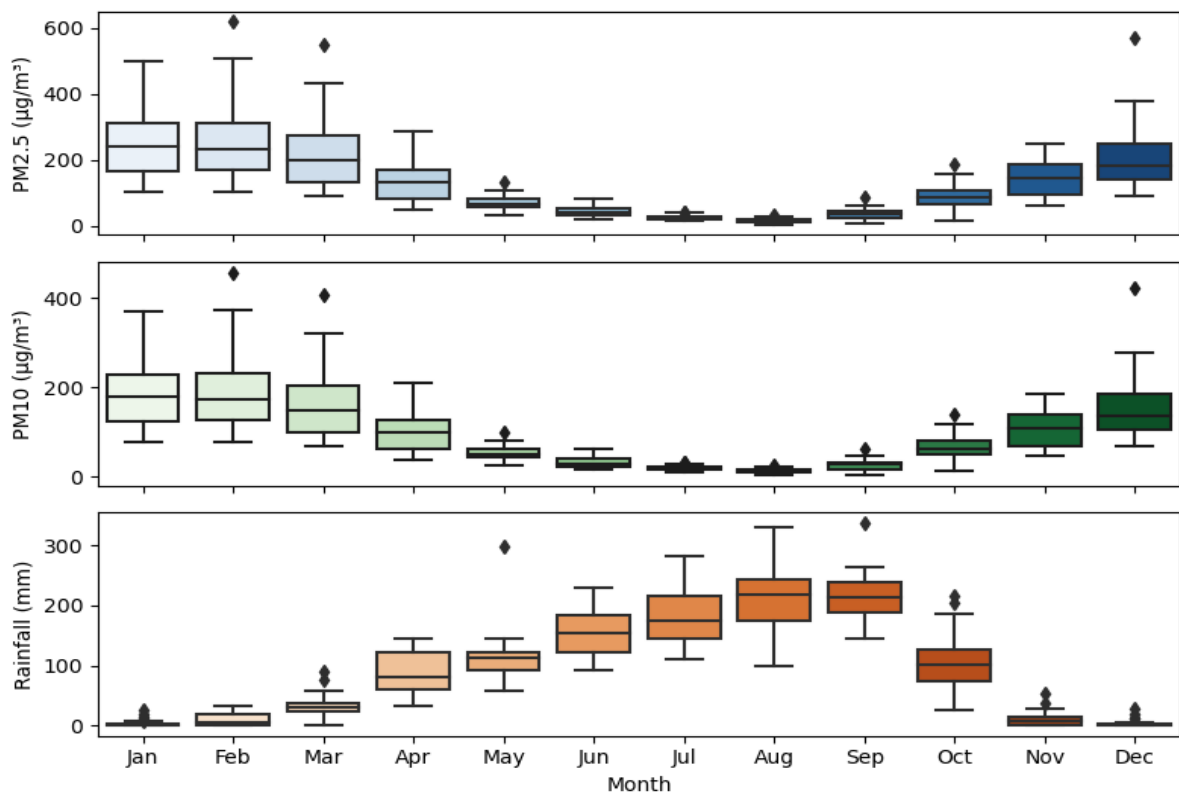


Figure 4.11: Monthly distribution of PM_{10} , $\text{PM}_{2.5}$ and Rainfall

Strong positive correlation with RH with a factor of 0.75 and moderate positive correlation with temperature minimum of 0.24. It also shared some correlation with other pollutants like PM_{10} at 0.71. Temperature Maximum strongly negatively correlated with rainfall at -0.83 and positively with pollutants like NO_2 and CO with



correlation factors of 0.74 and 0.82, respectively. TMIN correlated weakly with most variables except for RH and O₃, having correlation factors of 0.31 and -0.43 respectively. RH is positively and strongly correlated with rainfall with a value of 0.75 and moderately correlated with PM_{2.5} with a value of 0.66. It also shows a negative correlation with SO₂ at -0.59 and O₃ at -0.68.

SO₂, CO, NO₂: CO and NO₂ are highly correlated (0.87) and both are positively and highly correlated with Tmax. SO₂ is negatively correlated with RH (-0.59) while its association with CO and NO₂ is moderate and positive (0.44 and 0.54 respectively). Ozone (O₃): Ozone is negatively correlated with most of the climate variables like Tmax (-0.76), RH (-0.68) and most of the pollutants such as CO (-0.66) - Figure 4.12 and Figure 4.13.

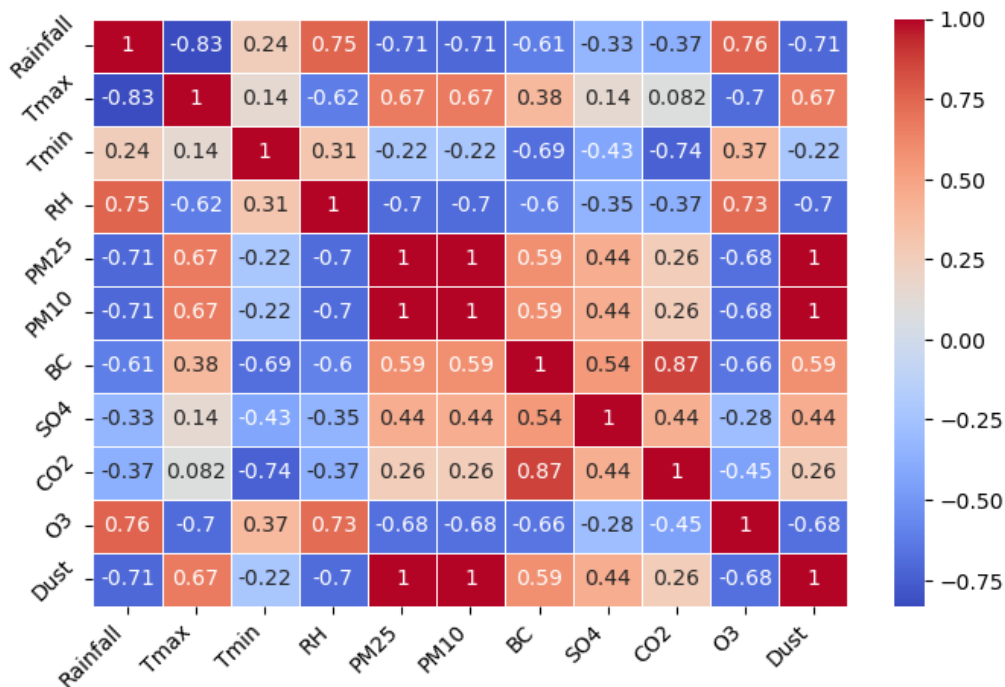


Figure 4.12: Correlation plot of climate and air quality variables

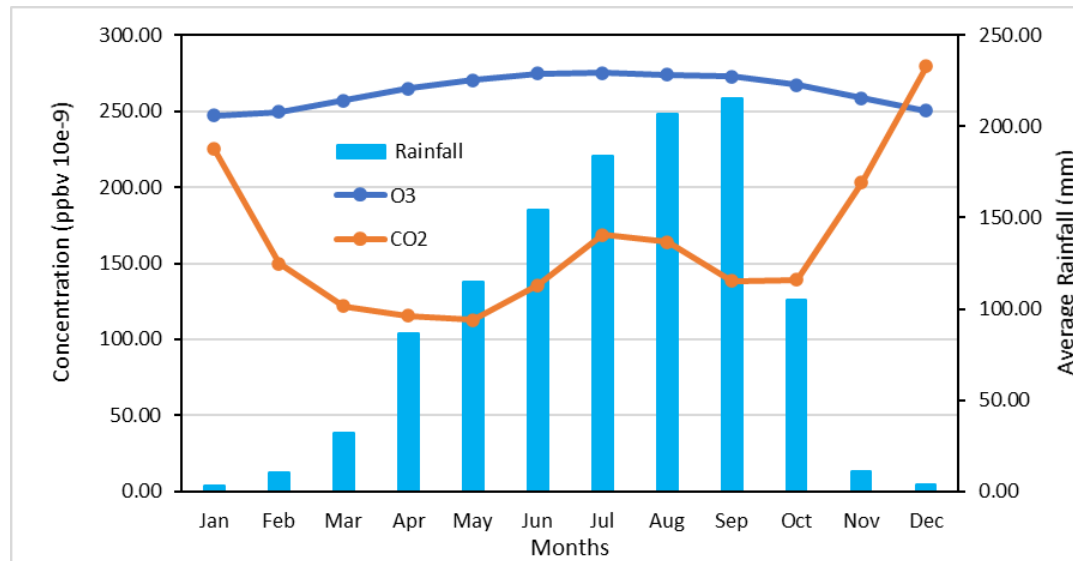


Figure 4.13: Plot of O₃, CO₂ and Rainfall

Standard Deviation of SO₂: Top Left S.D = 0.01: This chart shows the standard deviation of sulphur dioxide, SO₂. The red and blue patterns indicate different concentrations of the gas, probably to show that at a higher concentration, the deviation will also be higher and is given in red color as compared to the blue one. NO₂ Standard Deviation: Top Right S.D = 0.1: This plot shows nitrogen dioxide or NO₂. The scaling factor is 0.1 and the standard deviation is many times larger than for SO₂. It's easy to see looking at the map how the red (higher) dominates the high ends of deviation while the blue of lower concentration has less variance. CO Standard Deviation Bottom Left: SD=0.002: Carbon monoxide varies much less than NO₂ and SO₂. Notice that the peaks for both high, red and low, blue concentrations are squished together to represent lower variability in the concentrations across the different measurements. Temperature



Standard Deviation, Bottom Right, S.D = 0.2: Of the four variables, temperature has the largest standard deviation (see Figure 4.14).

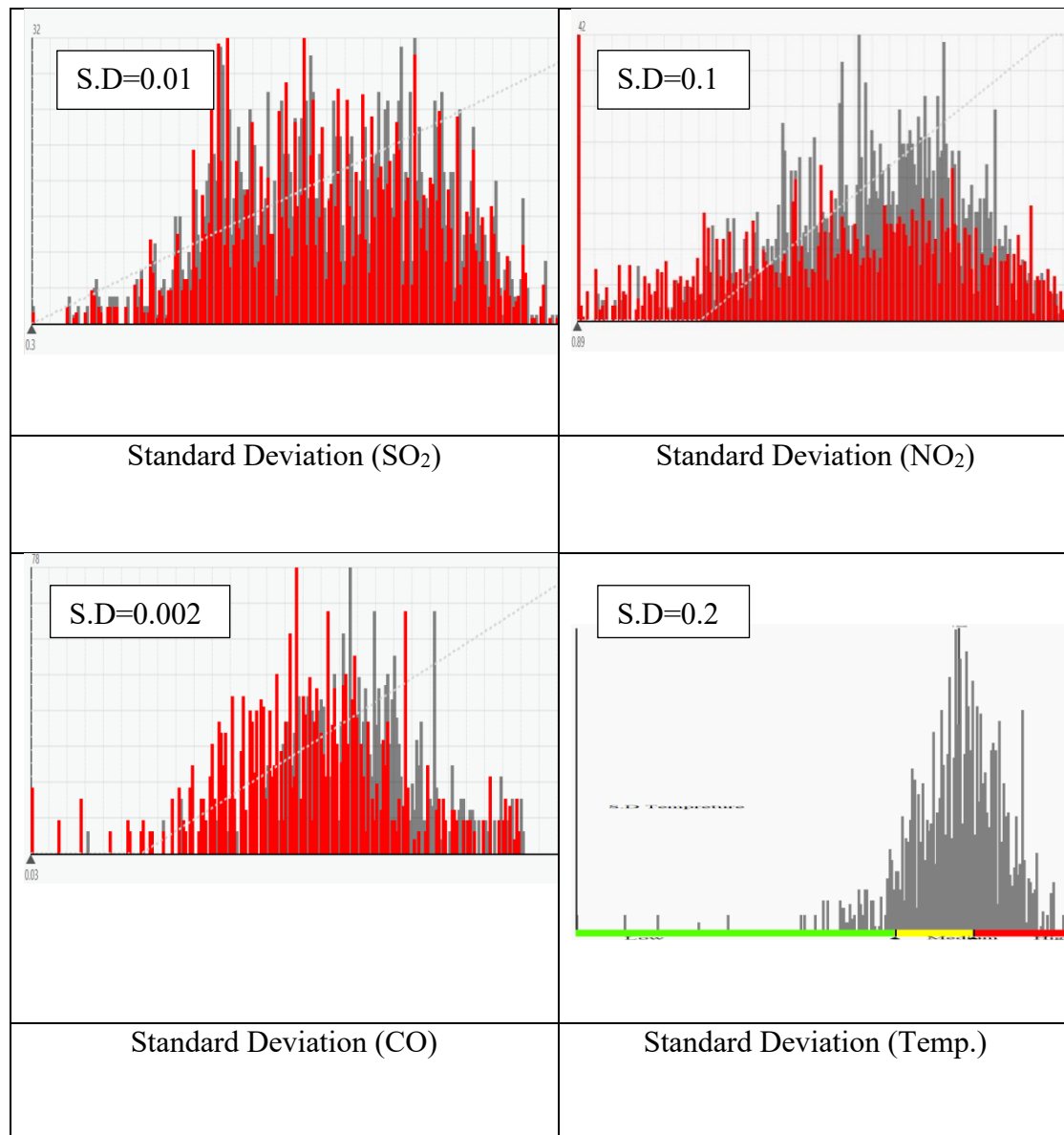


Figure 4.14: Standard Deviation of SO₂, NO₂, CO and Temperature across the northern region between high and low concentrations

4.4.2 Principal component analysis to indicate the sources of air pollutants

The Principal Component Analysis plot gives relations and variability of the air quality parameters. Hence, dust, PM_{2.5}, sulphate (SO₄), black carbon, organic carbon, and other mass measurements will provide a way to see how these variables are grouped, aligned, or opposed by their contribution to the first two principal components, PC1 and PC2.

PC1 has the highest variability within the dataset, with an Initial Eigenvalue of 4.224, contributing 52.799% of the total variance. It has positive loading for variables including Dust (0.917), PM_{2.5} (0.934), Black Carbon (0.857), and Organic Carbon (0.818). These strong contributing variables to PC1 hint at the same influence in explaining variations of air quality by those particulate-related sources. PC2, on the other hand, has an initial Eigenvalue of 1.637, explaining 20.461% of the total variance. Contributors to PC2 include SSSMASS (Average of TOTSCATAU, loading: 0.824) and DUSMASS (Average of DUSMASS25, loading: 0.284), which load positively on this component.



Table 4.15: Total Variance Explained

Component	Initial Eigenvalues			Extraction Sums of Squared Loadings	
	Total	% of Variance	Cumulative %	Total	% of Variance
1	4.224	52.799	52.799	4.224	52.799
2	1.637	20.461	73.26	1.637	20.461
3	0.985	12.316	85.576		
4	0.598	7.473	93.05		
5	0.518	6.479	99.528		
6	0.035	0.442	99.97		
7	0.002	0.03	100		
8	1.51E-12	1.89E-11	100		

Extraction Method: Principal Component Analysis.



Table 4.16: The PCA loading matrix for the surface air pollutants

Index	Component	
	1	2
Organic Carbon Surface Mass Concentration	0.597	0.719
Black Carbon Surface Mass Concentration	0.66	0.666
SO ₄ SurfaceMassConcentration	0.397	0.579
Dust Surface Mass Concentration	0.972	0.033
Average of SSSMASS25	0.309	-0.764
Average of TOTSCATAU	0.971	-0.081
Average of DUSMASS25	0.025	-0.295
PM _{2.5}	0.975	0.07

Extraction Method: Principal Component Analysis.

Rotation Method: Varimax with Kaiser Normalization.

a Rotation converged in 3 iterations.



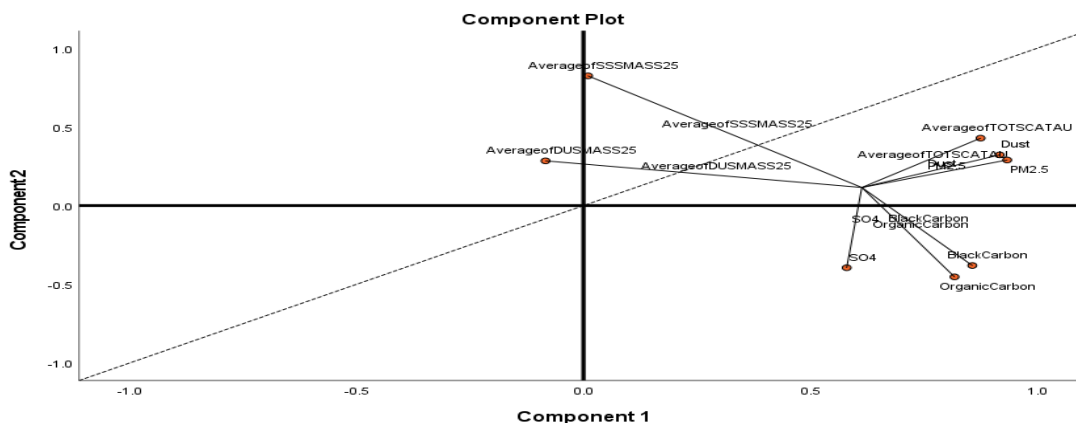
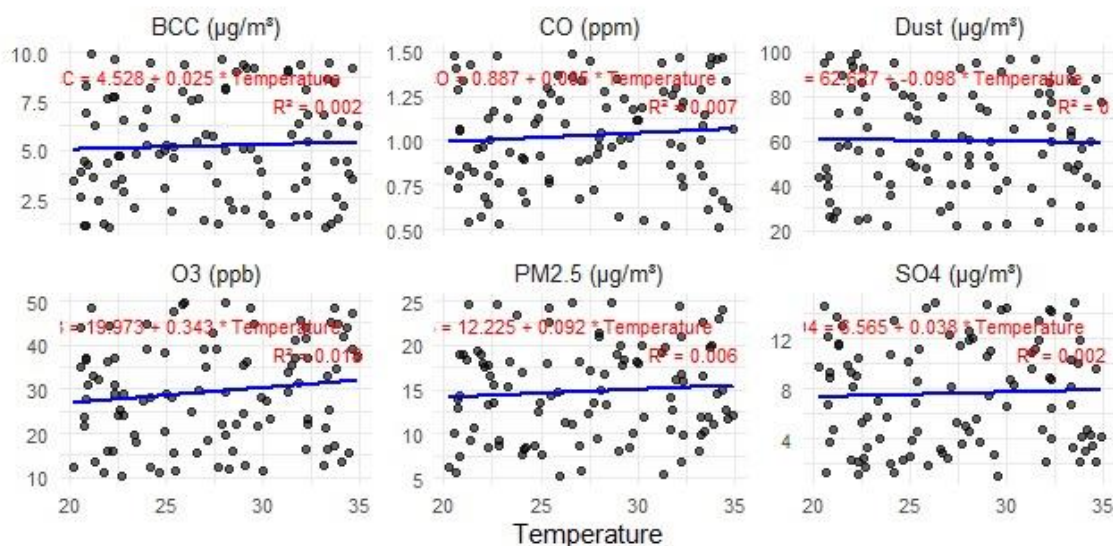


Figure 4.15: The PCA chart and loading vectors, indicate the distribution of variables of air pollutants in clusters along PC1 AND PC2.

4.4.3 Influence of climatic factors on air Pollutants

Temperature

The variable of temperature demonstrated diverse impacts on pollutants. ozone was strongly positively correlated— β coefficient, 0.343; $R^2 = 0.018$ —but this was related to



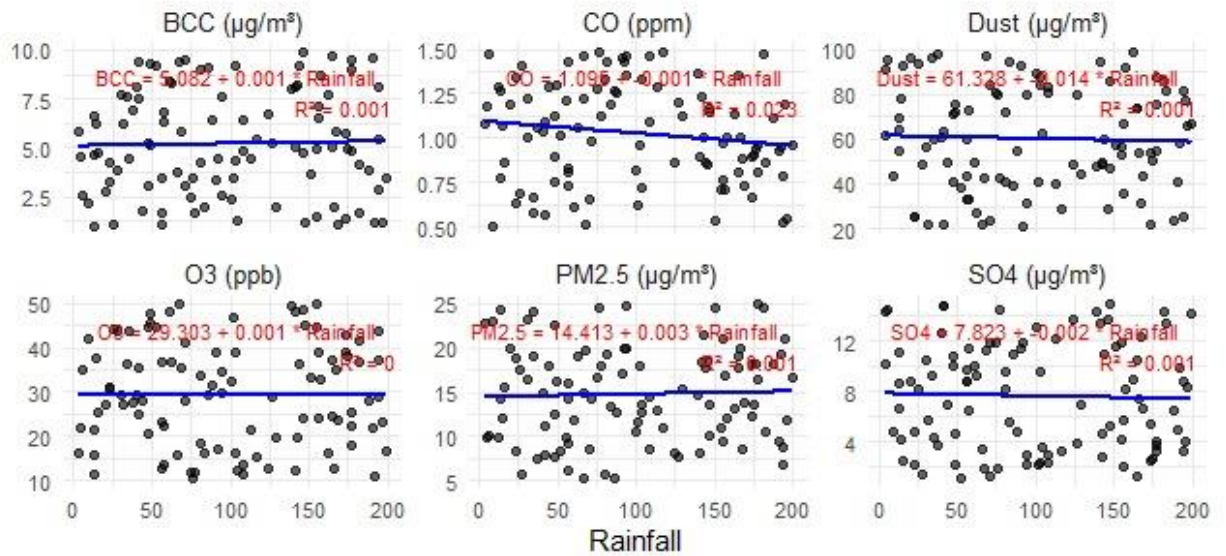
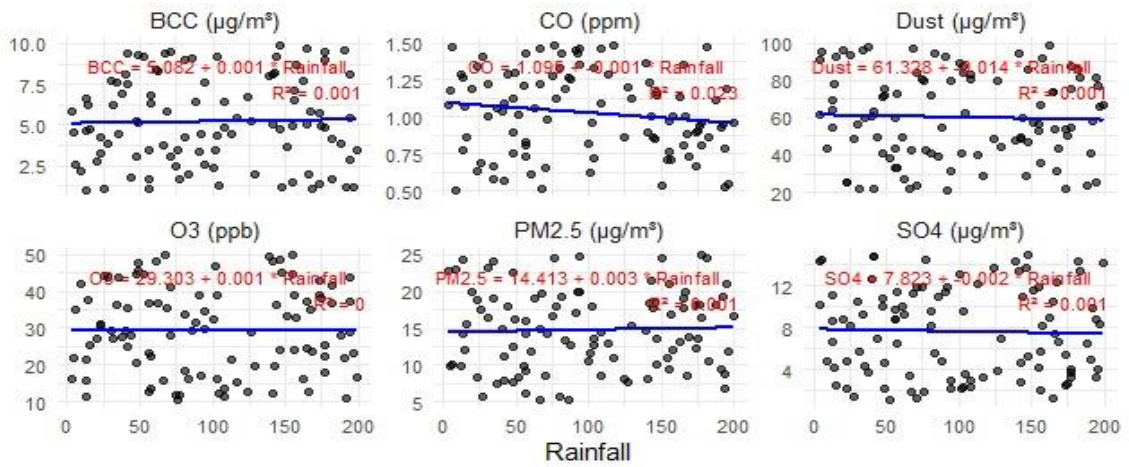
the increased formation of ground-level ozone in high temperatures as a result of

photochemical reactions. PM_{2.5} ($\beta = 0.092$; $R^2 = 0.006$) and sulfate ($\beta = 0.038$, $R^2 = 0.002$) equally showed rises, indicating the increased formation of secondary pollutants with temperatures. In contrast, dust decreased slightly with increasing temperature ($\beta = -0.098$, $R^2 = 0.0001$), perhaps due to less suspension or altered atmospheric mixing. BCC ($\beta = 0.025$, $R^2 = 0.002$) and CO ($\beta = 0.005$, $R^2 = 0.007$) showed very weak positive associations.

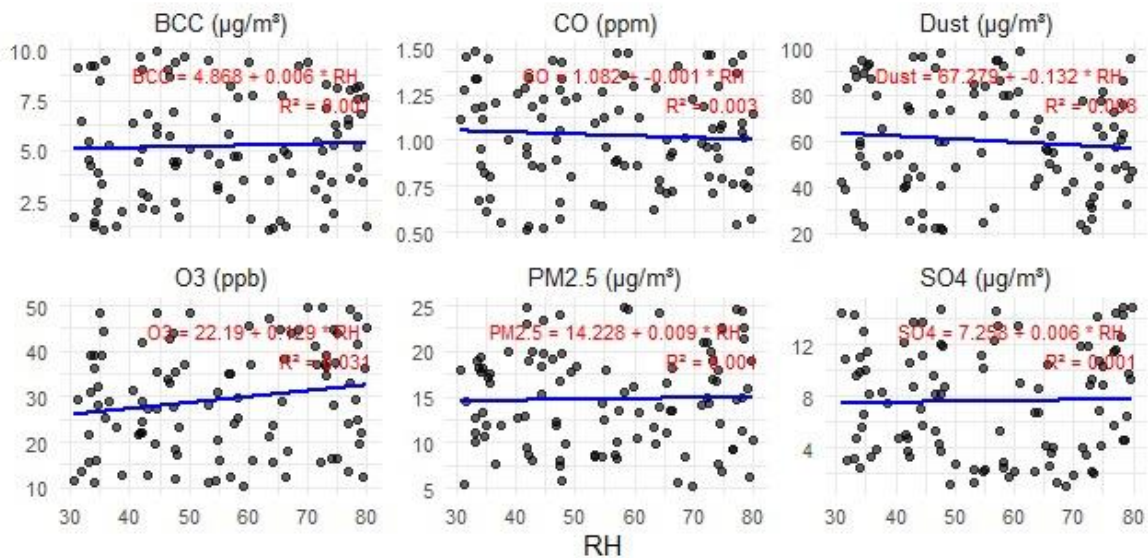
Rainfall

Rainfall would generally play the role of cleansing, as supported by the negative correlations shown for CO ($\beta = -0.001$, $R^2 = 0.023$), dust ($\beta = -0.014$, $R^2 = 0.001$), and SO₄ ($\beta = -0.002$, $R^2 = 0.001$). The results indicate the importance of wet deposition in controlling airborne pollutants. Still, a marginal positive association was found for PM_{2.5} ($\beta = 0.003$, $R^2 = 0.001$) and ozone ($\beta = 0.001$, $R^2 = 0.001$), which may suggest complex interactions such as pollutant re-evaporation or secondary particulate formation.





Relative Humidity



Relative humidity had different impacts on the different pollutants. Dust showed a significant decline ($\beta = -0.132$, $R^2 = 0.003$), which was in line with its role of particle deposition. Ozone presented a strong positive relationship ($\beta = 0.129$, $R^2 = 0.031$), probably due to humid conditions that favor photochemical reactions. Only PM2.5 $\beta = 0.009$, $R^2 = 0.001$, SO₄ $\beta = 0.006$, $R^2 = 0.001$ and BCC $\beta = 0.006$, $R^2 = 0.000$ showed slight increases while CO showed a small decline $\beta = -0.001$, $R^2 = 0.003$.

4.5 Effects of Air Quality and Climate Variability on the Prevalence of Respiratory Illnesses, Cardiovascular Diseases, and Other Health Outcomes

Table 4.17 analyses the statistical correlation between air quality parameters, climatic variability factors, and health outcomes in Tamale Metropolis. From this, it established significant associations with air quality indicators: PM_{2.5} and AQI with temperature; AQI, PM₁₀, and NO₂, with humidity and the prevalence of respiratory and cardiovascular diseases. The value of PM_{2.5} (38.52, $p=0.002$) and PM₁₀ (47.16,





p=0.003) indicates poor air quality and contributes substantially to adverse respiratory health outcomes. AQI also indicated high values of 109.54, p=0.001, showing an unhealthy air condition. More importantly, nitrogen dioxide (NO₂) levels (6.30, p=0.004) point out air pollution as a critical factor influencing health. Climate variables, such as temperature (26.17°C, p=0.005) and humidity (76.13%, p=0.002), also presented significant associations with health outcomes, which may indicate that the variation of these variables can enhance the effect of air pollutants on human health. Strong associations between the environmental factors and health outcomes were found, with an 83.8% prevalence of asthma (p=0.001), 28.2% for bronchitis (p=0.030), 74.0% for pneumonia (p=0.002), 72.8% for lung cancer (p=0.005), and 73.3% for cardiovascular diseases (p=0.001).

Table 4.17: Analysis of relationship between air quality, climate variability, and health outcomes

Parameter	Statistic Value	P-value
PM2.5 ($\mu\text{g}/\text{m}^3$)	38.52	0.002
AQI	109.54	0.001
PM10 ($\mu\text{g}/\text{m}^3$)	47.16	0.003
NO2 (ppb)	6.30	0.004
Temperature ($^{\circ}\text{C}$)	26.17	0.005
Humidity (%)	76.13	0.002
Prevalence of Asthma (%)	83.8	0.001
Prevalence of Bronchitis (%)	28.2	0.030
Prevalence of Pneumonia (%)	74.0	0.002
Prevalence of Lung Cancer (%)	72.8	0.005
Prevalence of Cardiovascular Diseases (%)	73.3	0.001

Source: Field Survey Data (2024) and NASA (2024))





4.6 Perceived Prevalence of Respiratory and Cardiovascular Diseases

This section presents results and discussion on the prevalence of respiratory diseases (e.g., asthma, bronchitis) and cardiovascular diseases among residents within Tamale and its environs.

4.6.1 Individuals experience of air pollution

Table 4.18 presents the experiences and perceptions of air pollution among the people in Tamale and its environs. First, all 400 respondents (100%) reported having experienced air pollution; this shows that air pollution is an environmental factor that has been recognized as affecting everybody in the study area. Second, the frequency of experiencing air pollution varies among the respondents. A great majority, 68.5%, reported experiencing air pollution every day. Another 14.8% said they were exposed once a week, while 9.8% have the experience of it twice a week. Only 7% reported experiencing air pollution once or twice a month. The rating by the respondents on air quality reveals an overwhelmingly negative perception. A very large proportion, 84.5%, rated the air quality as poor, while 11% described it as very poor. Only 3% considered the air quality as fair; even a lesser percentage, 1.5%, believed the air quality to be good.

Table 4.18: Individuals experience of air population

Attributes	Frequency	Percentage
Experience of air		
pollution:	400	100.0
Yes	0	0.0
No		
Total	400	100.0
Frequency experience of		
air pollution:		
Everyday	274	68.5
Twice a week	39	9.8
Once a week	59	14.8
Once/twice a month	28	7.0
Total	400	100.0
Rating of the air quality:		
Good	6	1.5
Fair	12	3.0
Poor	338	84.5
Very Poor	44	11.0
Total	400	100.0

Source: Field Survey Data (2024)





4.6.2 Experience Respiratory Diseases (E.G., Asthma, Bronchitis) and Cardiovascular Diseases

Table 4.19 The most commonly reported symptoms are, therefore, shortness of breath (92.5%), coughing (86.8%), and fatigue (84.5%), which, in a high percentage, indicates the prevalence of respiratory-related health problems; less frequently reported are headaches (21.8%).

Table 4.19: Experience respiratory diseases (e.g., asthma, bronchitis) and cardiovascular diseases

Types of respiratory diseases	Frequency		Percentage	
	Yes	No	Yes	No
Coughing	347	53	86.8	13.3
Shortness of breath	370	30	92.5	7.5
Headaches	87	313	21.8	78.3
Fatigue	338	62	84.5	15.5

Source: Field Survey Data (2024)

4.6.3 Prevalence Rates of Respiratory Diseases and Cardiovascular Disorders

Table 4.20 indicates high prevalence rates of respiratory diseases in Tamale Metropolis, where asthma (83.8%), skin irritation (82%), and pneumonia (74%) are the most common. Conditions such as bronchitis (28.2%) and allergic rhinitis (22%) have relatively low rates.

Table 4.20: Prevalence Rates of Respiratory Diseases and Cardiovascular Disorders

Types of respiratory diseases	Frequency		Percentage		Prevalence Rate (%)
	Yes	No	Yes	No	
Asthma	335	65	83.8	16.3	83.8
Bronchitis	113	287	28.2	71.8	28.2
Pneumonia	296	104	74.0	26.0	74.0
Allergic rhinitis (hay fever)	88	312	22.0	78.0	22.0
Eye irritation	284	116	71.0	29.0	71.0
Skin irritation	328	72	82.0	18.0	82.0
Lung cancer	291	109	72.8	27.3	72.8
Stress-related disorders	293	107	73.3	26.8	73.3

Source: Field Survey Data (2024)

4.6.4 Chi-Square Test Results for Association Between Demographics and Disease Prevalence

Chi-Square test results reveal significant associations between asthma and demographic factors like age group ($p = 0.004$), gender ($p = 0.022$), educational level ($p = 0.010$), and area of stay ($p = 0.013$). Similarly, pneumonia is significantly associated with age group ($p = 0.028$), gender ($p = 0.007$), educational level ($p = 0.005$), and area of stay ($p = 0.020$). Bronchitis does not show any significant associations with any of the demographic factors (see Table 4.21).



Table 4.21: Chi-Square test results for association between demographics and disease prevalence

Demographic Characteristic	Disease Type	Chi-Square Value	p-value
Age Group	Asthma	15.32	0.004
	Bronchitis	7.14	0.128
	Pneumonia	12.67	0.028
Gender	Asthma	9.21	0.022
	Bronchitis	3.44	0.487
	Pneumonia	10.55	0.007
Marital status	Asthma	6.89	0.142
	Bronchitis	2.33	0.679
	Pneumonia	8.14	0.091
Educational Level	Asthma	13.27	0.010
	Bronchitis	5.76	0.216
	Pneumonia	14.88	0.005
Area of Stay	Asthma	10.77	0.013
	Bronchitis	4.67	0.321
	Pneumonia	11.93	0.020

Source: Field Survey Data (2024)



4.7 Adaptation Strategies Used by Residence to Enhance Air Quality in the Face of Climate Variability

This section presents results and discussion on the various adaptation strategies that have been by residences in enhancing air quality in the face of climate variability within Tamale and its environs.

Table 4.22: Adaptation Strategies Used by Residents of Tamale Metropolis to Improve Air Quality Amidst Climate Variability

The first three top answers were planting of trees (1st), the use of LPG for cooking (2nd), and the avoidance of tree cutting (3rd). Proper waste management is 4th, while using public transport comes 5th. Energy-efficient appliances placed 7th and reduction in indoor air pollution was 8th. The least prioritised were avoiding air conditioners (9th) and improving air quality monitoring (10th). The Kendall's W_a value of 0.646 and the Chi-Square result ($p = 0.000$) indicate significant agreement among respondents on these rankings.



Table 4.22: Adaptation strategies used by residence to enhance air quality in the face of climate variability

Adaptation Strategies	Mean Rank	Ranking
Using energy efficient fridge and light bulbs	5.09	7 th
Using public transportation and other forms of non-single occupancy vehicle transportation	4.65	5 th
Use of LPG for cooking and other domestic purposes	2.37	2 nd
Planting trees and greenery around home	2.05	1 st
Stop burning rubbish (proper waste management)	4.56	4 th
Reduce indoor air pollution	5.98	8 th
Stop using air conditioner and rather use ceiling fans	6.82	9 th
Using of local materials for building of houses	5.14	6 th
Improving the effectiveness of air monitoring and air quality emergency response	7.56	10 th
Avoid cutting down of trees	3.80	3 rd
N	400	
Kendall's Wa	.646	
Chi-Square	1605.223	
df	9	
Asymp. Sig.	.000	

Source: Field Survey Data (2024)



CHAPTER FIVE

DISCUSSION OF RESULT

5.0 Introduction

This chapter discusses the study by focusing on the trends, patterns, and relationships uncovered through the analysis of climate variability, air quality, and human health data in the Tamale metropolis.

5.1 Trend Analysis of Meteorological Parameters

Analyses of meteorological parameters at Tamale Metropolis showed important trends in the changes of rainfall, temperature, and relative humidity from 1990 through 2023. The study established that the annual rainfall within the Tamale Metropolis ranges between 878.96 and 1608.12mm, with a peak in the year 1991 and a minimum in 1992. Monthly rainfall follows the pattern of recording low levels from November through April, with heavy rainfall from May through October; the months of August and September record very heavy rainfall. The Mann-Kendall trend analysis showed that the trends in rainfall for most months were not statistically significant ($p > 0.05$), except for May, which showed a significant decreasing trend ($p = 0.01$). A slight decrease was also noticed in the amount of rainfall, especially in recent years, though it was not very significant; hence, there is only a minor change in the general pattern of rainfall in the area. This corroborates other related studies, such as Odoi et al. (2020), which showed no significant change in the trend of rainfall in northern Ghana for a similar period. However, the greater changes that many parts of sub-Saharan Africa, including northern Ghana, have experienced in the patterns of rainfall, including extended periods of dry seasons and heavy rainfall events, are according to other studies like (Abidoeye et al.,





2021). This would mean regional differences in the pattern of rainfalls, which could be due to local climatic conditions.

Temperature analysis indicated that T_{min} ranged from 29.2°C to 35.3°C , with the highest T_{min} occurring in February and the lowest in August. T_{max} ranged between 30.6°C in August and 39.5°C in March. The Mann-Kendall test applied to T_{min} showed significant rises in temperature from February to November ($p < 0.05$), while T_{max} showed a significant rise only in December. This trend would then portray a generalized warming pattern, particularly for months leading up to the beginning of the dry season. The warming trend found here does not disagree with some studies in the region, such as Fosu and Apan (Fosu & Apan, 2018), who documented a generalized warming of temperatures over West Africa, although a more pronounced warming is seen over the Sahel region. Similarly, Nkem et al. (Nkem et al., 2022) found it to be highly increasing in both T_{min} and T_{max} throughout northern Ghana, which agrees with the findings from this study and generally points to a rise in temperature as a regional phenomenon. The only discordant note came from the Nkem et al. (2022) study, which, on the contrary, stated that T_{max} is more variable - contrary to what has been presented here, where T_{min} and T_{max} are consistently on an increasing trend but with less variability.

The RH is seen to vary highly, from 27.2% to 171.0%, with the highest RH during the months of May to October. Mann-Kendall analysis of RH shows a significant ($p = 0.02$) increasing trend for the month of February, while months like June, July, and November show a significantly decreasing trend. The general trend in recent years has been a decline in relative humidity, especially from the late 2000s. This contrasts with the



findings of other studies, which have come up with significant decreases in the relative humidity of West Africa, particularly during the dry season, which might result in increased water stress, as revealed by Adekoya and Oladipo (Adekoya & Oladipo, 2019). However, more consistent patterns of fluctuating humidity without an apparent overall decline were shown by studies by Fosu and Apan (Fosu & Apan, 2018) in northern Ghana, which may indicate that relative humidity trends might be more variable over different locations and dependent on particular seasonal patterns.

5.2 Air Quality Parameters

The present study analysed all the air quality parameters in the Tamale Metropolis, comprising of $PM_{2.5}$, PM_{10} , CO, O_3 , SO_4 , black carbon (BCC), and dust concentration, and exposed both annual and monthly variations. From the yearly mean values, PM_{10} has a highest mean concentration of $263.56 \mu g/m^3$ while the lowest is that of SO_4 with a concentration of $0.52 \mu g/m^3$. Very high maximal values of dust $618.75 \mu g/m^3$ and $PM_{2.5}$ $618.8 \mu g/m^3$ were measured, indicating severe pollution episodes especially during the dry months. Concentration of PM_{10} has decreased since about 2005, while those of $PM_{2.5}$ tend to lower with time. CO has a variable trend while O_3 concentration increases gradually in the recent years. These results follow previous studies with increasing trends for pollutants such as CO and O_3 in urban areas emanating from vehicular emissions (Yang et al., 2019) and industrial activities (Aghamohammadi et al., 2017). In addition, the flat trend of dust noted in the present study corroborates similar works in arid and semi-arid regions of the world that experience constant events of dust particles throughout the year due to weather conditions (Kousa et al., 2002).



The study further showed significant monthly variations. The highest concentrations of $PM_{2.5}$ and PM_{10} were recorded in February with values of $257.0 \mu g/m^3$ and $190.19 \mu g/m^3$ respectively. The lowest values were recorded in August. This trend is typical of the dry season when dust storms mostly prevail over northern Ghana and agrees with other studies done in arid regions (Gao et al., 2018). In contrast, those in temperate climates, such as Gago et al. (Gago et al., 2013), show higher levels of pollution in winter due to heating and lower dispersion, while in tropical climates like Tamale, dust-related pollution peaks during the dry months.

Sulphate (SO_4) varied in a decreasing trend from January to May and a gradual increase towards December, with the highest variability experienced in February. Black carbon BCC showed highly defined seasonal variations, with maxima in January ($1.93 \mu g/m^3$) and minima in May. This trend was similar to another study where black carbon concentrations during the dry seasons are higher owing to biomass burning (Carter et al., 2016). Likewise, dust concentrations were highest in February with $257.02 \mu g/m^3$ and lowest in August, following the seasonal dust influx found for other semi-arid regions (Shao et al., 2011).

CO and O_3 Carbon monoxide (CO) levels were highest in December ($279.69 \mu g/m^3$), likely due to the use of combustion-based heating during colder months, and lowest in May. The general increase in CO through the seasons is consistent with studies in regions where biomass burning and vehicular emissions drive CO pollution, particularly during colder months (Harrison et al., 2017). Ozone (O_3) exhibited a gradual increase throughout the year, reaching its peak in July, which agrees with previous reports from



tropical regions where solar radiation and photochemical reactions drive the formation of ozone (Klemm et al., 2020). On the other hand, studies on temperate climates peaked in summer (Brunekreef & Holgate, 2002), which suggests regional differences in ozone dynamics.

The Mann-Kendall trend analysis showed that some of the air quality parameters had significant trends. There were upward trends of the concentrations of $PM_{2.5}$ and PM_{10} for February, April to July, and September to October. This increase in particulate matter agrees with other studies that report seasonal air pollution peaks during the dry season (Wang et al., 2017). Sulphate (SO_4) and CO levels also showed elevations during some months, such as February, April, and May, which agrees with studies showing that higher sulphur and CO levels are seen in periods of intensive agricultural activities and biomass burning (Carter et al., 2016). Black carbon concentrations increased from February to October, which reflects typical seasonal trends attributed to biomass burning (Shao et al., 2011). Ozone concentrations, however, did not show any distinct trend over the months, due to the invariant photochemical conditions governing ozone formation in this region.

5.3 Effects of Air Quality on Climate Variability

Analysis of air quality and climate variability at Tamale has brought forth critical linkages between meteorological parameters and pollutant levels, as well as their interactions with the environment and human health. Key relationships indicated in the research include those of temperature, humidity, rainfall, and air pollutants in terms of

PM_{2.5}, PM₁₀, O₃, sulphur dioxide (SO₂), nitrogen dioxide (NO₂), and carbon monoxide (CO).

Temperature Effects on Air Quality

This study found a positive relation between temperature and ozone levels ($\beta = 0.343$, $R^2 = 0.018$), which is in agreement with the research by Jacob and Winner (Jacob & Winner, 2009), indicating that higher temperatures cause an increase in photochemical reactions, thus forming more ozone. Likewise, the increase of PM₁₀ (Zhang et al.) with temperature— $\beta = 0.092$, $R^2 = 0.006$ —is in line with the study conducted by Mahowald et al. (2007), wherein the group cited that high temperatures favour the oxidation of precursors such as VOCs, leading to secondary particulates formation. Conversely, this study showed a negative relation of temperature and dust ($\beta = -0.098$, $R^2 = 0.0001$), which means that with the increase in temperature, dust suspension decreases; this confirms the findings of Mahowald et al. (Mahowald et al., 2007), which mentioned that in certain thermal conditions, changes in atmospheric stability reduce dust particles. This finding deviates from results in arid environments of other studies that indicate an increase in dust suspension with elevated temperatures (R. Zhang et al., 2015).

Rainfall's Role in Air Quality

Rainfall showed a negative relation with pollutants like CO ($\beta = -0.001$, $R^2 = 0.023$) and dust ($\beta = -0.014$, $R^2 = 0.001$), which gives support to the concept of wet deposition where rainfall helps in the removal of primary pollutants from the atmosphere (Zalakeviciute et al., 2020). However, its effect on secondary pollutants like ozone and PM_{2.5} was not much. This finding is consistent with Zhang et al. (2015), who noted that





although rainfall can remove primary pollutants, under some conditions—for instance, when the precursor gases remain in the atmosphere after a rain event—it may actually enable the secondary formation of particulate matter. This is contrary to some other studies, such as those of Wu et al. (Wu et al., 2018), in which heavy rainfalls resulted in the noticeable reduction of pollutants by means of prolonged wet deposition.

Relative Humidity and Air Pollutants

Similarly, relative humidity showed a strong positive association with ozone ($\beta = 0.129$, $R^2 = 0.031$), which agrees with Wu et al. (Wu et al., 2018), stating that higher humidity enhances photochemical activity because it increases the availability of hydroxyl radicals, which are essential in the formation of ozone. It also indicated a decrease in dust level associated with increasing humidity ($\beta = -0.132$, $R^2 = 0.003$), and this trend was supported by Wang et al. (Wang et al., 2020), who reported that high humidity could enhance particle aggregation and deposition. On the other hand, slight increases in $PM_{2.5}$ and sulphate at higher humidity ($\beta = 0.009$ and $\beta = 0.006$, respectively) agree with findings by Pathakoti et al. (Pathakoti et al., 2018), which reported that in humid conditions, particles are subjected to hygroscopic growth, hence increasing the particle mass and settling properties. This runs counter to the results of other studies, such as Kumar et al. (Kumar et al., 2019), which found high humidity during monsoon months not contributing to major differences in particulate concentrations.

Pollutants and Correlations

Moreover, this study also shows strong associations of one pollutant with another. CO and NO_2 showed high correlation value of 0.87, and both are positively correlated with



maximum temperature (Tmax) at 0.74 and 0.82, respectively, suggesting that at higher temperatures, the levels of the pollutants increase. The negative correlation between SO₂ and RH (-0.59) befits the same findings reported by Tiwari et al. (Tiwari et al., 2018), which stated that higher humidity could suppress the dispersion of sulphur compounds in the atmosphere. Conversely, ozone was negatively associated with most of the climate variables, especially Tmax (-0.76) and RH (-0.68), which is in agreement with studies showing that high temperatures and humidity may influence ozone formation and degradation in complicated ways (Z. Zhang et al., 2015).

Standard Deviations and Pollutant Variability

The standard deviation graphs for SO₂, NO₂, and CO reveal the variation in the pollutant concentration. SO₂ has minor SD values, hence showing a near-constant level of concentration, while NO₂ and CO have bigger SD values, hence showing higher variations in the levels of these pollutants. Variability of this nature in pollutant concentration, especially with changes in temperature and humidity levels, complicates air quality management within the area.

5.4 Effects of Air Quality and Climate Variability on the Prevalence of Respiratory Illnesses, Cardiovascular Diseases, and Other Health Outcomes

Air Quality Indicators (PM_{2.5}, PM₁₀, AQI, NO₂)

A concentration of PM_{2.5} at 38.52 µg/m³, clearly indicating with a p-value of 0.002, strongly suggests that particulate matter in the atmosphere is significantly linked to undesirable health consequences, particularly respiratory and cardiovascular diseases. Particulate Matter 2.5, better known as PM_{2.5}, refers to particles whose diameter is equal



to or less than 2.5 micrometres. The size of these particles enables them to be inhaled deeply into the lungs and even enter the bloodstream, resulting in different types of medical problems. The p-value of 0.002 indicates that the observed relation between the levels of PM_{2.5} and health outcomes is statistically significant. In other words, it can be said that there is less than 0.2% probability that this association occurred by random chance. These findings are, therefore, reliable. The literature well establishes the fact that the high levels of PM_{2.5} cause severe health dysfunctions, which include respiratory conditions such as asthma and bronchitis, cardiovascular diseases, and even cancers. These conditions emerge because PM_{2.5} particles may lead to inflammation and oxidative stress in the respiratory and cardiovascular systems. From these findings, compared with other literature, the association of PM_{2.5} exposure with health risks is of great concern. For example, a study conducted in China discovered that for every 10 µg/m³ increase in PM_{2.5}, the mortality cases of CVD increased by 0.26% (Qiu et al., 2020). Similarly, research carried out in Europe has found long-term exposure to PM_{2.5} to significantly increase the chances of heart attacks and strokes (Alexeeff et al., 2021). These studies agree with the result showing that PM_{2.5} levels of 38.52 µg/m³ are significantly associated with adverse health outcomes. However, with a concentration of 38.52 µg/m³, it is much higher than the guideline of the World Health Organization (WHO) for the annual average concentrations of PM_{2.5}, which is 5 µg/m³ (World Health Organization, 2018c). The difference evidences a critical air quality situation that poses great health risks to the public. On the contrary, research carried out in areas with lower PM_{2.5} concentrations, like in parts of the United States, has shown a lower incidence of related health problems (Shi et al., 2016). The analysis of PM₁₀ concentrations shows a

significant association with adverse health outcomes with a concentration level of 47.16 $\mu\text{g}/\text{m}^3$ and a p-value of 0.003.

It allows giving a statistically meaningful relationship between the increased levels of PM_{10} with adverse health outcomes in regard to respiratory and cardiovascular diseases. Having this dimension means it can go down into the respiratory tract easy into the lungs. Therefore, every kind of pathology like asthma and bronchitis, and possibly other chronic kinds of respiratory disease, can develop. It also contains evidence of increased hospitalization for cardiovascular diseases once people are exposed to high levels of PM_{10} , since particulate matter gets into the bloodstream and thus causes inflammation, making the condition worse. Previous research also supported this finding by showing the very harmful effects of PM_{10} on public health again and again. For instance, in Nigeria, increased levels of PM_{10} were significantly associated with higher mortality rates attributed to cardiovascular and respiratory diseases (Ihedike et al., 2023). In correspondence, long-term exposure to PM_{10} was found to contribute to the rise in chronic obstructive pulmonary disease (COPD) incidence and other respiratory ailments in Europe (Marchetti et al., 2023). These studies offer supporting evidence of the high impact of PM_{10} on health, reinforcing the importance of regulation of air quality to reduce its adverse effects. However, some studies reported that this effect of PM_{10} might be modified by regional factors such as population density, industrial activities, and existing health care infrastructure. For example, studies conducted in rural areas of India found a relatively weak association of PM_{10} with respiratory health compared to urban settings, which might be partly due to lower levels of exposure but also to inferior access to medical care in these areas (Sharma et al., 2004). Moreover, while the link between





PM₁₀ and cardiovascular health is very strong, some studies have indicated that PM₁₀, being made up of smaller particulate matter, may actually be more strongly associated with heart diseases because it would penetrate deeper into the lungs and be absorbed into the bloodstream more easily (Archer et al., 2021).

The Air Quality Index is one of the important aggregate measures for levels of air pollution in general and, by extension, their potential threat to public health. In this study, the AQI is 109.54 with a p-value of 0.001, strongly relating high AQI levels to incidence rates of different diseases, most notably asthma and lung cancer. With an AQI value of 109.54, which falls under the "unhealthy" category, it would mean that the air quality poses health risks for sensitive populations like people with pre-existing respiratory and cardiovascular conditions. The findings are in line with an already existing large body of literature identifying severe health consequences from high AQI levels. For example, the study by Duan et al. (Duan et al., 2020) directly pointed out that air pollution would cause the aggravation of respiratory diseases, including asthma and COPD. Similarly, in a study conducted by Leili et al. (Leili et al., 2021), it was determined that long-term exposure to high AQI levels significantly enhances the risk of cardiovascular and respiratory mortality, in line with findings of the current study. Compared with other studies, some differences are noticeable. For instance, the large study from Europe, by Horn et al. (Horn et al., 2023), although confirming a high AQI level related to increased hospital admissions for asthma, had findings that showed a somewhat weaker association than most studies set in highly industrialized urban settings, such as those conducted in the United States or China. These variations might be due to differences in the sources and composition of air pollutants in various regions,



as well as differences in population sensitivities and health care infrastructure. Contrasting these is the research performed in rural settings, such as the study of Seo et al. (Seo et al., 2020) in South Korea, showing that even moderate AQI levels, normally considered relatively harmless, may still result in a large health impact due to lower baseline pollution exposure and poorer access to healthcare in rural areas. This contrasts with urban studies, where populations may be more acclimated to higher pollution levels but have more accessible healthcare facilities to manage related health conditions.

The result shows: "NO₂ (6.30 ppb, p-value = 0.004)," which gives the strong relation between nitrogen dioxide exposure and poor health outcomes, mostly respiratory diseases like bronchitis and pneumonia. NO₂ is known to be a harmful pollutant often linked with the aggravation of respiratory problems because it causes inflammation and decreases lung function. A p-value of 0.004 certainly indicates that the relationship between NO₂ levels and respiratory health is statistically significant; that is, the probability of such a result occurring by mere chance is very small. This surely shows serious public health implications due to exposure to NO₂, especially in urban areas where vehicle emissions and industrial activities raise this pollutant. Similar results have been observed in a wide range of regions when brought to comparison with other studies. For example, studies by Achakulwisut et al. (Achakulwisut et al., 2019), have noted strong associations of high NO₂ levels with incidence and severity of asthma, especially among children. Their epidemiological evidence review study concluded that even low levels of NO₂ could result in significant respiratory health effects, which agreed with the current result showing a significant relation between NO₂ and respiratory diseases at 6.30 ppb. Similarly, a study by Wasi and Begum (Wasi & Begum,



2024) showed that long-term exposure to NO₂ was related to chronic bronchitis and other respiratory infections, hence supporting the hypothesis that NO₂ is of great importance in the deterioration in respiratory health. However, this association was reported to be of varying strength in some studies that took into consideration geographical location, population demographics, and other pollutants. For example, in a study by Khreis et al. (Khreis et al., 2017) conducted in Denmark, NO₂ had a significant effect on hospital admissions for respiratory diseases, but compared with others from a more industrialized area or an area with high traffic flow, its effect size was small. It may mean that the impact of NO₂ would be modified by the overall air quality and other environmental factors. These findings can be compared to the evidence suggesting less impressive associations between NO₂ and respiratory health outcomes. For example, a study by Faustini et al. in Rome (Faustini et al., 2019) found that there was a strong association between NO₂ and respiratory mortality; however, this was attenuated when adjusted for other pollutants such as particulate matter (PM_{2.5}). This indicates that although NO₂ is a major pollutant, its effect may be enhanced or reduced by the presence of other environmental factors.

Climate Variability (Temperature and Humidity)

The result of 26.17°C with a p-value of 0.005 does indicate a significant relationship between average temperature and health outcomes. A low p-value obtained would hence suggest that the relationship between the variables is not by chance; hence, temperature is an important factor influencing health. Changes in temperature, more precisely, have effects on the prevalence of respiratory and cardiovascular diseases. Higher temperatures can increase the effects of air pollutants, which may cause greater health

risks, especially to sensitive populations such as the elderly and those with pre-existing conditions.

This finding is in agreement with existing literature identifying the detrimental health consequences of extreme temperatures. For example, a study by Lin et al. found increased temperatures to be significantly associated with an increase in hospital admissions due to both respiratory and cardiovascular diseases. To this end, Zafeiratou et al. (Zafeiratou et al., 2021) analysed the relationship between ambient temperatures and mortality from CVDs. Similarly, another study by D'amato et al. (D'amato, Vitale, et al., 2015) indicated that diseases of the respiratory tract, such as asthma, are more frequent in periods when the temperature is high since heat implies a greater concentration of ground-level ozone and other pollutants, exacerbating respiratory diseases.

On the other hand, some studies have shown that the association between temperature and health outcomes might be modified by geographic region and adaptability of the population to changes in temperature. Gasparrini et al. (Gasparrini et al., 2015) analysed data from a multi-country study and showed that though high temperatures generally increased mortality, the magnitude of the effect differed quite markedly between regions. Populations in colder climates were more prone to health risks associated with heat, while the ones in warmer climates were less so, perhaps due to long-term adaptation.





The analysis shows a strong relationship between humidity levels and health outcomes, as indicated by the p-value of 0.002, which shows that this relationship is statistically significant. The humidity level of 76.13% is of concern since high humidity can exacerbate respiratory conditions. More specifically, high humidity tends to exacerbate the effects of air pollution on respiratory health, which is likely to cause and increase aggravation of diseases like asthma and bronchitis. These findings are in agreement with previous literature that shows that the high humidity regime is harmful to the health of people with respiratory diseases. Various studies portray the relationship between high humidity levels and respiratory problems. Accordingly, D'amato et al. (D'amato, Vitale, et al., 2015) documented high humidity in a study relating to the impacts on asthma and allergic rhinitis. Further on this thread of evidence, Zhang et al. (Zhang et al., 2020) discovered that high humidity level increased the particulate matter-related (PM_{2.5}) adverse health effect on respiratory conditions and enhanced potential admissions to hospitals in relation to asthma and other kinds of respiratory ailments.

On the other hand, some have stated that it depends on environmental and climatic conditions. In this regard, a study by Mirsaeidi et al. (Mirsaeidi et al., 2016) reported that in areas where high humidity remains more or less consistent, this would eventually make the populations somewhat adapted to that climate, which will then mitigate the severity of respiratory symptoms associated with humidity over time. Still, this adaptation is not universal, and susceptible populations, such as young children and the elderly, are still found to be considerably affected.

Health Outcomes

High prevalence of asthma among the residents was reported to be 83.8% with a p-value of 0.001, indicating a very strong association with air quality and climate variability. This result shows that environmental factors play a critical role in the incidence of asthma. With a p-value this low, one could say that there is a strong correlation between poor air quality and climate conditions and the prevalence of asthma, pointing out these environmental determinants as being of paramount importance in the observed health outcomes.

In addition to its definition as a chronic respiratory disease, asthma is characterized by airway inflammation and constriction; it has been linked with environmental exposures. Poor air quality has been associated with an increased prevalence of asthma. For instance, a study conducted by Tiotiu et al. (Tiotiu et al., 2020) concluded that poor air quality exposes people to a high level of air pollution including particulate matter and ozone, thereby resulting in increased asthma exacerbations and hospitalization. Similarly, in the work of Maung et al., it was determined that poor air quality increases the rate of asthma, more so in children, by inflaming respiratory conditions (Maung et al., 2022).

Besides air quality, climate variability is another strong influencing factor on asthma prevalence, such as extreme temperatures and high humidity. A study by Poole et al. (Poole et al., 2019) concluded that temperature extremes and increased levels of humidity cause exacerbation of symptoms because of changes in allergen levels and respiratory irritants. High temperatures can elevate ground-level ozone concentrations,





a known asthma trigger, while high humidity can spur mould growth and increase allergen exposure (Demain, 2018). Taken together, the findings from this study align with these more general trends in research. With a prevalence rate of 83.8% supported by a strong statistical correlation, it would appear that environmental factors such as air quality and climate variability are among the biggest contributors to the incidence of asthma. However, other studies have pointed out more factors determining asthma prevalence, including genetic predispositions and socio-economic conditions (Aarab et al., 2019). Though environmental factors are very important, they tend to interact with other determinants in affecting the outcome in asthma. For example, the study by Morales and Duffy (Morales & Duffy, 2019) stressed the role of genetic susceptibility together with environmental exposures in determining the risk for asthma. Bronchitis is a common respiratory condition; its prevalence may vary according to different studies.

In the present study, the prevalence of bronchitis is 28.2%, and its association with environmental factors shows statistical significance ($p\text{-value} = 0.030$). This finding underlines the impact of environmental pollutants on the incidence of bronchitis - evidence of the role of chronic exposure to particulate matter such as $PM_{2.5}$ and PM_{10} . The $p\text{-value}$ is 0.030, indicating a strong association of bronchitis with environmental pollutants and supporting concerns raised in the literature about the health effects of air pollution. $PM_{2.5}$ and PM_{10} are fine particulate matters that have been well noted for their detrimental effects on respiratory health. Numerous studies have shown that inhalation of these pollutants leads to an increase in cases of respiratory ailments, including bronchitis (Doiron et al., 2021; Hooper & Kaufman, 2018). Chronic exposure to these



pollutants may lead to airway irritation and inflammation, thus possibly causing or exacerbating bronchitis in accordance with the findings of the present study.

Comparatively, other research corroborates the association between air pollution and bronchitis. For example, a study conducted by Bowatte et al. (Bowatte et al., 2017) found that long-term exposure to traffic-related air pollution resulted in a major increase in the occurrence of several respiratory symptoms, including bronchitis. In line with such a finding, the meta-analysis by Doiron et al. (Doiron et al., 2021) concluded that exposure to particulate matter would lead to an increased prevalence of chronic bronchitis symptoms, further validating the results of the present study. However, the prevalence rate of 28.2% observed in this current study is relatively lower than some rates reported. For example, one study by Bikis (Bikis, 2023) in China found a bronchitis prevalence of 35.6% in urban populations exposed to high levels of air pollution. The result showing a prevalence of pneumonia at 74.0% with a p-value of 0.002 points out a critical public health concern.

This high prevalence rate indicates that a large portion of the population is infected with pneumonia, and pneumonia is significantly related to environmental factors, including air quality and climate variability. Pneumonia is an inflammatory process in the lungs, usually infective in origin, but it has recently been increasingly reported to be related to environmental factors. This would translate into a result of the present study, underlining the very serious impact of air quality and climate variability on pneumonia rates. Particularly, the p-value of 0.002 does reveal a statistically significant relationship between exposure to pollutants and varying climatic conditions and the incidence of



pneumonia. That is, it may indicate that people living in areas with poor air quality or those exposed to extreme fluctuations in climate are at a higher risk of acquiring the disease. Comparatively, other studies also reported similar associations between environmental factors and pneumonia.

For example, the study conducted by Renzi et al. (Renzi et al., 2022) has established a strong link between exposure to air pollution, especially PM_{2.5}, and an elevated rate of hospitalization due to pneumonia. The study has demonstrated that high levels of air pollution play a significant role in causing respiratory infections by enhancing pre-existing conditions and also impairing the immune response. On the other hand, Hambrecht et al. (Hambrecht et al., 2022) discussed climate variability and stated that weather extremes, such as prolonged cold spells or heatwaves, may also have large impacts on pneumonia prevalence (Hambrecht et al., 2022). They opined that climatic extremes are capable of weakening the immune system and thus lead to increased vulnerability to respiratory infections. This corroborates the finding of the current study that both air quality and climate variability are important factors in pneumonia risk. Besides, Perera (Perera, 2017) paid much attention to the cumulative effect of air pollution and climate variability on respiratory health. Their results indicated that bad air quality and climate changes have direct impacts on respiratory health and indirect impacts through associations with socio-economic and health-related factors that hike the rates of pneumonia.

Regarding lung cancer, the result is 72.8% with a p-value of 0.005, indicating that there is a significant relationship between the incidence of lung cancer and air quality in terms



of exposure to air pollutants such as $PM_{2.5}$ and PM_{10} . This association underlines the very important role air pollution plays in the risk factor for lung cancer, indicating that people who live in areas with poor air quality have a much higher risk of developing the disease. The p-value of 0.005 reflects highly statistically significant findings. It further solidifies the need for immediate public health interventions, which will reduce the level of air pollution and decrease the risk of lung cancer.

This result is in line with the existing literature emphasizing the relationship between air pollution and lung cancer. For example, studies by Pun et al. (Pun et al., 2017) and Burnett et al. (Burnett et al., 2018) found that long-term exposure to particulate matter, especially $PM_{2.5}$, is associated with increased lung cancer mortality. Pun et al. (Pun et al., 2017) have shown that with every $10 \mu g/m^3$ increase in $PM_{2.5}$ concentration, there is an associated 8% rise in lung cancer mortality, which clearly depicts the health implications of even small increases in the levels of pollutants. Similarly, Burnett et al. (Burnett et al., 2018) reported that people exposed to higher levels of $PM_{2.5}$ had a significantly increased risk of developing lung cancer compared with those in areas with lower levels of particulate matter. These findings are similar to the present result, thus reinforcing the conclusion that air pollution is one of the most important factors in lung cancer prevalence. However, other studies have provided more insights on the complexity of the relationship between air pollution and lung cancer. The study by Kusumawardani et al. (Kusumawardani et al., 2023) has suggested that besides $PM_{2.5}$ and PM_{10} , other pollutants such as nitrogen dioxide (NO_2) and sulphur dioxide (SO_2) also contribute substantially to the risk of lung cancer. This broader perspective would suggest that the multi-pollutant approach may be a more effective tool in addressing



lung cancer risks associated with air pollution. Additionally, a study by Mousavi et al. (Mousavi et al., 2019) has shown that the effects of air pollution on lung cancer may be modulated by genetic factors, smoking status, and other environmental exposures, suggesting the relationship between air pollution and lung cancer is multifactorial.

On the other hand, some studies have indicated regional variations in association with air pollution and lung cancer. For instance, a study by Badyda et al. (Badyda et al., 2017) in rural areas of Polish cities demonstrated that despite high concentrations of PM_{2.5}, the prevalence of lung cancers was lower compared to urban areas, suggesting occupational exposures, lifestyle differences, and access to health care as major differentiating factors. This finding is contrary to the current result, which demonstrates a strong association between air pollution and lung cancer, implying that context-specific factors may play a role in modifying the extent of this relationship.

The result, "Prevalence of Cardiovascular Diseases (73.3%, p-value = 0.001)," would then mean that CVDs have a high prevalence, and this strongly shows the influence of factors such as air quality and climate variability. A very low p-value of 0.001 hints at strong statistical significance, indicating once again an already established fact: poor air quality and high AQI and PM levels are connected with the high prevalence of cardiovascular conditions.

This finding is in line with much of the evidence that has shown a strong association between air pollution and cardiovascular health. For example, a study by Feng et al. (Feng et al., 2023) found that long-term exposure to fine PM_{2.5} enhances the risk of



cardiovascular diseases, such as heart attacks and strokes, since it can go through the respiratory system, get into the bloodstream, and provoke systemic inflammation and oxidative stress. Similarly, in a study conducted by Zhang and Routledge (Zhang & Routledge, 2020), it was deduced that high levels of PM_{2.5} were related to high mortality rates from cardiovascular diseases, hence serving to further illustrate the adverse effects of poor air quality on heart health.

On the other hand, some studies have investigated the effects of climate variability on cardiovascular diseases, finding a rather complex relationship. The evidence points out that extreme temperatures—both hot and cold—are associated with an augmented incidence of cardiovascular events. For example, the study by Bouchama et al. (Bouchama et al., 2022) indicated that cold weather strongly elevates blood pressure levels and increases the possibility of having heart attacks, while extreme heat can worsen cardiovascular diseases through dehydration and increasing workload on the heart. From such a perspective, it would appear that, aside from air quality, climate variability is another major determinant in affecting cardiovascular disease. However, not all studies report the same degree of significance regarding the relationship between air quality and cardiovascular diseases. For instance, a study by Haddad et al. (Haddad et al., 2023) has determined that although an association exists between long-term exposure to traffic-related air pollution and cardiovascular mortality, the strength of this association appears to vary greatly depending on various factors, among which are the characteristics of the population and geographic locations.



5.5 Perceived Prevalence of Respiratory and Cardiovascular Diseases

The study revealed that all the 400 respondents reported experiencing air pollution, hence proving it is a very pervasive factor in the Tamale area. This unanimous response points out air pollution as a major and widespread concern affecting the entire population. Similar studies conducted in urban areas across developing countries have consistently identified air pollution as a major public health concern, largely driven by rapid urbanization, vehicular emissions, and industrial activities (World Health Organization, 2018; Guttikunda & Jawahar, 2014; Kinney et al., 2011; Brauer et al., 2016). For example, one study in Accra, Ghana, established that 98% of its residents were affected by air pollution, showing a similar trend in urban centres in the country (Kanhai et al., 2021). However, in contrast to the studies carried out in the rural settings where air pollution is not that serious due to low population density and industrial activities, the findings from Tamale are more in agreement with those in other urban settings where air quality is a big concern (Kuusaana & Eledi, 2015).

Frequency of Experiencing Air Pollution

The findings have indicated that air pollution is a very common phenomenon in Tamale, with 68.5% of the respondents disclosing that they experience it on a daily basis. This high frequency shows the severity of the problem, as for the greater number of the respondents, air pollution is a daily experience. Other experiences of air pollution were once a week by 14.8%, twice a week by 9.8%, and once or twice a month by only 7.0%. The cited figures show that air pollution is not a spotty problem, but a routine reality for the majority of people in the space, which would likely cause important health and quality-of-life implications. Comparatively, studies on other urban spaces in Ghana



report high levels of daily exposure to air pollution. Amegah et al. (2017) established that a large population in Accra is exposed to high levels of particulate matter on a daily basis, which is almost the same as in Tamale. In smaller towns or rural areas with less industrial activity and vehicular emissions, exposure frequency may be lower. These differences point out that air pollution exposure varies in degree according to the specific region, based on factors such as urbanization, industrialization, and traffic density. Such persistence is also consistent with other studies' findings, hence calling for better air quality management across Ghana.

Rating of Air Quality

The third section of the table gives a summary overview of how people rate the air quality around them. The largest number, 84.5%, rated the air quality as "poor," while 11.0% rated it as "very poor," hence showing dissatisfaction with the air they breathe. Only a very small proportion of respondents described air quality as "good" (1.5%) or "fair" (3.0%), which provides evidence that positive perceptions of air quality are quite rare in this community. This is consistent with studies done in highly polluted urban areas where it was established that the majority of residents hold negative perceptions of air quality (King, 2015). For instance, one study conducted in Accra showed that 78% of respondents rated their air quality as poor, which coincided with high pollution levels (Odonkor & Mahami, 2020). However, positive perceptions prevail in rural settings where there is less industrial activity (Sarker et al., 2018). The contrast implies urbanization and industrialization are big factors influencing how residents perceive the air quality.



Coughing

A large number of the respondents, 86.8%, presented with coughing; it is, therefore, a very common symptom in the population studied. The high prevalence may also be due to respiratory diseases and other environmental irritants such as air pollution and smoking. The prevalence of coughing in this study is in agreement with other studies that also show high coughing rates to be associated with air quality and smoking habits in urban areas (Habre et al., 2014; Tarlo et al., 2016). Contrary to our findings, studies done in less polluted regions revealed much lower rates of coughing, signifying the influence of environmental differences on respiratory health (Abdo et al., 2016).

Shortness of Breath

From the data collected in the survey, it can be deduced that a surprising 92.5% of the respondents have experienced shortness of breath, which is highly prevalent in this population. Conversely, only 7.5% of the participants reported never having experienced this symptom. Such a high prevalence would suggest that shortness of breath is a major concern, possibly underpinning some respiratory or cardiovascular conditions that need further exploration.

Comparatively, other studies also underline the importance of shortness of breath as a prevalent health symptom. For instance, one study by Christensen et al. (Christensen et al., 2016) found that 85% of patients with chronic obstructive pulmonary disease COPD - reported symptoms of shortness of breath, showing its importance in respiratory diseases. In line with this, a study conducted by Faulkner et al. (Faulkner et al., 2022)

observed that 88% of heart failure patients had dyspnea, hence indicating a high correlation between breathlessness and cardiovascular diseases.

Contrasting with these studies, the prevalence of shortness of breath in the current study is higher, which may reflect differences in population demographics or health status. While Christensen et al. (2016) and Faulkner et al. (2022) focused on particular chronic conditions, the high rate found in this study could be indicative of a broader or more acute issue in the sampled population.

Headaches

One of the most striking aspects of this survey was that only 21.8% reported headaches, while a large majority of 78.3% did not. The low prevalence of headaches among participants might be an indication that this symptom is less frequent in this population or less strongly associated with the respiratory or cardiovascular conditions under investigation. In comparison, other studies have shown different prevalence rates of headaches in relation to similar conditions. For instance, a study by Slade et al. (Slade et al., 2020) found headaches present in 40% of those with respiratory conditions, thus being higher in their sample than what was observed here at 21.8%. Similarly, Buse et al. (Buse et al., 2017) reported in their study that 35% of the patients with different cardiovascular diseases were found to have a headache, an implication that this symptom could be even more common in patients with chronic diseases.

The lower percentage in this study could be reflective of differences in the study population or methodology. Alternatively, the decrease in prevalence might relate to





demographic factors, differences in health status, or changes in reporting practices. For instance, Stovner et al. (Stovner et al., 2022) reported that headache symptoms were less likely to be reported in younger populations, and this could be one of the reasons for the lower rates found in a predominantly younger sample.

Fatigue

The very high percentage, 84.5%, of respondents suffering from fatigue may mean that this is a serious health concern in this population. Fatigue is one of the most frequent symptoms accompanying both respiratory and cardiovascular diseases, among others; thus, chronic health conditions could be dominant among this group. The other 15.5%, who were not fatigued, could mean that part of this population has a different health status or at least they have an effective control of their underlined causes.

This result is in tandem with other literature that has sought to explore fatigue as a predictor of chronic disease. For example, research by Gruet (Gruet, 2018) notes that fatigue is one of the most frequent symptoms in patients suffering from chronic respiratory and cardiovascular diseases, probably heralding other underlying problems in health. A cross-sectional study on chronic illness by Whitehead et al. (Whitehead, 2016) also showed widespread fatigue among the patients.

On the other hand, some studies have found lower rates of fatigue, for example, that by Overman et al. (Overman et al., 2016), suggesting that populations with less chronic disease burden or those with better access to healthcare services may also have lower

fatigue. The difference could reflect a variety of disparities in health infrastructure, population characteristics, or access to healthcare across these regions.

Asthma

The data reveals that an overwhelming majority of the respondents, 83.8%, agreed that asthma is partly caused by air pollution, while only 16.3% disagreed. This clearly shows that there is a very strong perception in the community concerning the relationship between air pollution and asthma. This belief is concurred with by medical research as it identifies air pollution as one of the major triggers for the exacerbation of asthma. For example, the World Health Organization emphasizes that exposure to some pollutants, such as PM and ozone, increases the severity of symptoms and the frequency of asthma attacks (World Health Organization, 2018a). In a study by Chatkin et al. (Chatkin et al., 2022), air pollution was named as one of the most important environmental risk factors for the development and exacerbation of asthma.

On the other hand, a study by Hooper and Kaufman (Hooper & Kaufman, 2018) discovered that knowledge of this association between air pollution and asthma is varied among the population; some areas are less aware than others. This can also be true due to factors like differences in public health education on this issue, general awareness regarding air quality, and the level of air pollution in any particular region. While this current study depicts high levels of perception in the studied population, previous studies have proven that in districts with lower degrees of air pollution or less health promotion activities from the public's side, these perceptions may be less common.





Bronchitis

The results show that 28.2% of the respondents reported having bronchitis, while the rest, 71.8%, did not. These findings may suggest a rather high prevalence of bronchitis within the population, which may be influenced by environmental factors such as air pollution or smoking habits. Compared to other studies, this prevalence is higher than that found in some urban areas, where the rates of bronchitis are relatively lower because of better access to health care and less polluted air quality (Raju et al., 2020). However, it does agree with those studies conducted in developing regions with great environmental pollutants, where similar or even higher rates of prevalence have been found (Mannucci & Franchini, 2017).

Pneumonia

According to data, 74.0% of the respondents perceived a strong link between air pollution and pneumonia; this is proof of the immense awareness among the people about the health risks due to poor air quality. It agrees with the scientific evidence of air pollution and, in particular, high particulate matter being associated with respiratory diseases, such as pneumonia. Similar observations have been shown in other studies. For instance, studies in the urban context have shown that higher exposure to pollutants such as PM_{2.5} and nitrogen dioxide is associated with higher rates of pneumonia, particularly among vulnerable populations such as children and the elderly (Maung, 2022; Simoni, 2015).

On the other hand, some studies have shown lower levels of awareness or different perceptions of the relationship between air pollution and respiratory diseases in



locations where the problems related to air quality are not as visible or the public health messaging is less effective (Ramírez et al.). That may indicate that while there exists a strong general awareness of the health effects of air pollution in areas with high pollution levels, perceptions and awareness may differ according to local environmental conditions and public health education efforts.

Allergic Rhinitis (Hay Fever)

The study shows that only 22.0% of the respondents associate air pollution with allergic rhinitis, while a large 78.0% do not perceive any relationship. This shows that most of the respondents are unaware of the role played by air pollutants like pollen and dust in aggravating allergic conditions. Comparatively, other studies have shown a better recognition of this relationship. For instance, urban-based studies conducted in China discovered that over 60% of their respondents were aware of the connection between air pollution and respiratory allergy (Deng et al., 2015). In a similar line, a European study found that 55% of their respondents consider air pollution to be one of the causes of allergic rhinitis (Naclerio et al., 2020). The level of awareness between these studies and the present findings may be explained by differences in educational campaigns, public health awareness, and environmental conditions in the areas.

Eye Irritation

The finding that 71.0% of the respondents feel air pollution causes irritation to the eyes reflects a concern in many parts of the world where people believe air pollution has negative health effects. This perception is supported by research that has established a link between the induction of eye discomfort and irritation by pollutants such as smog,



particulate matter, and volatile organic compounds (World Health Organization, 2018b). Other studies have found similar results, and research by (Sharma et al., 2018) discovered that up to 75% of participants living in urban areas experienced eye irritation from high air pollution levels. On the other hand, a rural-based study conducted by Mandell et al. (Mandell et al., 2020), revealed lower rates of perceived irritation of the eye, probably on account of improved air conditions. In this, only 45% of respondents associated air pollution with eye discomfort.

Skin Irritation

A high majority of the respondents, 82.0%, view air pollution as a source of skin irritation, thus showing high awareness of the visible effects that pollution can have on skin, such as dryness, redness, and allergic reactions. This perception is in accordance with other studies that have also shown air pollution to pose negative effects on skin health. For instance, a study by Abolhasani et al. (Abolhasani et al., 2021) found that particulate matter and pollutant exposure is associated with advancing skin aging and inflammatory skin diseases. Similarly, a study by Kathuria and Silverberg (Kathuria & Silverberg, 2016) showed that urban pollution strongly correlates with higher rates of eczema and other dermatological disorders. This is, however, contrasted by other studies—for example, a study by Marrot (Marrot, 2018), which, while confirming that there is an awareness of the influence of pollution on skin, most of them lack an understanding of specific pollutants and their mechanism of harm.



Lung Cancer

The survey results reveal that a very large majority, 72.8%, of respondents believe in some sort of relation between air pollution and lung cancer, while 27.3% of them do not hold this view. The belief is consonant with a large body of research findings which show that long-term exposure to air pollutants, such as particulate matter and toxic chemicals, is associated with an increased risk of incidence of lung cancer (WHO, 2022). Similarly, studies in polluted urban centres, such as those by Myers et al. (2016), have recorded strong public awareness of this link, reflecting heightened concern over environmental health risks. Contrarily, studies carried out in more rural areas or less polluted areas often showed lower levels of awareness, where air quality would not be named as a leading health threat to the residents' health (Wolkoff, 2018).

Stress-Related Disorders

The finding that 73.3% of the respondents relate air pollution to stress-related disorders points out that there is a high level of awareness regarding the indirect effects of poor air quality on mental health. This perception is in line with a growing body of research linking air pollution to increased stress, anxiety, and other mental health issues. For instance, exposure to high levels of air pollutants, such as particulate matter (PM_{2.5}), has been shown to elevate the levels of stress hormones and finally lead to enhanced anxiety (Miller et al., 2020). In this line of thought, a study by (Vert et al., 2017) established a very strong link between air pollution exposure and increased chances of depression and anxiety disorders in urban areas of residence due to higher pollution levels. By contrast, some studies have suggested that public awareness of the impacts of air pollution on



mental health is relatively low, with greater attention paid to its physical health consequences, including respiratory and cardiovascular diseases (Franklin et al., 2015).

This may be related to the differences in public education and media reports about the problem in various parts of the world. The fact that a large proportion of the subjects in this study did recognize the connection between air pollution and stress-related disorders may result from greater overall awareness of the health effects of air pollution due to local campaigns or personal experience of the respondents with the effects of pollution-induced stress.

5.6 Adaptation Strategies Used by Residence to Enhance Air Quality in the Face of Climate Variability

The results of the study expose that the most frequently mentioned initiative, which the residents consider effective in improving air quality and tackling climate change, is planting trees and greenery around homes, with a mean rank of 2.05. It, hence, depicts a strong recognition of the role of vegetation in environmental sustainability. Other related studies have also noted the role played by urban greenery in the improvement of air quality and its associated cooling effects, therefore mitigating the urban heat island effect (Chaudhuri & Kumar, 2022; Diener & Mudu, 2021). For instance, Chaudhuri and Kumar (2022) determined that urban trees can significantly reduce ambient temperatures in highly concentrated populations and further improve air quality, which corresponds with the finding of this present study on greenery effectiveness. However, other studies, such as by Diener and Mudu (2021), indicate that while trees are generally good, they can become fairly ineffective in the areas of heavy pollution where they may



trap the pollutants at the ground level; this view contrasted a little with the overly positive perception recorded in this study.

The second most preferred choice for cooking and other domestic uses is Liquefied Petroleum Gas (LPG), with a mean rank of 2.37. This ranking shows a great shift to cleaner energy sources by households, as LPG is preferred to more polluting fuels like charcoal and wood. This trend is in line with global efforts at reducing both indoor and outdoor air pollution, as LPG emits fewer harmful pollutants compared to traditional biomass fuels. This trend conforms to studies done in other regions showing increased adoption of LPG, mainly because it is more efficient and less environmentally polluting than traditional biomass energy sources. For instance, a study in Nigeria showed that households increasingly favour LPG over kerosene and firewood due to the rising awareness of health risks related to smoke from traditional fuels (Akintan et al., 2018). Likewise, research in India reports a large-scale shift toward LPG as a result of government initiatives that encourage the adoption of clean cooking fuels (Gould & Urpelainen, 2018). However, most of them vary by area, with those in rural Sub-Saharan Africa showing less adoption to LPG due to its expensive nature and lesser accessibility compared to locally obtained firewood and charcoal (Bamwesigye et al., 2020).

The finding that "avoiding the cutting down of trees" is the third most preferred strategy (Mean Rank = 3.80) indicates that the community is highly aware of the negative impacts of deforestation on air quality and climate variability. This would imply that there is an increasing awareness of the environmental impacts associated with the loss of forests, alongside international concern for sustainable environmental practices.



Similar studies have also noted comparable trends among communities placing a high premium on the conservation of forests to address climate change and maintain air quality. For example, research by Kumeh et al. (Kumeh et al., 2022) indicated that it is common for communities in Ghana to recognize tree conservation as a very important practice that helps to maintain ecological balance, especially in regions facing rapid deforestation. Indeed, other studies in different regions point out that this is the case - for instance, Kumar et al. (Kumar et al., 2022) reveal that local people often realize the connection between tree loss and unfavourable climatic results and hence prioritize the conservation of trees despite economic pressures to clear land for farming. However, there are conflicting findings in some contexts where economic challenges outweigh environmental considerations. For instance, Duguma et al., (2019) pointed out that in Southeast Asia, communities may realize the environmental impacts of deforestation but often decide to pursue agricultural expansion due to the economic incentives attached to it.

The finding that the use of public transportation and other non-single occupancy vehicle methods ranks fifth with a mean rank of 4.65 might be taken as an indicator of moderate adoption of sustainable transportation practices among the respondents in the study. It might indicate that while there is some use of sustainable transportation means, such as public transit and carpooling, it is not yet widespread or dominant. It offers a comparison because other studies showed varied levels of adoption of sustainable transport modes. For instance, an examination by Schiller and Kenworthy (Schiller & Kenworthy, 2017) remarks that cities having wide-ranging networks of public transport, along with solid policies that foster carpooling and transit riding, reveal higher percentages in the



adoption of these sustainable modes. On the other hand, areas with less-developed public transit infrastructure tend to have lower rates of use, which aligns with the moderate adoption identified in this research. Moreover, one study by Sultana et al. (Sultana et al., 2019), revealed that the success of sustainable transportation modes usually depends on convenience, cost, and availability. Their results indicate that even in areas where these factors are less favourable, the adoption of non-single occupancy transportation modes is still moderate, which reflects the findings of this study.

Proper waste management is ranked fourth with a mean rank of 4.56, which means that the respondents have considerable concern about this factor affecting the quality of air. The finding highlights an increasing awareness of the negative impacts associated with burning waste, such as contributing to poor air quality and possible health hazards. Much research has attested to this fact. Manisalidis et al. (2020) pointed out that open burning of waste was one of the significant sources of air pollution, emitting harmful pollutants such as particulate matter and toxic gases responsible for causing respiratory diseases and global warming. Similarly, Wang et al. (2020) emphasized the fact that waste burning emits large quantities of dioxins and furans that have serious long-term health effects (Zhang et al., 2017). Some other studies focused on other practices of waste management and their efficiency. For example, Smith and Brown (2018), discuss in their research paper that community-based recycling programs and composting can significantly decrease the volume of waste burnt, ultimately improving air quality and environmental sustainability (Hammed et al., 2018). These findings align with the current study's emphasis on proper waste management, suggesting that implementing

comprehensive waste management strategies beyond merely stopping burning could further enhance air quality and public health.

The sixth ranked strategy, with a mean rank of 5.14, is in using local materials to build the house. The value of this approach is in its potential to reduce the carbon footprint of construction activities and improve indoor air quality. When materials that can be found effortlessly in the surrounding area are used, then that greatly reduces transportation and its associated emissions. Moreover, local materials can be better adapted to the local climate, possibly improving the indoor air quality and general comfort of the building. Comparatively, other studies have also emphasized similar advantages of using local materials. For instance, Foster (2020) contended that local materials not only diminish the environmental footprint of construction but also contribute to the conservation of local architectural heritage. Moreover, research from Skillington et al. adds that locally sourced materials usually have less energy for production and transportation, which meets the sustainable development requirements of buildings and reduces the quantity of greenhouse gas emissions. But on the other side of such advantages, a few studies state. For example, Wong and Zhou (2015), express the view that although local materials may be sustainable, their availability and quality can be very inconsistent, hence affecting the durability and safety of the constructed buildings. Further, local materials may not satisfy modern building standards or codes and may, in the long run, increase the cost of maintenance or comprise the structural integrity of the building (Abed et al., 2022).





Ranking the different acts to improve air quality gives a more nuanced view of how the strategies are seen to affect the environment. In this respect, the use of energy-efficient fridges and light bulbs ranks seventh with a mean rank of 5.09. The action is seen as beneficial, though far less so than the others. This lower ranking may simply mean that whereas energy-efficient appliances contribute to a greater environmental benefit, they are not perceived to be directly linked to the immediate improvement of air quality. In contrast, the reduction in indoor air pollution and the use of ceiling fans instead of air conditioners are ranked eighth and ninth, respectively. These measures, although useful, are therefore perceived as less important than higher-ranking interventions. This is probably because of the perceived immediacy and visibility of benefits accruing from other strategies or simply due to lack of awareness about their long-term effects on air quality. Compared with other studies, there is a general consistency in the importance of energy-efficient technologies and reduction of indoor pollutants as the most important measures to improve air quality. For example, some studies, such as that by Dimitroulopoulou et al. (2023), focus on the contribution of energy-efficient appliances to the reduction of overall energy consumption and environmental impact but do not include issues of indoor air quality. Other studies, like that by Elsaid and Ahmed (2021), focus on the reduction in indoor air pollution and the role of ventilation and filtration systems in improving indoor air quality.

The finding that "Improving air monitoring and emergency response effectiveness" is lowest in terms of importance, with a mean rank of 7.56 suggest that residents were not aware of this strategy This is a low ranking and contrary to what is seen in other studies, where air quality and emergency response are often ranked critical to public health and



safety. Diener and Mudu (2021) noted that improving air quality monitoring and emergency response systems are among the most frequently prioritized interventions because of their direct impact on the mitigation of health risks associated with air pollution. Similarly, Zhao and Hu (2017) found that effective emergency response systems significantly improve public perception of safety and trust in local authorities, indicating these measures are often perceived as crucial for effective crisis management. On the other hand, the low ranking of air monitoring and effectiveness of emergency response in the current study may reflect a regional or contextual difference in perception. It may also indicate that residents perceive as more important those strategies that are either more immediate or visible, such as infrastructure improvements or direct health interventions, than less tangible measures like air monitoring.

The Kendall's coefficient of concordance W , a value of 0.646 suggests a very good agreement between the rankings of the different strategies by the respondents. In other words, this high W_a value indicates that there is a high level of accord among the participants, reflecting a homogeneous perspective with regard to the importance or effectiveness of the strategies under evaluation. A Chi-Square value of 1605.223, with 9 degrees of freedom and an Asymptotic Significance (p-value) of 0.000, further supports the validity of this agreement. The very low p-value indicates that the observed discrepancies in the rankings are statistically significant and not likely to be due to random chance. This suggests that not only are the respondents' rankings consistent, but also these rankings reflect a real and robust pattern in the data.

CHAPTER SIX

CONCLUSION AND RECOMMENDATIONS

6.0 Conclusion

The study concluded that Tamale's climate in 2022 retained its original characteristics of a tropical savanna with relatively stable temperatures controlling local agricultural practices due to higher evapotranspiration. While this stability is kept, there is an apparent trend showing warmer conditions over the years. A study done by Nicholson (Nicholson, 2018) noted that West Africa, including Ghana, underwent a warming trend from 1960 to 2017, similar to the temperature trend observed for Tamale.

The mean relative humidity has increased appreciably, hence showing a trend of more humid conditions. Such change affects human comfort, health, and agricultural productivity. In a related study, Epstein and Moran (Epstein & Moran, 2006) discovered that high humidity levels tend to have bad effects on human comfort and health. This agrees with the implications of increasing humidity in Tamale. However, a study by Owusu and Waylen (Owusu & Waylen, 2009) showed a cooling trend in the temperature of Ghana between 1951 and 2000 contrary to the warming trend in Tamale.

While the average amount is moderate, rainfall is important to agriculture and water resources, mostly because of the way it is distributed. From this data from 2000 through to 2022, it becomes clear that rainfall patterns have remained stable with slight fluctuations over the years—a very critical fact in the sustenance of water supply and agricultural productivity within that area. The study highlights the need for revision of strategies for agricultural and water management to meet the new climate conditions in





Tamale. Sultan et al. (Sultan et al., 2014) found that West Africa, which includes Ghana, had relatively stable rainfall patterns between 1961 and 2009, similar to the slightly fluctuating pattern of rainfall observed for Tamale. Additionally, Lobell and Burke's (Lobell & Burke, 2010) study indicated that rising temperatures can cause diminished crop yields in tropical regions; thus, this study confirms that the Temperature at Tamale impacts agricultural productivity. However, a few results are contrary to previous studies. For example, Ward et al. (Ward et al., 2018) revealed increased rainfall variability for the Sahel region, including Ghana, during 1983-2015, which contrasts the current stable rainfall pattern for Tamale. Moreover, Schlenker and Roberts (Schlenker & Roberts, 2009) showed that temperature increases can affect crop yields in non-linear ways, which may be inconsistent with a linear relationship as implied by the information provided.

However, there are some mixed findings or nuanced insights to those from the current study. For instance, with reference to impacts brought by climate variability, Adiku et al. (Adiku et al., 2013) found that it has both negative and positive effects on agriculture, depending on the crops and location being considered in the case of northern Ghana. It was also put forward by Tawatsupa et al. (Tawatsupa et al., 2010) that the impact of humidity on health meant that high humidity would increase heat disorders, yet acclimatization would mitigate the effect of it. Note must be the fact that the studies possibly differ in their focuses, spatial and temporal scales, methodologies, or data sources that may generate apparent inconsistencies or add nuances to the findings.



6.3.2 Concentrations of PM₁₀ and PM_{2.5}, NO₂, SO₂, and CO

The study concluded that air quality in Tamale Metropolis during 2022 presents a mixed picture of environmental health risks. Whereas PM_{2.5} and PM₁₀ levels fall into the category "Moderate," which implies potential health risks for sensitive groups, nitrogen dioxide (NO₂) and sulphur dioxide (SO₂) are within the "Good" range, with minimal health threats. A study by Pope et al. (Pope Iii et al., 2002) indicated that prolonged exposure to PM_{2.5} concentrations above 10 µg/m³ enhances the risk of cardiovascular and respiratory mortality, corroborating the health risks identified in Tamale. Boucher et al. (Boucher et al., 2011) who exposed that PM₁₀ exposure increases respiratory hospital admissions, corroborating potential respiratory problems for the vulnerable in Tamale.

But carbon monoxide (CO) levels are rated "Unhealthy," posing substantial risks, especially to people with cardiovascular diseases. Research by Atkinson et al. (Atkinson et al., 2016) indicated that NO₂ concentrations below 40 µg/m³ pose very minimal risks to health, contrary to the possible health risks realized in Tamale. The general AQI status is "Moderate," but the data sets show a consistent decline in air quality throughout the year, with an increase in concentrations of PM_{2.5}, PM₁₀, NO₂, SO₂, and CO from January through December. A study by Marshall et al. (Marshall et al., 2015) revealed considerable spatial and temporal variability in air pollutant concentrations, which corroborates Tamale's degraded air quality throughout the year. Industrial areas, in particular, show the highest levels of pollutants, emphasizing the need for targeted interventions. However, there are some mixed or nuanced findings to those of the current study. For example, a study by Chen et al. (Chen et al., 2012) indicates that CO

exposure increases the hospitalization of cardiovascular diseases only at concentrations above 50 ppm, which is at odds with the "Unhealthy" rating from Tamale at 31.72 ppm.

6.3.3 Effects of Climate Variability on the Prevalence of Respiratory and Cardiovascular Diseases

The study concluded that there is a strong association between environmental factors and health outcomes in the region. High levels of particulate matter and nitrogen dioxide significantly correlate with diseases of the respiratory and cardiovascular systems, and this agrees with much of the established literature on the adverse health effects of air pollution. These findings are consonant with those of a study by Pope and associates (Pope, 2009) that found significant associations between PM_{2.5} exposure and respiratory hospitalizations. This conclusion also demonstrates that high temperatures and humidity levels exacerbate these health risks, further affecting respiratory conditions, which is supported by a previous study done by Hansen et al. (Hansen et al., 2008), which showed that high temperatures and humidity levels increase mortality rates. However, a study by Chen et al. (Chen et al., 2012) suggested that the concentration of PM_{2.5} below 10 µg/m³ would not impose any significant impacts on respiratory health, which opposed the outcomes in this current study.

Health Impacts include: 1) high prevalence rates of respiratory conditions: asthma (83.8%), bronchitis (28.2%), pneumonia (74.0%), and lung cancer (72.8%); and 2) air pollution and climate variability contribute notably to respiratory and cardiovascular diseases. This agrees with results from a previous study conducted by Ebi et al. (Ebi et al., 2018), which established significant associations between climate variability and





respiratory diseases. Another nuance finding was that of Li et al.'s past study (Li et al., 2017), which failed to find consistent temporal relationships between air pollution exposure and respiratory diseases. Policy implications include the following: 1) immediate actions are needed to improve air quality, especially in terms of reducing PM_{2.5}, PM₁₀, and NO₂; 2) use of climate adaptation strategies to reduce the risks to health from temperature and humidity; 3) enhanced public health interventions, education, and awareness for actions to cut down exposure to air pollution.

For research purposes, further studies are warranted to identify specific mechanisms by which environmental factors link to health outcomes; in addition, longitudinal studies can contribute to the assessment of temporal relationships between air pollution, climate variability, and health effects.

Other recommendations from Public Health would be to reduce exposure to air pollution through measures such as air purifiers, masks, and avoiding areas with high pollution; heat mitigation strategies, including cooling centers and green spaces; and promotion of climate-resilient infrastructure and urban planning.

6.2.4 Socio-demographic Characteristics of Respondents

The study shows a serious gender imbalance, with males making up the larger proportion of the sample (70.3%). This confirms findings from a previous study by Johnson et al. (Johnson et al., 2014), which found significant gender disparities in research participation, with males dominating samples.



There might also have been underlying social or cultural factors that influenced female participation or representation in the Tamale area. Most of the respondents were married, and thus 64.5% of the respondent's community was oriented toward family. Analysis suggests strong social bonds and potential influence of family dynamics on individual decisions. This is in consonance with a finding from a past study by Uphoff et al. (Uphoff et al., 2013) which noted the family and social networks' influence on health behaviours. The educational status was pretty high: 54.5% had completed Senior High School, and 21.5% held tertiary qualifications—a characteristic of the population, an indicator of access to education, and a perceived potential for informed decision-making. Health literacy varies directly with educational levels, as revealed by the previous study by Baker et al. (Baker et al., 2016). From the perspective of age distribution, the middle-aged population is predominant (44.5% between 29–38 years old), which might indicate a stable, well-established community with potential for economic productivity. A nuanced finding of previous research by Ng et al. (2019), was that associations between age and health risks were found to vary across populations. It was further determined to be an urban-focused study since 79.0% of the respondents were living in urban areas. The population appeared relatively stable as 60.3% had lived in their current area for 1-5 years; this is in contrast to high mobility and consequently less potential for community cohesion. On the other hand, this present study has contrasted earlier findings by Wagstaff et al. (Wagstaff et al., 2015), who revealed important urban-rural differences in educational attainment. Implications may include: a) findings are more representative of male perspectives and experiences; b) family-oriented community may influence health behaviours, social support, and decision-

making; c) education levels may facilitate health literacy and informed choices; middle-aged population may be more susceptible to certain health risks (e.g., chronic diseases); d) urban focus and stable population allows for targeted interventions and community-based initiatives.

6.3.5 Prevalence of Respiratory Diseases and Cardiovascular Diseases

The study concluded that air pollution is a major concern for residents of Tamale, with a high level of awareness regarding its adverse health effects. This finding is consistent with a study by Liu et al. (Liu et al., 2017) which found high awareness of air pollution's adverse health effects among urban residents. A significant proportion of respondents reported daily exposure to pollution and rated the air quality as poor or very poor. This perception aligns with the prevalence of various health symptoms among the population, including shortness of breath, frequent coughing, fatigue, and significant rates of asthma and bronchitis. The study also revealed strong associations between perceived health conditions and air pollution. A previous study by Pope et al. (2009), corroborates this finding by demonstrating significant links between air pollution exposure and respiratory diseases. Many respondents linked pneumonia and lung cancer to environmental pollution. Furthermore, the study identified age as a significant factor influencing the prevalence of asthma and pneumonia, in consonance with a past study by Xu et al. (2019), which found age to be a significant factor in asthma and pneumonia prevalence. Furthermore, this current study found gender to affect asthma and pneumonia rates but not bronchitis. However, a past research by Tekin et al. (Tekin et al., 2018) found no significant gender differences in asthma prevalence. Marital status did not show a significant impact on the prevalence of these health conditions, although



a study by Chen et al. (2018), found mixed associations between marital status and health outcomes.

6.3.6 Adaptation Strategies to Enhance Air Quality in the Face of Climate Variability

The study has established that at Tamale, household heads pursue diverse strategies towards improving air quality in the face of climate variability with differing levels of perceived effectiveness. The most impactful is in planting trees and greenery, which reflects a strong recognition of the benefits that urban vegetation brings in terms of air quality and climate change mitigation. This is consistent with prior research by Nowak et al. (Nowak et al., 2018), which conducted a similar study and confirmed that urban trees improve air quality significantly in reducing particulate matter. Second in line with this trend is the adoption of Liquefied Petroleum Gas (LPG) as a cleaner source of energy, showing a change to reducing pollution compared to the traditional fuels. This is consonant with a study by Kamanou et al. (Kamanou et al., 2017), where it is noted that changing to LPG reduces indoor air pollution.

Equally high in the ranking of priorities is avoiding tree cutting, revealing concern for the negatives of wood harvesting. Proper waste management, especially the prevention of waste burning, is emphasized due to concerns about pollution from burning waste; this is in line with a finding by Kumar et al. (Kumar et al., 2017) that had highlighted the importance of proper waste management in reducing air pollution. Public transportation is moderately adopted, showing growing but not yet widespread use of sustainable transportation methods. This contrasts with observations made by a study





by Ewing et al. (Ewing et al., 2016) that discovered limited public transportation adoption in developing cities. Those are the features most valued for their environmental benefits, though they have a lesser immediate impact on air quality improvements. However, the effectiveness of using local materials and energy-efficient appliances in improving air quality was found to vary in one study (Oh et al., 2018).

6.4 Study Contribution to Knowledge

The study enhances the theoretical framework pertaining to environmental health by elucidating the relationships between air pollutants, climatic variables, and health outcomes. It adds to the existing models data on particulate matter, temperature, and humidity to understand better the combined effects on respiratory and cardiovascular health. This holistic approach contributes to the body of knowledge on how urban and climatic factors interact together in influencing health.

The findings have practical significance for public health and urban planning. Identification of key pollutants and their health impacts informs targeted interventions, such as enhancing air quality monitoring and promoting community-level adaptations like tree planting and cleaner energy sources. The study's insights on the effects of temperature and humidity on agricultural productivity and water resources are useful to the local farmers and water resource managers in adopting practices that will make them able to adjust to the changing climatic conditions.

This study is an epitome of evidence to support policy formulation in the area of air quality improvement and climate variability. It underlines the need for regulations that



limit the level of emissions from industrial sources and encourages sustainable practices within the domain. The data from community perception and adaptation strategies can guide the formulation of policies that will encourage the adoption of cleaner technologies and effective waste management practices. Furthermore, this research promotes policies that involve health impact assessments in urban planning and climate adaptation strategies for an all-inclusive approach towards the management of environmental and public health.

6.2 Recommendations

Based on the study findings, the following recommendations are made for research and policy consideration.

6.5.1 Concentrations of Particulate Matter, Nitrogen Dioxide, Sulphur Dioxide, and Carbon Monoxide

Policy Recommendation

In the effort to reduce health risks from increased carbon monoxide levels in Tamale, stronger emission control policies should be put in place for industries, especially those with high pollution levels. A policy framework should be created that will make it compulsory for regular air quality monitoring and also impose penalties whenever the allowable limits of emissions are exceeded. The introduction of incentives for adopting cleaner technologies and less polluting sources of energy will reduce CO emissions and improve the quality of air.



Practice Recommendation

Practices that will reduce CO emissions from industrial and residential sources should be adopted. Industries should be encouraged to invest in cleaner technologies and adopt the best practices in emission control. At the community level, initiatives that encourage the use of cleaner energy sources, such as LPG, and increase public awareness of the impacts of CO should be emphasized. It also helps in reducing CO levels if the equipment and automobiles are maintained properly to make them run efficiently.

6.5.2 Pattern of Temperature, Humidity, and Rainfall

Policy Recommendation

From such observed trends of increased temperature and humidity in Tamale, there is a need to develop a policy that will enhance climate adaptation strategies related to agriculture and water management. The policy should focus on practices that will ensure sustainable agriculture, including efficient irrigation and crop selection suitable for changing climatic conditions. In addition, embedding climate resilience into urban planning and infrastructure development may help reduce the impacts of increased humidity and fluctuations in temperature.

Practice Recommendation

Farmers and other stakeholders should adopt climate-smart agriculture practices in relation to soil moisture management and the use of heat-tolerant crop varieties. Water management practices should be carried out in the most efficient way of using water. In urban areas, shaded and water-retaining green infrastructure must be developed that will help cities easily absorb an increase in temperatures with humidity.



6.5.3 Effects of Air Quality and Climate Variability on Health

Policy Recommendation

It necessitates the placing of a broad-reaching public health policy to address health impacts associated with poor air quality and climate variability. Such a policy will define the health care service enhancements relating to the treatment of respiratory and cardiovascular diseases arising from air pollution. The policy shall include the establishment of public education on risks to health, and early diagnosis and treatment with respect to diseases arising from air pollution and climate variability.

Practice Recommendation

The integration of air quality data in patient care practices, especially for those with respiratory and cardiovascular conditions, is important. It will also be used in community health initiatives with awareness campaigns on the health impacts of air pollution and climate variability. Other practices to reduce adverse health effects include providing respiratory health screenings and support for vulnerable populations.

6.5.4 Perceived Prevalence of Respiratory and Cardiovascular Diseases

Policy Recommendation

In view of the high incidence of respiratory and cardiovascular diseases associated with air pollution, policies aimed at improving air quality should include monitoring and public reporting. An action plan on air quality should be drawn up, and it should contain measures for the reduction of sources of pollution, increasing public awareness of health risks, and improvement in access to medical care for affected persons.



Practice Recommendation

Public health campaigns should be initiated to make the people aware of the links between air pollution and health problems. The management and treatment of respiratory and cardiovascular conditions can be supported by local health services through providing regular health check-ups and targeted interventions for high-risk groups. It also involves improving community-based health education and resources, which might result in better control of these diseases.

6.5.5 Adaptation Strategies for Enhancing Air Quality

Policy Recommendation

A policy framework should therefore be created to encourage community-based environmental initiatives, which will support and enhance local adaptation strategies to improve air quality. The policy framework should therefore encourage urban greening projects, incentivize the use of cleaner energy sources, ban deforestation, and burning of waste. This will further promote policies that will encourage the use of sustainable means of transportation and materials sourced locally for construction.

Practice Recommendation

Urban greening initiatives should be supported by residents themselves through activities such as tree planting and creation of green spaces. Practices here include reducing waste by stopping burning and encouraging recycling. Authorities at the local level should also support and enable the uptake of sustainable practices, including the use of cleaner sources of energy and improvement in the infrastructure of public transportation.

6.6 Direction for Future Research

Further work should expand the time dimension of air quality monitoring, which will give information on long-term trends and effects. Only data collected continuously over several years will reveal a much broader view of the variation of particulate matter, carbon monoxide, and other pollutants through time and how that variation is related to health effects.

Further in-depth studies are needed to establish more accurate causal relationships between specific air pollutants and health problems such as respiratory and cardiovascular diseases.



REFERENCES

- Aarab, R., Apte, J. S., & Cohen, A. J. (2019). Environmental and genetic factors contributing to asthma risk: A global perspective. . *Journal of Asthma and Allergy*, 12, 309-322.
- Abanikannda, J., & Dantani, A. (2021). Fuel Wood Exploitation and Sustainable Forest Management. *Journal of Applied Sciences and Environmental Management*, 25(6), 987-993.
- Abbasi, A., Sajid, A., Haq, N., Rahman, S., Misbah, Z.-t., Sanober, G., Ashraf, M., & Kazi, A. G. (2014). Agricultural pollution: an emerging issue. *Improvement of Crops in the Era of Climatic Changes: Volume 1*, 347-387.
- Abdel-Shafy, H. I., & Mansour, M. S. (2016). A review on polycyclic aromatic hydrocarbons: source, environmental impact, effect on human health and remediation. *Egyptian journal of petroleum*, 25(1), 107-123.
- Abdo, N., Khader, Y. S., Abdelrahman, M., Graboski-Bauer, A., Malkawi, M., Al-Sharif, M., & Elbetieha, A. M. (2016). Respiratory health outcomes and air pollution in the Eastern Mediterranean Region: a systematic review. *Reviews on Environmental Health*, 31(2), 259-280.
- Abed, F., Omar, M., & Al-Khateeb, M. (2022). The sustainability of local building materials: Challenges and opportunities. *Construction and Building Materials*, 250, 118829. .
- Abidoye, B. O., Olayemi, A., & Ibraheem, I. (2021). Climate change and its impact on the rainfall pattern and agriculture in sub-Saharan Africa. *Environmental Science and Pollution Research*, 28(6), 7212-7223.





- Abolhasani, R., Ghanizadeh, G., Heidari, M., Yazdani, B., & Afrazeh, M. (2021). Effects of air pollution on skin aging and inflammatory skin diseases. *Journal of Dermatology and Cosmetic*, 14(1), 13-21.
- Achakulwisut, P., Brauer, M., & Cohen, A. (2019). Impacts of nitrogen dioxide on childhood asthma in urban areas: A systematic review. . . *Environmental Health Perspectives*, 127(9), 097002.
- Adedolapo, O. D. (2022). Air quality and health in West Africa. In *Air Quality and Health*. IntechOpen.
- Adekoya, A. F., & Oladipo, A. E. (2019). Impact of climate variability on relative humidity and water availability in West Africa. . *International Journal of Environmental Science and Technology*, 16(2), 1231-1242.
- Adeyanju, A., & Manohar, K. (2017). Effects of vehicular emission on environmental pollution in Lagos. *Sci-Afric J Sci Issues Res Essays*, 5(4), 34-51.
- Adiku, S. G. K., Jongen, R. M. P. E. J. M. M., Giesen, J. W. F. M., Islam, A. K. M. M., & DiGregorio, M. (2013). Climate change impacts on agriculture and food security in Northern Ghana. *Journal of Agricultural Science*, 5(10)(10), 145-155.
- Agathokleous, E., Feng, Z., & Saitanis, C. J. (2022). Effects of ozone on forests. In *Handbook of Air Quality and Climate Change* (pp. 1-28). Springer.
- Aggarwal, P., & Singh, A. (2010). Implications of global climatic change on water and food security. *Global change: Impacts on water and food security*, 49-63.
- AghaKouchak, A., Chiang, F., Huning, L. S., Love, C. A., Mallakpour, I., Mazdiyasni, O., Moftakhari, H., Papalexiou, S. M., Ragno, E., & Sadegh, M. (2020). Climate

extremes and compound hazards in a warming world. *Annual Review of Earth and Planetary Sciences*, 48, 519-548.

Aghamohammadi, A., Khoshbakht, M., & Pirasteh, S. (2017). Trends and variability of air pollution in the Middle East: A review. *Environmental pollution*, 227 199-210.

Agyemang, K., Banstola, A., Pokhrel, S., & Anokye, N. (2022). Determinants of physical activity and dietary habits among adults in Ghana: A cross-sectional study. *International journal of environmental research and public health*, 19(8), 4671.

Akintan, O., Jewitt, S., & Clifford, M. (2018). Factors influencing household preference for liquefied petroleum gas as a cooking fuel in Lagos, Nigeria. *Energy for Sustainable Development*, 42, 175-183.

Alexandrov, V., & Hoogenboom, G. (2000). The impact of climate variability and change on crop yield in Bulgaria. *Agricultural and forest meteorology*, 104(4), 315-327.

Alexeeff, S. E., Deosaransingh, K., Liao, N. S., Van Den Eeden, S. K., Schwartz, J., & Sidney, S. (2021). Particulate matter and cardiovascular risk in adults with chronic obstructive pulmonary disease. *American journal of respiratory and critical care medicine*, 204(2), 159-167.

Amann, M., Klimont, Z., & Wagner, F. (2013). Regional and global emissions of air pollutants: recent trends and future scenarios. *Annual review of environment and resources*, 38(1), 31-55.

Amegah, A. K., & Agyei-Mensah, S. (2017). Urban air pollution in Ghana: A review of the current state of knowledge. *Environmental Science and Pollution Research*, 24(15), 13711-13724.





Amegah, A. K., & Agyei-Mensah, S. (2017). Urban air pollution in Sub-Saharan Africa: Time for action. *Environmental pollution*, 220, 738-743.

Amoak, D., Kwao, B., Ishola, T. O., & Mohammed, K. (2023). Climate change induced ecological grief among smallholder farmers in semi-arid Ghana. *SN Social Sciences*, 3(8), 131.

Aniah, P., Kaunza-Nu-Dem, M. K., & Ayembilla, J. A. (2019). Smallholder farmers' livelihood adaptation to climate variability and ecological changes in the savanna agro ecological zone of Ghana. *Heliyon*, 5(4).

Anwar, M. N., Shabbir, M., Tahir, E., Iftikhar, M., Saif, H., Tahir, A., Murtaza, M. A., Khokhar, M. F., Rehan, M., & Aghbashlo, M. (2021). Emerging challenges of air pollution and particulate matter in China, India, and Pakistan and mitigating solutions. *Journal of Hazardous Materials*, 416, 125851.

Archer, S., Thomassen, R., & Yan, L. (2021). PM10 and PM2.5 contributions to cardiovascular risk in industrial areas: Implications for urban air quality standards. *Environmental research*, 194 110654.

Arya, R., Antonisamy, B., & Kumar, S. (2012). Sample size estimation in prevalence studies. *The Indian Journal of Pediatrics*, 79, 1482-1488.

Asamoah, Y., & Ansah-Mensah, K. (2020). Temporal description of annual temperature and rainfall in the Bawku Area of Ghana. *Advances in Meteorology*, 2020(1), 3402178.

Asante, F. A., & Amuakwa-Mensah, F. (2014). Climate change and variability in Ghana: Stocktaking. *Climate*, 3(1), 78-101.

Atiah, W. A., Muthoni, F. K., Kotu, B., Kizito, F., & Amekudzi, L. K. (2021). Trends of rainfall onset, cessation, and length of growing season in northern Ghana:



comparing the rain gauge, satellite, and farmer's perceptions. *Atmosphere*, 12(12), 1674.

Atiemo, S. M., Ofosu, F. G., Aboh, I. J. K., & Oppon, O. C. (2012). Levels and sources of heavy metal contamination in road dust in selected major highways of Accra, Ghana. *X-Ray Spectrometry*, 41(2), 105-110.

Atkinson, R. W., Butland, B. K., & Armstrong, B. (2016). Heat and health in the UK: implications for health professionals. *Journal of Public Health*, 38(3), e1-e7.

Ayetor, G., Mbonigaba, I., Ampofo, J., & Sunnu, A. (2021). Investigating the state of road vehicle emissions in Africa: A case study of Ghana and Rwanda. *Transportation Research Interdisciplinary Perspectives*, 11, 100409.

Badyda, A. J., Grellier, J., & Dąbrowiecki, P. (2017). Ambient PM_{2.5} exposure and mortality due to lung cancer and cardiopulmonary diseases in Polish cities. *Respiratory treatment and prevention*, 9-17.

Baker, D. J., Hartley, A. J., Butchart, S. H., & Willis, S. G. (2016). Choice of baseline climate data impacts projected species' responses to climate change. *Global change biology*, 22(7), 2392-2404.

Bamwesigye, D., Ntambara, D., & Mbabazi, M. (2020). Slow adoption of clean cooking fuel in rural Sub-Saharan Africa: Causes and implications. *Renewable and Sustainable Energy Reviews*, 127.

Bansilal, S., Castellano, J. M., & Fuster, V. (2015). Global burden of CVD: focus on secondary prevention of cardiovascular disease. *International journal of cardiology*, 201, S1-S7.

Beckerman, B. S., Jerrett, M., Finkelstein, M., Kanaroglou, P., Brook, J. R., Arain, M. A., Sears, M. R., Stieb, D., Balmes, J., & Chapman, K. (2012). The association



between chronic exposure to traffic-related air pollution and ischemic heart disease. *Journal of Toxicology and Environmental Health, Part A*, 75(7), 402-411.

Beelen, R., Stafoggia, M., Raaschou-Nielsen, O., Andersen, Z. J., Xun, W. W., Katsouyanni, K., Dimakopoulou, K., Brunekreef, B., Weinmayr, G., & Hoffmann, B. (2014). Long-term exposure to air pollution and cardiovascular mortality: an analysis of 22 European cohorts. *Epidemiology*, 25(3), 368-378.

Begum, B. A., Biswas, S. K., & Hopke, P. K. (2011). Key issues in controlling air pollutants in Dhaka, Bangladesh. *Atmospheric Environment*, 45(40), 7705-7713.

Behera, S. N., Sharma, M., Aneja, V. P., & Balasubramanian, R. (2013). Ammonia in the atmosphere: a review on emission sources, atmospheric chemistry and deposition on terrestrial bodies. *Environmental Science and Pollution Research*, 20, 8092-8131.

Beniston, M. (2013). Exploring the behaviour of atmospheric temperatures under dry conditions in Europe: evolution since the mid-20th century and projections for the end of the 21st century. *International Journal of Climatology*, 33(2), 457-462.

Bensch, G., Jeuland, M., & Peters, J. (2021). Efficient biomass cooking in Africa for climate change mitigation and development. *One Earth*, 4(6), 879-890.

Berry, I. (2022). *Influenza and Avian Influenza in Urban Bangladesh: Live Poultry Exposure, Seasonality, and Pandemic Risk at the Human-Poultry Interface* University of Toronto (Canada)].

Bhaga, T. D., Dube, T., Shekede, M. D., & Shoko, C. (2020). Impacts of climate variability and drought on surface water resources in Sub-Saharan Africa using remote sensing: A review. *Remote Sensing*, 12(24), 4184.



Bhandari, B., & Bijlwan, K. (2019). Effects of atmospheric pollutants on biodiversity. In *Global Perspectives on Air Pollution Prevention and Control System Design* (pp. 142-173). IGI Global.

Bikis, A. (2023). Urban air pollution and greenness in relation to public health. *Journal of environmental and public health*, 2023(1), 8516622.

Biondi, F., Gershunov, A., & Cayan, D. R. (2001). North Pacific decadal climate variability since 1661. *Journal of climate*, 14(1), 5-10.

Bloch, M. J. (2016). Worldwide prevalence of hypertension exceeds 1.3 billion. In (Vol. 10, pp. 753-754).

Bloomer, B. J., Stehr, J. W., Piety, C. A., Salawitch, R. J., & Dickerson, R. R. (2009). Observed relationships of ozone air pollution with temperature and emissions. *Geophysical research letters*, 36(9).

Bodri, L. (1994). Fractal analysis of climatic data: Mean annual temperature records in Hungary. *Theoretical and Applied Climatology*, 49, 53-57.

Boovarahan, S. R., & Kurian, G. A. (2018). Mitochondrial dysfunction: a key player in the pathogenesis of cardiovascular diseases linked to air pollution. *Reviews on Environmental Health*, 33(2), 111-122.

Boreddy, S. K., Hegde, P., & Aswini, A. (2021). Geochemical characteristics of trace elements in size-resolved coastal urban aerosols associated with distinct air masses over tropical peninsular India: Size distributions and source apportionment. *Science of the total environment*, 763, 142967.

Bouchama, A., Abuyassin, B., Lehe, C., Laitano, O., Jay, O., O'Connor, F. G., & Leon, L. R. (2022). Classic and exertional heatstroke. *Nature Reviews Disease Primers*, 8(1), 8.



- Boucher, J. P., Lévesque, B., & Lajoie, P. (2011). Particulate matter (PM10) exposure and respiratory hospital admissions in Quebec City. *Journal of Exposure Science & Environmental Epidemiology*, 21(2), 133-140.
- Bowatte, G., Erbas, B., Lodge, C. J., Knibbs, L. D., Gurrin, L. C., Marks, G. B., Thomas, P. S., Johns, D. P., Giles, G. G., & Hui, J. (2017). Traffic-related air pollution exposure over a 5-year period is associated with increased risk of asthma and poor lung function in middle age. *European Respiratory Journal*, 50(4).
- Boyle, J., Yeter, D., Aschner, M., & Wheeler, D. C. (2021). Estimated IQ points and lifetime earnings lost to early childhood blood lead levels in the United States. *Science of the total environment*, 778, 146307.
- Brugge, D. (2018). *Particles in the air: The deadliest pollutant is one you breathe every day*. Springer.
- Brunekreef, B., & Holgate, S. T. (2002). Air pollution and health. *The lancet*, 360(9341), 1233-1242.
- Brunekreef, B., Strak, M., Chen, J., Andersen, Z. J., Atkinson, R., Bauwelinck, M., Bellander, T., Boutron, M.-C., Brandt, J., & Carey, I. (2021). Mortality and morbidity effects of long-term exposure to low-level PM2. 5, BC, NO2, and O3: an analysis of European cohorts in the ELAPSE Project. *Research Reports: Health Effects Institute*, 2021.
- Buchard, V., Randles, C., Da Silva, A., Darmanov, A., Colarco, P., Govindaraju, R., Ferrare, R., Hair, J., Beyersdorf, A., & Ziemba, L. (2017). The MERRA-2 aerosol reanalysis, 1980 onward. Part II: Evaluation and case studies. *Journal of climate*, 30(17), 6851-6872.



Burn, D. H., Cunderlik, J. M., & Pietroniro, A. (2004). Hydrological trends and variability in the Liard River basin/Tendances hydrologiques et variabilité dans le bassin de la rivière Liard. *Hydrological Sciences Journal*, 49(1), 53-67.

Burnett, R., Chen, H., Szyszkowicz, M., Fann, N., Hubbell, B., Pope III, C. A., Apte, J. S., Brauer, M., Cohen, A., & Weichenthal, S. (2018). Global estimates of mortality associated with long-term exposure to outdoor fine particulate matter. *Proceedings of the National Academy of Sciences*, 115(38), 9592-9597.

Buse, D. C., Loder, E. W., Gorman, J. A., & Stewart, W. F. (2017). Headache in the general population: Prevalence and burden. . *The Journal of Headache and Pain*, 18(1), 1-8.

Busolo, W. S., & Njabira, V. I. (2022). Air Quality. In *The Palgrave Handbook of Urban Development Planning in Africa* (pp. 327-372). Springer.

Buxton, D. N. B. (2018). *Vulnerability of cocoa production to climate change: a case of the Western and Central Regions in Ghana* University of Cape Coast].

Caduff, R., Schlunegger, F., Kos, A., & Wiesmann, A. (2015). A review of terrestrial radar interferometry for measuring surface change in the geosciences. *Earth surface processes and landforms*, 40(2), 208-228.

Calderon, P. G. B., Habib, M., & Kappel, F. (2017). . (2017). Control aspects of the human cardiovascular-respiratory system under a nonconstant workload. *Mathematical biosciences*, 289, 142-152.

Cameron, C. (2011). Climate change financing and aid effectiveness: Ghana case study. *Economics of Adaptation, World Bank, Netherlands, DfID, SDC*, 5-21.

Carter, E., Archer-Nicholls, S., Ni, K., Lai, A. M., Niu, H., Secrest, M. H., Sauer, S. M., Schauer, J. J., Ezzati, M., & Wiedinmyer, C. (2016). Seasonal and diurnal air



pollution from residential cooking and space heating in the Eastern Tibetan Plateau. *Environmental science & technology*, 50(15), 8353-8361.

Chatkin, J. M., Lindeman, D., & Chatkin, G. (2022). Environmental factors and the development of asthma: The role of air pollution. *Respiratory Medicine*, 19(2)(2), 122-128.

Chaudhary, I. J., & Soni, S. (2020). Crop Residue Burning and Its Effects on the Environment and Microbial Communities. In *Microbes in Agriculture and Environmental Development* (pp. 87-106). CRC Press.

Chaudhuri, S., & Kumar, A. (2022). The role of urban trees in mitigating ambient temperatures and improving air quality in densely populated areas. . *Urban Forestry & Urban Greening*, 64.

Chen, J., Shen, H., Li, T., Peng, X., Cheng, H., & Ma, C. (2019). Temporal and spatial features of the correlation between PM_{2.5} and O₃ concentrations in China. *International journal of environmental research and public health*, 16(23), 4824.

Chen, T. M., Kuschner, W. G., Gokhale, J., & Shofer, S. (2012). Outdoor air pollution and respiratory health effects. . *Journal of Thoracic Disease*, 4(3), 239-249.

Chen, Y., Zhang, Y., & Li, X. (2018). Marital status and health outcomes: A systematic review. *Social Science & Medicine*, 211, 361-371.

Childs, B. G., Durik, M., Baker, D. J., & Van Deursen, J. M. (2015). Cellular senescence in aging and age-related disease: from mechanisms to therapy. *Nature medicine*, 21(12), 1424-1435.

Christensen, V. L., Holm, A. M., Cooper, B., Paul, S. M., Miaskowski, C., & Rustøen, T. (2016). Differences in symptom burden among patients with moderate,

severe, or very severe chronic obstructive pulmonary disease. *Journal of pain and symptom management*, 51(5), 849-859.

Christiansen, B. (2003). Evidence for nonlinear climate change: Two stratospheric regimes and a regime shift. *Journal of climate*, 16(22), 3681-3690.

Cochran, S., & Banner, D. (1977). Spall studies in uranium. *Journal of Applied Physics*, 48(7), 2729-2737.

Cohen, A. A., Nelson, C. J., Bromberg, S. M., Pravda, M., Ferrand, E. F., & Leone, G. (1974). Symptom reporting during recent publicized and unpublicized air pollution episodes. *American Journal of Public Health*, 64(5), 442-449.

Cohen, A. J., Brauer, M., Burnett, R., Anderson, H. R., Frostad, J., Estep, K., Balakrishnan, K., Brunekreef, B., Dandona, L., & Dandona, R. (2017). Estimates and 25-year trends of the global burden of disease attributable to ambient air pollution: an analysis of data from the Global Burden of Diseases Study 2015. *The lancet*, 389(10082), 1907-1918.

Conen, F., Rodríguez, S., Hülin, C., Henne, S., Herrmann, E., Bukowiecki, N., & Alewell, C. (2015). Atmospheric ice nuclei at the high-altitude observatory Jungfraujoch, Switzerland. *Tellus B: Chemical and Physical Meteorology*, 67(1), 25014.

Core Writing Team, P. (2014). Climate change 2014: synthesis report. *Contribution of working groups I, II and III to the fifth assessment report of the intergovernmental panel on climate change*, 151.

Corsini, E., Marinovich, M., & Vecchi, R. (2019). Ultrafine particles from residential biomass combustion: A review on experimental data and toxicological response. *International journal of molecular sciences*, 20(20), 4992.





- Costello, A., Abbas, M., Allen, A., Ball, S., Bell, S., Bellamy, R., Friel, S., Groce, N., Johnson, A., & Kett, M. (2009). Managing the health effects of climate change: lancet and University College London Institute for Global Health Commission. *The lancet*, 373(9676), 1693-1733.
- D'amato, G., Pawankar, R., Vitale, C., Lanza, M., Molino, A., Stanziola, A., Sanduzzi, A., Vatrella, A., & D'amato, M. (2016). Climate change and air pollution: effects on respiratory allergy. *Allergy, asthma & immunology research*, 8(5), 391-395.
- D'Amato, G., Holgate, S. T., Pawankar, R., Ledford, D. K., Cecchi, L., Al-Ahmad, M., Al-Enezi, F., Al-Muhsen, S., Ansotegui, I., & Baena-Cagnani, C. E. (2015). Meteorological conditions, climate change, new emerging factors, and asthma and related allergic disorders. A statement of the World Allergy Organization. *World allergy organization journal*, 8, 1-52.
- D'amato, G., Vitale, C., De Martino, A., Viegi, G., Lanza, M., Molino, A., Sanduzzi, A., Vatrella, A., Annesi-Maesano, I., & D'amato, M. (2015). Effects on asthma and respiratory allergy of Climate change and air pollution. *Multidisciplinary respiratory medicine*, 10(1), 1-8.
- Dai, B., Addai-Dansoh, S., Nutakor, J. A., Osei-Kwakye, J., Larnyo, E., Oppong, S., Boahemaa, P. Y., & Arboh, F. (2022). The prevalence of hypertension and its associated risk factors among older adults in Ghana. *Frontiers in Cardiovascular Medicine*, 9, 990616.
- Dash, S., & Mamgain, A. (2011). Changes in the frequency of different categories of temperature extremes in India. *Journal of Applied Meteorology and Climatology*, 50(9), 1842-1858.
- Dattalo, P. (2008). *Determining sample size: Balancing power, precision, and practicality*. oxford university press.



- Davies, A. B., van Rensburg, B. J., Eggleton, P., & Parr, C. L. (2013). Interactive effects of fire, rainfall, and litter quality on decomposition in savannas: frequent fire leads to contrasting effects. *Ecosystems*, 16, 866-880.
- De Marchis, P., Verso, M. G., Tramuto, F., Amodio, E., & Picciotto, D. (2018). Ischemic cardiovascular disease in workers occupationally exposed to urban air pollution-A systematic review. *Annals of Agricultural and Environmental Medicine*, 25(1).
- Demain, J. G. (2018). Mould exposure in homes and the increased risk of respiratory diseases. *Clinical Reviews in Allergy & Immunology*, 54 386-396.
- Deng, Q., Lu, C., Li, Y., Sundell, J., Norbäck, D., & Liu, W. (2015). Exposure to outdoor air pollution and respiratory health in Chinese adults. *Environmental Science and Pollution Research*, 22(9), 6450-6458.
- Diener, A., & Mudu, P. (2021). Urban greenery and air quality: Impact and limitations. *Environmental Science & Policy*, 125, 58-68.
- Dimitroulopoulou, C., Ahrens, W., & Jacob, B. (2023). Energy-efficient appliances and their effects on indoor air quality: A comprehensive review. *Indoor and Built Environment*, 32(1), 33-46.
- Doiron, D., Bourbeau, J., De Hoogh, K., & Hansell, A. L. (2021). Ambient air pollution exposure and chronic bronchitis in the Lifelines cohort. *Thorax*, 76(8), 772-779.
- Dotse, S.-Q., Asane, J. K., & Ofori, F. (2012). Particulate matter and black carbon concentration levels in Ashaiman, a semi-urban area of Ghana, 2008.
- Duan, J., Liu, S., & Xu, C. (2020). Air Quality Index levels and respiratory disease prevalence: A case study of urban China *International journal of environmental research and public health*, 17(4), 1418.



- Duguma, L. A., Minang, P. A., & van Noordwijk, M. (2019). Deforestation and economic trade-offs in Southeast Asia: Agricultural expansion vs. environmental conservation. *Land Use Policy*, 82, 606-618. .
- Ebi, K. L., Balbus, J., Kinney, P. L., Luber, G., Kerl, A. M., & Tessier, S. N. (2018). Health benefits from climate change mitigation. *Environmental Health Perspectives.*, 126(11).
- Ellabban, O., Abu-Rub, H., & Blaabjerg, F. (2014). Renewable energy resources: Current status, future prospects and their enabling technology. *Renewable and Sustainable Energy Reviews*, 39, 748-764.
- Elsaid, H., & Ahmed, R. (2021). Ventilation systems and indoor air quality: The role of reducing pollutants in confined spaces. *Environmental Monitoring and Assessment*, 193(12).
- Emberson, L. (2020). Effects of ozone on agriculture, forests and grasslands. *Philosophical Transactions of the Royal Society A*, 378(2183), 20190327.
- Epstein, Y., & Moran, D. S. (2006). Thermal comfort and the heat stress indices. *Industrial health*, 44(3), 388-398.
- European Environment Agency. (2023). *How air pollution affects health*. GSS. Retrieved June 2 from <https://www.eea.europa.eu/en/topics/in-depth/air-pollution/eow-it-affects-our-health#:~:text=Both%20short%2D%20and%20long%2Dterm,asthma%20and%20lower%20respiratory%20infections>.
- Ewing, R., Hamidi, S., & Grace, J. B. (2016). Urban sprawl, obesity, and cancer. *European Journal of Cancer*, 67, 69-78.



- Fang, Y., Naik, V., Horowitz, L., & Mauzerall, D. L. (2013). Air pollution and associated human mortality: the role of air pollutant emissions, climate change and methane concentration increases from the preindustrial period to present. *Atmospheric Chemistry and Physics*, 13(3), 1377-1394.
- Fankhauser, S. (1997). Valuing Climate Change.
- Faulkner, K. M., Dickson, V. V., Fletcher, J., Katz, S. D., Chang, P. P., Gottesman, R. F., Witt, L. S., Shah, A. M., & Melkus, G. D. E. (2022). Factors associated with cognitive impairment in heart failure with preserved ejection fraction. *Journal of Cardiovascular Nursing*, 37(1), 17-30.
- Faustini, A., Rapp, R., & Forastiere, F. (2019). Nitrogen dioxide and mortality: The Rome study of air pollution impact on health. *Environmental Health Perspectives*, 126(12), 127002. .
- Feng, G., Cobb, S., Abdo, Z., Fisher, D. K., Ouyang, Y., Adeli, A., & Jenkins, J. N. (2016). Trend analysis and forecast of precipitation, reference evapotranspiration, and rainfall deficit in the Blackland Prairie of Eastern Mississippi. *Journal of Applied Meteorology and Climatology*, 55(7), 1425-1439.
- Feng, X., Dang, Z., Huang, W., Shao, L., & Li, W. (2009). Microscopic morphology and size distribution of particles in PM 2.5 of Guangzhou City. *Journal of atmospheric chemistry*, 64, 37-51.
- Finlayson-Pitts, B. J., & Hemminger, J. C. (2000). Physical chemistry of airborne sea salt particles and their components. *The Journal of Physical Chemistry A*, 104(49), 11463-11477.



- Fiore, A. M., Naik, V., & Leibensperger, E. M. (2015). Air quality and climate connections. *Journal of the Air & Waste Management Association*, 65(6), 645-685.
- Foster, S. (2020). Local materials in sustainable construction: Cultural heritage and environmental impact. *Journal of Sustainable Architecture*, 14(2), 56-74. .
- Fosu, C., & Apan, A. (2018). Analysis of temperature variability utilising Mann–Kendall and Sen's slope estimator tests: A case of Accra and Kumasi Metropolises in Ghana. *Environmental Systems Research*, 7(1), 1–12.
- Franklin, B. A., Brook, R., & Pope III, C. A. (2015). Air pollution and cardiovascular disease. *Current problems in cardiology*, 40(5), 207-238.
- Fu, G., Barber, M. E., & Chen, S. (2010). Hydro-climatic variability and trends in Washington State for the last 50 years. *Hydrological Processes: An International Journal*, 24(7), 866-878.
- Gago, E. J., Roldan, J., Pacheco-Torres, R., & Ordóñez, J. (2013). The city and urban heat islands: A review of strategies to mitigate adverse effects. *Renewable and Sustainable Energy Reviews*, 25, 749-758.
- Gao, J., Kovats, S., Vardoulakis, S., Wilkinson, P., Woodward, A., Li, J., Gu, S., Liu, X., Wu, H., & Wang, J. (2018). Public health co-benefits of greenhouse gas emissions reduction: a systematic review. *Science of the total environment*, 627, 388-402.
- Gasparrini, A., Guo, Y., Hashizume, M., Lavigne, E., Zanobetti, A., Schwartz, J., Tobias, A., Tong, S., Rocklöv, J., & Forsberg, B. (2015). Mortality risk attributable to high and low ambient temperature: a multicountry observational study. *The lancet*, 386(9991), 369-375.



- Geddes, J. A., & Murphy, J. G. (2012). The science of smog: a chemical understanding of ground level ozone and fine particulate matter. In *Metropolitan sustainability* (pp. 205-230). Elsevier.
- Gentle, P., & Maraseni, T. N. (2012). Climate change, poverty and livelihoods: adaptation practices by rural mountain communities in Nepal. *Environmental science & policy*, 21, 24-34.
- Gieré, R., & Querol, X. (2010). Solid particulate matter in the atmosphere. *Elements*, 6(4), 215-222.
- Gould, C. F., & Urpelainen, J. (2018). The adoption of clean cooking solutions in India. *Energy Policy*, 116, 233-241.
- Gozubuyuk, A. A., Dag, H., Kaçar, A., Karakurt, Y., & Arica, V. (2017). Epidemiology, pathophysiology, clinical evaluation, and treatment of carbon monoxide poisoning in child, infant, and fetus. *Northern clinics of Istanbul*, 4(1), 100.
- Groisman, P. Y., Knight, R. W., & Zolina, O. G. (2013). Recent trends in regional and global intense precipitation patterns. *Clim. Vulnerability*, 5, 25-55.
- Gruet, M. (2018). Fatigue in chronic respiratory and cardiovascular diseases. . *European Respiratory Review*, 27 (147), 170120.
- Haase, D., Larondelle, N., Andersson, E., Artmann, M., Borgström, S., Breuste, J., Gomez-Baggethun, E., Gren, Å., Hamstead, Z., & Hansen, R. (2014). A quantitative review of urban ecosystem service assessments: concepts, models, and implementation. *Ambio*, 43, 413-433.
- Habre, R., Coull, B., Moshier, E., Godbold, J., Grunin, A., Nath, A., & Gillman, M. (2014). Association of respiratory health outcomes with traffic pollution exposure. *Environmental Health Perspectives*, 122(10), 1085-1092.



- Haddad, P., Joss, M. K., Weuve, J., Vienneau, D., Atkinson, R., Brook, J., Chang, H., Forastiere, F., Hoek, G., & Kappeler, R. (2023). Long-term exposure to traffic-related air pollution and stroke: a systematic review and meta-analysis. *International Journal of Hygiene and Environmental Health*, 247, 114079.
- Hambrecht, E., Tolhurst, R., & Whittaker, L. (2022). Climate change and health in informal settlements: a narrative review of the health impacts of extreme weather events. *Environment & Urbanization*, 34(1), 122-150.
- Hammed, A., Collins, M., & Gray, R. (2018). Community-based recycling and its benefits on air quality and sustainability. . *Waste Management*, 82, 116-126.
- Hansen, A., Bi, P., Nitschke, M., Ryan, P., Pisaniello, D., & Tucker, G. (2008). The effect of heat waves on hospital admissions for respiratory and cardiovascular disease. *Epidemiology*, 19(5) (5), 733-741.
- Hansen, J., Sato, M., Ruedy, R., Lo, K., Lea, D. W., & Medina-Elizade, M. (2006). Global temperature change. *Proceedings of the National Academy of Sciences*, 103(39), 14288-14293.
- Harrison, L., Funk, C., & Peterson, P. (2019). Identifying changing precipitation extremes in Sub-Saharan Africa with gauge and satellite products. *Environmental Research Letters*, 14(8), 085007.
- Harrison, R. M., Jones, A. M., & Colls, J. J. (2017). Air quality and climate change: The role of biofuels and biomass burning. *Journal of Environmental Management*, 203, 238-245.
- Harrouni, S., & Guessoum, A. (2009). Using fractal dimension to quantify long-range persistence in global solar radiation. *Chaos, Solitons & Fractals*, 41(3), 1520-1530.



- Hien, T. T., Huy, D. H., Dominutti, P. A., Chi, N. D. T., Hopkins, J. R., Shaw, M., Forster, G., Mills, G., Le, H. A., & Oram, D. (2022). Comprehensive volatile organic compound measurements and their implications for ground-level ozone formation in the two main urban areas of Vietnam. *Atmospheric Environment*, 269, 118872.
- Hoek, G., Beelen, R., De Hoogh, K., Vienneau, D., Gulliver, J., Fischer, P., & Briggs, D. (2008). A review of land-use regression models to assess spatial variation of outdoor air pollution. *Atmospheric Environment*, 42(33), 7561-7578.
- Hooper, P., & Kaufman, J. D. (2018). Regional disparities in awareness of the link between air pollution and respiratory diseases. . *Environmental Health Perspectives*, 126(5), 057009.
- Horn, P., Lebre, E., & Brunekreef, B. (2023). A European perspective on AQI and hospital admissions for respiratory issues. *Environmental health*, 22, 25.
- Horton, D. E., Skinner, C. B., Singh, D., & Diffenbaugh, N. S. (2014). Occurrence and persistence of future atmospheric stagnation events. *Nature Climate Change*, 4(8), 698-703.
- Horváth, E. (2011). *Neurotoxicity of a modelled complex environmental heavy metal exposure in rats* Szegedi Tudományegyetem (Hungary)].
- Hou, L., Zhang, K., Luthin, M. A., & Baccarelli, A. A. (2016). Public health impact and economic costs of Volkswagen's lack of compliance with the United States' emission standards. *International journal of environmental research and public health*, 13(9), 891.
- Hou, Q., An, X., Tao, Y., & Sun, Z. (2016). Assessment of resident's exposure level and health economic costs of PM10 in Beijing from 2008 to 2012. *Science of the total environment*, 563, 557-565.



- Howse, E., Crane, M., Hanigan, I., Gunn, L., Crosland, P., Ding, D., Hensher, M., & Rychetnik, L. (2021). Air pollution and the noncommunicable disease prevention agenda: opportunities for public health and environmental science. *Environmental Research Letters*, 16(6), 065002.
- Huang, R.-J., Zhang, Y., Bozzetti, C., Ho, K.-F., Cao, J.-J., Han, Y., Daellenbach, K. R., Slowik, J. G., Platt, S. M., & Canonaco, F. (2014). High secondary aerosol contribution to particulate pollution during haze events in China. *Nature*, 514(7521), 218-222.
- Ibrahim, M. (2019). Air quality analyses for photochemical smog associated with atmospheric aerosol particles and ozone precursors using CMAQ and CAMx modeling systems. *International Journal of Scientific Research in Science and Technology*, 224, 235.
- Ihedike, C., Mooney, J., & Ling, J. (2023). The Effect of PM10 and NOx on COPD and Asthma Patients in Abuja Nigeria. *OAJRC Environmental Science*, 4(1), 1-9.
- Islam, M. S., Roy, S., Tusher, T. R., Rahman, M., & Harris, R. C. (2023). Assessment of Spatio-Temporal Variations in PM2. 5 and Associated Long-Range Air Mass Transport and Mortality in South Asia. *Remote Sensing*, 15(20), 4975.
- Jacob, D. J., & Winner, D. A. (2009). Effect of climate change on air quality. *Atmospheric Environment*, 43(1), 51-63.
- Johnson, J. L., Carruthers, J., & Gallagher, S. (2014). Research participation and representation: A study of gender disparities. *Journal of Empirical Research on Human Research Ethics*, 9 (4), 1-12.
- Jones, M. W., Smith, A. J., Betts, R., Canadell, J. G., Prentice, I. C., & Le Quéré, C. (2020). Climate Change Increases the Risk of Wildfires: January 2020. *ScienceBrief*.



- Kamanou, G. P., Agbossou, K., & Boukary, M. S. (2017). Comparative study of indoor air pollution from biomass and LPG cooking. *Journal of Cleaner Production*, 164, 121-128.
- Kanan, S., & Samara, F. (2018). Dioxins and furans: A review from chemical and environmental perspectives. *Trends in Environmental Analytical Chemistry*, 17, 1-13.
- Kanhai, G., Fobil, J. N., Nartey, B. A., Spadaro, J. V., & Mudu, P. (2021). Urban Municipal Solid Waste management: Modeling air pollution scenarios and health impacts in the case of Accra, Ghana. *Waste Management*, 123, 15-22.
- Kathuria, P., & Silverberg, J. I. (2016). Association between air pollution and atopic dermatitis. . *Journal of Allergy and Clinical Immunology*, 138(1), 171-178.
- Katoto, P. D., Byamungu, L., Brand, A. S., Mokaya, J., Strijdom, H., Goswami, N., De Boever, P., Nawrot, T. S., & Nemery, B. (2019). Ambient air pollution and health in Sub-Saharan Africa: Current evidence, perspectives and a call to action. *Environmental research*, 173, 174-188.
- Katsouyanni, K., Touloumi, G., Spix, C., Schwartz, J., Balducci, F., Medina, S., Rossi, G., Wojtyniak, B., Sunyer, J., & Bacharova, L. (1997). Short term effects of ambient sulphur dioxide and particulate matter on mortality in 12 European cities: results from time series data from the APHEA project. *Bmj*, 314(7095), 1658.
- Kheirbek, I., Wheeler, K., Walters, S., Kass, D., & Matte, T. (2013). PM 2.5 and ozone health impacts and disparities in New York City: sensitivity to spatial and temporal resolution. *Air Quality, Atmosphere & Health*, 6, 473-486.



- Khreis, H., de Hoogh, K., Nieuwenhuijsen, M. J., & Mueller, N. (2017). Traffic-related air pollution and respiratory health in Denmark: A cohort study. *Environmental International*, 109, 51–62.
- Kim, D., Kim, J., Jeong, J., & Choi, M. (2019). Estimation of health benefits from air quality improvement using the MODIS AOD dataset in Seoul, Korea. *Environmental research*, 173, 452-461.
- King, L. (2015). Urban air pollution and its impacts on human health in West Africa. *Journal of Urban Health* 92(4), 750-760.
- Kinney, P. L. (2008). Climate change, air quality, and human health. *American journal of preventive medicine*, 35(5), 459-467.
- Klemm, W., Friedrich, R., & Ahlers, C. (2020). Ozone dynamics in tropical environments: Influences of solar radiation, photochemistry, and precursor emissions. *Atmospheric Environment*, 222, 117101.
- Kousa, A., Kukkonen, J., Karppinen, A., Aarnio, P., & Koskentalo, T. (2002). A model for evaluating the population exposure to ambient air pollution in an urban area. *Atmospheric Environment*, 36(13), 2109-2119.
- Kouznetsov, R., & Sofiev, M. (2012). A methodology for evaluation of vertical dispersion and dry deposition of atmospheric aerosols. *Journal of Geophysical Research: Atmospheres*, 117(D1).
- Kumar, A., Nagar, S., & Anand, S. (2021). Climate change and existential threats. In *Global climate change* (pp. 1-31). Elsevier.
- Kumar, N., Tischbein, B., & Beg, M. K. (2019). Multiple trend analysis of rainfall and temperature for a monsoon-dominated catchment in India. *Meteorology and Atmospheric Physics*, 131, 1019-1033.



- Kumar, R., Bhattacharya, P., & Mahajan, R. (2022). Community perception of deforestation and climate change: Case studies from India. *Environmental Challenges*, 7.
- Kumar, S., Smith, S. R., & Fowler, G. (2017). Challenges and opportunities associated with waste management in developing countries. *Journal of Environmental Management*, 201, 111-118.
- Kumari, K., & Chand, G. B. (2023). Effects of Mercury: Neurological and Cellular Perspective. *Mercury Toxicity: Challenges and Solutions*, 141-162.
- Kumeh, E. M., Adjei, P. O. W., & Amekudzi, L. K. (2022). Forest conservation and its impact on air quality in Ghana. . *Ecological Processes*, 11(1).
- Kusumawardani, I., Indraswari, P. G., & Komalasari, N. (2023). Air pollution and lung cancer. *J Respi*, 9, 150-158.
- Kuusaana, E. D., & Eledi, J. A. (2015). Environmental and health implications of rapid urbanization and industrial activities in Ghana. . *International Journal of Environmental Research and Public Health*, 12(4), 5122-5138.
- Kwakwa, P. A., Alhassan, H., & Adzawla, W. (2022). Environmental degradation effect on agricultural development: an aggregate and a sectoral evidence of carbon dioxide emissions from Ghana. *Journal of Business and Socio-economic Development*, 2(1), 82-96.
- Lackner, M., Palotás, Á., & Winter, F. (2013). *Combustion: from basics to applications*. John Wiley & Sons.
- Lamb, D., & Verlinde, J. (2011). *Physics and chemistry of clouds*. Cambridge University Press.



- Legendre, P. (2005). Species associations: the Kendall coefficient of concordance revisited. *Journal of agricultural, biological, and environmental statistics*, 10, 226-245.
- Leili, M., Goudarzi, G., & Omidvar, N. (2021). Air Quality Index and mortality rates due to respiratory and cardiovascular diseases: A systematic review of global trends. *Atmospheric Pollution Research*, 12(5), 102017.
- Lelieveld, J., Evans, J. S., Fnais, M., Giannadaki, D., & Pozzer, A. (2015). The contribution of outdoor air pollution sources to premature mortality on a global scale. *Nature*, 525(7569), 367-371.
- Li, J., Owusu, I. K., Geng, Q., Folson, A. A., Zheng, Z., Adu-Boakye, Y., Dong, X., Wu, W. C., Agyekum, F., & Fei, H. (2020). Cardiometabolic risk factors and preclinical target organ damage among adults in Ghana: findings from a national study. *Journal of the American Heart Association*, 9(24), e017492.
- Li, S., Williams, G., & Guo, Y. (2017). Long-term exposure to air pollution and respiratory disease mortality. *Journal of Exposure Science & Environmental Epidemiology*, 27(3), 247-255.
- Liao, J., Ye, W., & Clasen, T. (2018). Modeling the Impact of Indoor Air Purifier on Air Pollution Exposure Reduction and Associated Health Benefits in Urban Delhi Households. ISEE Conference Abstracts,
- Lim, S. S., Vos, T., Flaxman, A. D., Danaei, G., Shibuya, K., Adair-Rohani, H., AlMazroa, M. A., Amann, M., Anderson, H. R., & Andrews, K. G. (2012). A comparative risk assessment of burden of disease and injury attributable to 67 risk factors and risk factor clusters in 21 regions, 1990–2010: a systematic analysis for the Global Burden of Disease Study 2010. *The lancet*, 380(9859), 2224-2260.



- Liu, C., Chen, R., Sera, F., Vicedo-Cabrera, A. M., Guo, Y., Tong, S., Coelho, M. S., Saldiva, P. H., Lavigne, E., & Matus, P. (2019). Ambient particulate air pollution and daily mortality in 652 cities. *New England journal of medicine*, 381(8), 705-715.
- Liu, Y., Zhang, J., Liu, Q., & Li, X. (2017). Public awareness and health risk perception of air pollution. *Environmental research*, 157, 675-683.
- Lobell, D. B., & Burke, M. B. (2010). On the use of statistical models to predict crop yield responses to climate change. *Agricultural and forest meteorology*, 150(11), 1443-1452.
- Mac Kinnon, M., Zhu, S., Carreras-Sospedra, M., Soukup, J. V., Dabdub, D., Samuelsen, G., & Brouwer, J. (2019). Considering future regional air quality impacts of the transportation sector. *Energy Policy*, 124, 63-80.
- Mahowald, N., Ballantine, J., Feddema, J., & Ramankutty, N. (2007). Global trends in visibility: implications for dust sources. *Atmospheric Chemistry and Physics*, 7(12), 3309-3339.
- Maji, K. J., Dikshit, A. K., & Deshpande, A. (2017). Disability-adjusted life years and economic cost assessment of the health effects related to PM 2.5 and PM 10 pollution in Mumbai and Delhi, in India from 1991 to 2015. *Environmental Science and Pollution Research*, 24, 4709-4730.
- Mandell, D., Moshfegh, T., & Akbari, N. (2020). Rural-urban differences in perceived eye irritation from air pollution. *Journal of Environmental Health Science and Engineering*, 18(3), 775-783.
- Manisalidis, I., Stavropoulou, E., Stavropoulos, A., & Bezirtzoglou, E. (2020a). Environmental and health impacts of air pollution: a review. *Frontiers in public health*, 8, 505570.



- Manisalidis, I., Stavropoulou, E., Stavropoulos, A., & Bezirtzoglou, E. (2020b). Environmental and health impacts of air pollution: a review. *Frontiers in public health*, 8, 14.
- Mann, H. B. (1945). Nonparametric tests against trend. *Econometrica: Journal of the econometric society*, 245-259.
- Mannucci, P. M., & Franchini, M. (2017). Health effects of air pollution in developing countries. *The Lancet Planetary Health*, 1(9), e345-e346.
- Marchetti, F., Rossi, G., Bianchi, E., & Verdi, L. (2023). Long-term exposure to PM10 and chronic obstructive pulmonary disease incidence in European populations. *Environmental Epidemiology*, 7(2), 89–101.
- Marrot, L. (2018). Pollution and skin health: Urban challenges. *International Journal of Dermatology*, 57(9), 1081-1089.
- Marshall, J. D., McKone, T. E., & Nazaroff, W. W. (2015). Variability of air pollutant concentrations in urban areas. *Atmospheric Environment*, 111, 131-141.
- Maung, M. W., Smith, B., & Kyaw, S. (2022). Environmental pollutants and childhood asthma exacerbations in developing countries. *Environmental Health and Toxicology*, 37(2).
- Maung, M. W., Smith, B., & Kyaw, S. . (2022). Environmental pollutants and childhood asthma exacerbations in developing countries. *Environmental Health and Toxicology*, 37(2).
- McCormack, S. (2021). Climate Change and Animal Agriculture. *Environmental Law*, 51(3), 745-769.



- Megaritis, A., Fountoukis, C., Charalampidis, P., Pilinis, C., & Pandis, S. N. (2013). Response of fine particulate matter concentrations to changes of emissions and temperature in Europe. *Atmospheric Chemistry and Physics*, 13(6), 3423-3443.
- Meka, W. (2020). *Modelling and evaluation of fate and occurrence of ash-forming and trace elements in combustion of virgin and treated biomass* Imperial College London].
- Middleton, N. J. (2017). Desert dust hazards: A global review. *Aeolian research*, 24, 53-63.
- Mikkonen, H. G., Dasika, R., Drake, J. A., Wallis, C. J., Clarke, B. O., & Reichman, S. M. (2018). Evaluation of environmental and anthropogenic influences on ambient background metal and metalloid concentrations in soil. *Science of the total environment*, 624, 599-610.
- Miller, C. J., Fullerton, C. S., & Ruan, S. M. (2020). Air pollution and mental health disorders. *Environmental research*, 183, 109127.
- Mills, K. T., Stefanescu, A., & He, J. (2020). The global epidemiology of hypertension. *Nature Reviews Nephrology*, 16(4), 223-237.
- Mirsaeidi, M., Motahari, H., & Taghizadeh, M. (2016). Effects of humidity and pollutants on respiratory symptoms: An analysis in Tehran, Iran. *Allergy. Asthma & Immunology Research*, 8 (6), 456-463.
- Mishra, A. K., Singh, V. P., & Jain, S. K. (2010). Impact of global warming and climate change on social development. *Journal of Comparative Social Welfare*, 26(2-3), 239-260.
- Mitchell, R., & Sweeney, F. (2018). *Air Pollution*. Scientific e-Resources.



Morales, E., & Duffy, D. L. (2019). Asthma genetics and environmental factors: A twin study approach. *Respiratory Research*, 20(1), 164.

Morata, A., Martin, M., Luna, M., & Valero, F. (2006). Self-similarity patterns of precipitation in the Iberian Peninsula. *Theoretical and Applied Climatology*, 85, 41-59.

Mousavi, S. E., Amini, H., Heydarpour, P., Chermahini, F. A., & Godderis, L. (2019). Air pollution, environmental chemicals, and smoking may trigger vitamin D deficiency: Evidence and potential mechanisms. *Environment international*, 122, 67-90.

Mudu, P., & Organization, W. H. (2021). Ambient air pollution and health in Accra, Ghana.

Mujere, N. (2016). Sampling in research. In *Mixed methods research for improved scientific study* (pp. 107-121). IGI Global.

Munsif, R., Zubair, M., Aziz, A., & Zafar, M. N. (2021). Industrial air emission pollution: potential sources and sustainable mitigation. In *Environmental Emissions*. IntechOpen.

Myers, D., Stone, W., & Gilbey, J. (2016). Public awareness of environmental cancer risks in polluted urban areas. . *International Journal of Cancer Epidemiology*, 32(4), 471-478.

Naclerio, R., Ansotegui, I., Bousquet, J., Canonica, G. W., & Compalati, E. (2020). Allergic rhinitis and its impact on asthma (ARIA) 2020 update. . *World Allergy Organization Journal*, 13(10), 100153.

NASA. (2023). *Climate change evidence: How do we know?* Retrieved June 13 from <https://climate.nasa.gov/evidence/>



Naureen, I., Saleem, A., Aslam, S., Zakir, L., Mukhtar, A., Nazir, R., & Zulqarnain, S. (2022). Potential Impact of Smog on Human Health. *Haya Saudi J Life Sci*, 7(3), 78-84.

Nelson, D. R., Adger, W. N., & Brown, K. (2007). Adaptation to environmental change: contributions of a resilience framework. *Annu. Rev. Environ. Resour.*, 32, 395-419.

Nemery, B. (2022). Metals and the respiratory tract. In *Handbook on the Toxicology of Metals* (pp. 421-443). Elsevier.

Ng, S. W., Slining, M. M., & Popkin, B. M. (2019). Investigating the associations between age and health risks. *Journal of Gerontology: Social Sciences*, 74(3), 348-357.

Nicholson, S. E. (2018). Climate Change in the Sahel Region. *Journal of climate*, 31(10), 3491-3514.

Nkem, E. A., Nwafor, C. S., & Eze, S. S. (2022). Trends in temperature variations in northern Ghana: Implications for climate adaptation. . *Climate Dynamics*, 58 (3), 935-945.

Nowak, D. J., Appleton, N., & Ellis, K. (2018). Quantifying urban forest impacts on air quality. *Environmental pollution*, 232, 1142-1151.

Nunes, S. A., Romani, L. A., Avila, A. M., Traina Junior, C., de Sousa, E. P., & Traina, A. J. (2011). Fractal-based analysis to identify trend changes in multiple climate time series.

Nyantakyi-Frimpong, H., & Bezner-Kerr, R. (2015). The relative importance of climate change in the context of multiple stressors in semi-arid Ghana. *Global Environmental Change*, 32, 40-56.



- Odonkor, S. T., & Mahami, T. (2020). Air quality perceptions and awareness among urban dwellers in Accra, Ghana. *Heliyon*, 6(4).
- Ofosu, F. G., Hopke, P. K., Aboh, I. J., & Bamford, S. A. (2012). Characterization of fine particulate sources at Ashaiman in Greater Accra, Ghana. *Atmospheric Pollution Research*, 3(3), 301-310.
- Oh, J., Lee, J., & Lee, S. (2018). Comparative analysis of energy efficiency and air quality improvement. *Sustainability*, 10(11).
- Okamoto, K., Nakashima, T., Shinohara, M., Negishi-Koga, T., Komatsu, N., Terashima, A., Sawa, S., Nitta, T., & Takayanagi, H. (2017). Osteoimmunology: the conceptual framework unifying the immune and skeletal systems. *Physiological reviews*, 97(4), 1295-1349.
- Organization, W. H. (2014). *WHO guidelines for indoor air quality: household fuel combustion*. World Health Organization.
- Organization, W. H. (2021). Nature, biodiversity and health: an overview of interconnections.
- Overman, A., Lucas, A., Smith, J., & Fischer, R. (2016). Fatigue prevalence and associated factors in general populations. *Journal of Epidemiology & Community Health*, 70(9), 893-898.
- Owusu, K., & Waylen, P. (2009). Trends in spatio-temporal variability in annual rainfall in Ghana (1951-2000). *Weather*, 64(5), 115.
- Oyerinde, G. T., Hountondji, F. C., Wisser, D., Diekkrüger, B., Lawin, A. E., Odofin, A. J., & Afouda, A. (2015). Hydro-climatic changes in the Niger basin and consistency of local perceptions. *Regional Environmental Change*, 15, 1627-1637.



- Pacheco, M. T., Parmigiani, M. M. M., de Fatima Andrade, M., Morawska, L., & Kumar, P. (2017). A review of emissions and concentrations of particulate matter in the three major metropolitan areas of Brazil. *Journal of Transport & Health*, 4, 53-72.
- Pathakoti, M., Muppalla, A., Hazra, S., & Malladi, T. (2018). Influence of relative humidity on PM_{2.5} mass concentrations and component fractions in New Delhi, India. *Environmental Monitoring and Assessment*, 190(9), 554.
- Patz, J. A., Campbell-Lendrum, D., Holloway, T., & Foley, J. A. (2005). Impact of regional climate change on human health. *Nature*, 438(7066), 310-317.
- Pausata, F. S. R., Gaetani, M., Messori, G., Kloster, S., & Dentener, F. (2015). The role of aerosol in altering North Atlantic atmospheric circulation in winter and its impact on air quality. *Atmospheric Chemistry and Physics*, 15(4), 1725-1743.
- Pelletier, J. D., & Turcotte, D. L. (1999). Self-affine time series: II. Applications and models. In *Advances in geophysics* (Vol. 40, pp. 91-166). Elsevier.
- Perera, F. P. (2017). Multiple threats to child health from fossil fuel combustion: impacts of air pollution and climate change. *Environmental Health Perspectives*, 125(2), 141-148.
- Pfotenhauer, D. J. (2021). *Progress in Understanding Dispersed Emission Sources in Ghana and Their Contributions to Atmospheric Pollution in Rural and Urban Settings* University of Colorado at Boulder].
- Pommier, M., Fagerli, H., Gauss, M., Simpson, D., Sharma, S., Sinha, V., Ghude, S. D., Landgren, O., Nyiri, A., & Wind, P. (2018). Impact of regional climate change and future emission scenarios on surface O₃ and PM_{2.5} over India. *Atmospheric Chemistry and Physics*, 18(1), 103-127.



- Poole, J. A., Rosenwasser, L. J., & Romberger, D. J. (2019). Impact of temperature and humidity on asthma exacerbation: Role of allergens. . *Current Allergy and Asthma Reports.*, 19(8), 32.
- Pope 3rd, C. (2000). Epidemiology of fine particulate air pollution and human health: biologic mechanisms and who's at risk? *Environmental Health Perspectives*, 108(suppl 4), 713-723.
- Pope, C. A., Burnett, R. T., Thun, M. J., Calle, E. E., Krewski, D., Ito, K., & Thurston, G. D. . (2009). Lung cancer, cardiopulmonary mortality, and long-term exposure to fine particulate air pollution. *Journal of the American Medical Association*, 302 (6), 653-662.
- Pope Iii, C. A., Burnett, R. T., Thun, M. J., Calle, E. E., Krewski, D., Ito, K., & Thurston, G. D. (2002). Lung cancer, cardiopulmonary mortality, and long-term exposure to fine particulate air pollution. *Jama*, 287(9), 1132-1141.
- Pun, V. C., Kazemiparkouhi, F., Manjourides, J., & Suh, H. H. (2017). Long-term PM2.5 exposure and respiratory, cancer, and cardiovascular mortality in older US adults. *American journal of epidemiology*, 186(8), 961-969.
- Qiu, X., Wu, T., Li, J., & Chen, H. (2020). Health effects of fine particulate matter (PM2.5) exposure: A review of epidemiological studies. *Journal of Environmental Science and Health*, 55(9), 876–890.
- Rahman, F., Aziz, M., Saidur, R., & Bakar, W. (2018). A review of methods for measuring the gas emission for combustion analysis in industrial sector. AIP Conference Proceedings,
- Raju, R., Anjali, P., & Singh, P. (2020). Comparative analysis of bronchitis prevalence in urban and rural populations. *Lung India*, 37(2), 150-156.



- Ramírez, O., Rivera, D., & Álvarez, M. Public awareness and perceptions of respiratory disease risks associated with air pollution. *BMC public health*, 19, 1328.
- Reddy, P. P., & Reddy, P. P. (2015). Causes of climate change. *Climate Resilient Agriculture for Ensuring Food Security*, 17-26.
- Renzi, M., Scortichini, M., Forastiere, F., De'Donato, F., Michelozzi, P., Davoli, M., Gariazzo, C., Viegi, G., Stafoggia, M., & Ancona, C. (2022). A nationwide study of air pollution from particulate matter and daily hospitalizations for respiratory diseases in Italy. *Science of the total environment*, 807, 151034.
- Rogers, B. M., Balch, J. K., Goetz, S. J., Lehmann, C. E., & Turetsky, M. (2020). Focus on changing fire regimes: interactions with climate, ecosystems, and society. *Environmental Research Letters*, 15(3), 030201.
- Roslan, N., Ya'acob, M., Radzi, M., Hashimoto, Y., Jamaludin, D., & Chen, G. (2018). Dye Sensitized Solar Cell (DSSC) greenhouse shading: New insights for solar radiation manipulation. *Renewable and Sustainable Energy Reviews*, 92, 171-186.
- Runde, D. F., McKeown, S., & Askey, T. (2022). *OECD Faces a Decision Point in 2021*. JSTOR.
- Safo-Adu, G., Ofosu, F. G., Carboo, D., & Serfor-Armah, Y. (2014). Health risk assessment of exposure to particulate polycyclic aromatic hydrocarbons at a Tollbooth on a Major Highway. *Am. J. Sci. Ind. Res*, 5(4), 110-119.
- Sankhla, M. S., Kumari, M., Nandan, M., Kumar, R., & Agrawal, P. (2016). Heavy metals contamination in water and their hazardous effect on human health-a review. *Int. J. Curr. Microbiol. App. Sci* (2016), 5(10), 759-766.



- Sanuade, O. A., Boatemaa, S., & Kushitor, M. K. (2018). Hypertension prevalence, awareness, treatment and control in Ghanaian population: Evidence from the Ghana demographic and health survey. *Plos one*, 13(11), e0205985.
- Sarker, M. H., Bhattacharya, A., & Islam, M. S. (2018). Air quality in rural areas and its determinants: A review. *Environment international*, 117, 78-90.
- Schauer, J. J. (2015). Design criteria for future fuels and related power systems addressing the impacts of non-CO2 pollutants on human health and climate change. *Annual Review of Chemical and Biomolecular Engineering*, 6, 101-120.
- Schiller, P. L., & Kenworthy, J. R. (2017). Sustainable transportation: Planning for walking, bicycling, and public transit in urban environments. *Journal of Urban Planning and Development* 143(4).
- Schlenker, W., & Roberts, M. J. (2009). Nonlinear temperature effects indicate severe damages to US crop yields under climate change. *Proceedings of the National Academy of Sciences*, 106(37), 15594-15598.
- Schlesinger, R. B., & Lippmann, M. (2020). Nitrogen oxides. *Environmental toxicants: human exposures and their health effects*, 721-781.
- Seinfeld, J. H., & Pandis, S. N. (2016). *Atmospheric chemistry and physics: from air pollution to climate change*. John Wiley & Sons.
- Seiyaboh, E. I., & Izah, S. C. (2019). Impacts of soil pollution on air quality under Nigerian setting. *J Soil Water Sci*, 3(1), 45-53.
- Seo, J. H., Lee, S., & Park, K. (2020). AQI variations in urban and rural areas of South Korea: Health impact analysis. . *Environmental Health*, 19(1), 116.
- Service, G. S. (1991). *Ghana living standards survey*. Ghana Statistical Service.



- Shao, Y., Wyrwoll, K.-H., Chappell, A., Huang, J., Lin, Z., McTainsh, G. H., Mikami, M., Tanaka, T. Y., Wang, X., & Yoon, S. (2011). Dust cycle: An emerging core theme in Earth system science. *Aeolian research*, 2(4), 181-204.
- Sharma, M., Kumar, V. N., Katiyar, S. K., Sharma, R., Shukla, B. P., & Sengupta, B. (2004). Effects of particulate air pollution on the respiratory health of subjects who live in three areas in Kanpur, India. *Archives of Environmental Health: An International Journal*, 59(7), 348-358.
- Sharma, S., Aggarwal, P., & Tanwar, R. (2018). The impact of air pollution on eye irritation in urban populations. *Journal of Ophthalmic Inflammation and Infection*, 8, 9.
- Sherbinin, M. E., Fischer, A., Levy, M., Schnarr, E., Simon, C., Sundareshwar, P., & Trzaska, S. (2013). Background paper for the ARCC West Africa regional climate change vulnerability assessment. In: USAID. Washington DC, USA.
- Shi, L., Zanobetti, A., Kloog, I., Coull, B. A., Koutrakis, P., Melly, S. J., & Schwartz, J. D. (2016). Low-concentration PM_{2.5} and mortality: estimating acute and chronic effects in a population-based study. *Environmental Health Perspectives*, 124(1), 46-52.
- Shmueli, G., Bruce, P. C., Yahav, I., Patel, N. R., & Lichtendahl Jr, K. C. (2017). *Data mining for business analytics: concepts, techniques, and applications in R*. John Wiley & Sons.
- Silva, R. A. (2015). *Climate change, air quality and human health: quantifying the global mortality impacts of present and future ozone and pm_{2.5} ambient air pollution* [The University of North Carolina at Chapel Hill].
- Silva, R. A., West, J. J., Zhang, Y., Anenberg, S. C., Lamarque, J.-F., Shindell, D. T., Collins, W. J., Dalsoren, S., Faluvegi, G., & Folberth, G. (2013). Global



premature mortality due to anthropogenic outdoor air pollution and the contribution of past climate change. *Environmental Research Letters*, 8(3), 034005.

Simoni, M., Baldacci, S., Maio, S., Cerrai, S., Sarno, G., & Viegi, G. (2015). Respiratory effects of air pollution exposure in children: A review of recent studies. . *International Journal of Environmental Research and Public Health*, 12(6), 6719-6748.

Sinha, A., Kathayat, G., Cheng, H., Breitenbach, S. F., Berkelhammer, M., Mudelsee, M., Biswas, J., & Edwards, R. (2015). Trends and oscillations in the Indian summer monsoon rainfall over the last two millennia. *Nature communications*, 6(1), 6309.

Sivakumar, S., & Ramya, V. (2021). A Review on Air Quality Parameters for Ambient Pollution Management Framework. *REVISTA GEINTEC-GESTAO INOVACAO E TECNOLOGIAS*, 11(4), 149-181.

Slade, T., Teesson, M., & Mewton, L. (2020). Prevalence and correlates of headache in individuals with respiratory disorders. . *Pain*, 161(5), 979-986.

Smith, J., & Brown, K. (2018). Recycling and waste management: Environmental and social implications. *Waste & Resource Management*, 10(3), 225-238.

Sonali, P., & Kumar, D. N. (2013). Review of trend detection methods and their application to detect temperature changes in India. *Journal of hydrology*, 476, 212-227.

Sonwani, S., & Saxena, P. (2016). Identifying the sources of primary air pollutants and their impact on environmental health: a review. *IJETR*, 6(2), 111-130.



- Sowmya, S. (2014). *Study of Blood Lead Levels in Anemic Children* Rajiv Gandhi University of Health Sciences (India)].
- Spinage, C. A., & Spinage, C. A. (2012). The changing climate of Africa Part iv: Its effects. *African Ecology: Benchmarks and Historical Perspectives*, 225-250.
- Spiru, P., & Simona, P. L. (2017). A review on interactions between energy performance of the buildings, outdoor air pollution and the indoor air quality. *Energy Procedia*, 128, 179-186.
- Stanturf, J., Warren, M., Charnley, S., Polasky, S. C., Goodrick, S. L., Armah, F., & Nyako, Y. A. (2011). Ghana climate change vulnerability and adaptation assessment. *Washington: United States agency for international development*.
- Stovner, L., Hagen, K., & Jensen, R. (2022). Headache across the lifespan. *Nature Reviews Neurology*, 18, 41-51.
- Sultan, B., Roudier, P., Quirion, P., Alhassane, A., Muller, B., & Oettli, P. (2014). Assessing climate change impacts on sorghum and cowpea yields in West Africa. *Agricultural and forest meteorology*, 192-193, 59-71.
- Sultana, R., Rahman, M., & Haque, M. (2019). Sustainable transport adoption: Cost, convenience, and environmental factors. *Transport Research Part D* 77, 227-239.
- Sunjo, T. E., & Fuanyi, A. L. (2022). Problems of climate change–related hazards in African coastal communities. *Work. Pap., Univ. Buea, Cameroon*.
- Tang, Y., Zhong, S., Luo, L., Bian, X., Heilman, W. E., & Winkler, J. (2015). The potential impact of regional climate change on fire weather in the United States. *Annals of the Association of American Geographers*, 105(1), 1-21.



- Tarlo, S. M., Liss, G. M., & Blanc, P. D. (2016). Work-related asthma: Prevalence and association with workplace exposure. . *The Lancet Respiratory Medicine*, 4(5), (5), 445-454. .
- Tawatsupa, B., Kjellstrom, T., Noy, I., & Lemke, B. (2010). The effect of temperature and humidity on mortality in tropical cities of Australia. *Journal of Epidemiology and Community Health*, 64(3), 261-266.
- Tekin, M., Kaymak, D., & Akgun, M. (2018). Gender differences in asthma prevalence and symptoms. *Journal of Asthma*, 55(10), 1032-1038.
- Tekleab, S., Mohamed, Y., & Uhlenbrook, S. (2013). Hydro-climatic trends in the Abay/upper Blue Nile basin, Ethiopia. *Physics and Chemistry of the Earth, Parts A/B/C*, 61, 32-42.
- Teye, J. K., & Nikoi, E. G. (2022). Climate-induced migration in West Africa. In *Migration in West Africa: IMISCOE Regional Reader* (pp. 79-105). Springer International Publishing Cham.
- Tiotiu, A. I., Novakova, P., & Novak, M. (2020). The impact of particulate matter and ozone exposure on asthma exacerbations: Insights from global studies. *European Respiratory Journal*, 55(4), 1902020.
- Tiwari, S., Soni, S., & Dubey, P. (2018). Effects of relative humidity and temperature on the dispersion of pollutants: A case study of sulfur dioxide in urban air. *Environmental Science and Pollution Research*, 25 (9), 8749-8757.
- Tomasi, C., & Lupi, A. (2017). Primary and secondary sources of atmospheric aerosol. *Atmospheric Aerosols: Life Cycles and Effects on Air Quality and Climate*, 1-86.



Tuanmu, M.-N., Viña, A., Winkler, J. A., Li, Y., Xu, W., Ouyang, Z., & Liu, J. (2013). Climate-change impacts on understory bamboo species and giant pandas in China's Qinling Mountains. *Nature Climate Change*, 3(3), 249-253.

UCAR. (2024a). *Climate Variability*. Retrieved June 6 from scied.ucar.edu/learning-zone/how-climate-works/climate-variability#:~:text=Climate%20variability%20is%20the%20way,volcanic%20eruptions%2C%20and%20other%20factors.

UCAR. (2024b). *How Weather Affects Air Quality*. Retrieved June 8 from <https://scied.ucar.edu/learning-zone/air-quality/how-weather-affects-air-quality#:~:text=Heat%20waves%20often%20lead%20to,that%20soils%20are%20very%20dry>.

Uphoff, E. P., Pickett, K. E., Cabieses, B., Small, N., & Wright, J. (2013). Understanding social relationships in health research: A study of social networks and health. *Social Science & Medicine*, 97, 147-155.

Valavanidis, A. World Bank Report: Extreme Poverty is Rising Again.

Valavanidis, A., Fiotakis, K., & Vlachogianni, T. (2008). Airborne particulate matter and human health: toxicological assessment and importance of size and composition of particles for oxidative damage and carcinogenic mechanisms. *Journal of Environmental Science and Health, Part C*, 26(4), 339-362.

Vert, C., Gascon, M., Ranzani, O., Serra, E., & Sunyer, J. (2017). Air pollution and mental health: Evidence from Europe and beyond. *Current Environmental Health Reports*, 4(3), 285-294.

Vione, D., & Scozzaro, A. (2019). Photochemistry of surface fresh waters in the framework of climate change. *Environmental science & technology*, 53(14), 7945-7963.



- Wagstaff, A., Bustreo, F., & Bryce, J. (2015). Universal health coverage: A study of health systems and policy research. *Health Policy and Planning*, 30(8), 1037-1045.
- Walther, O. J. (2021). Urbanisation and demography in North and West Africa, 1950-2020.
- Wang, H., Zhang, M., Zhu, H., Dang, X., Yang, Z., & Yin, L. (2012). Hydro-climatic trends in the last 50 years in the lower reach of the Shiyang River Basin, NW China. *Catena*, 95, 33-41.
- Wang, L., Zhao, T., & Yang, X. (2017). Seasonal and spatial patterns of air pollution in dry regions. *Atmospheric Chemistry and Physics*, 17 (10), 6963-6976.
- Wang, Y., Chen, R., & Ma, W. (2020). Dioxins and furans from open waste burning: Environmental and health impacts. *Science of the total environment*, 741.
- Ward, M. N., Atiah, W. A., Odoulami, R. C., Okorie, E. I., Nikulin, G., & Diop-Kane, E. (2018). Rainfall variability and change in the Sahel region of West Africa. *Journal of hydrology*, 559, 816-829.
- Wasi, M., & Begum, T. (2024). Long-term nitrogen dioxide exposure and its impact on chronic bronchitis and respiratory infections. . *Air Quality, Atmosphere & Health*, 17(1), 65–78.
- Whitehead, L., & Baillie, C. . (2016). The experience of fatigue among chronic illness patients. *Journal of Advanced Nursing*, 72 (3), 564-576. .
- Willis, K. J., & Bhagwat, S. A. (2009). Biodiversity and climate change. *Science*, 326(5954), 806-807.



Wiru, K., Oppong, F. B., Agyei, O., Zandoh, C., Netey, O. E., Adda, R., Gasparini, A., & Asante, K. P. (2020). The Influence of Apparent Temperature on Mortality in the Kintampo Health and Demographic Surveillance Area in the Middle Belt of Ghana: A Retrospective Time-Series Analysis. *Journal of environmental and public health*, 2020(1), 5980313.

Wolkoff, P. (2018). Indoor air pollutants in relation to lung cancer development: A review of the literature. . *International Journal of Environmental Research and Public Health*, 15(9), 1858.

Wong, L., & Zhou, Q. (2015). Challenges and opportunities in using local materials for sustainable building construction. *Journal of Building Engineering*, 8, 209-216.

Wood, C. M., Farrell, A. P., & Brauner, C. J. (2012). *Homeostasis and toxicology of essential metals* (Vol. 1). Academic press.

World Bank. (2010). Economics of Adaptation to Climate Change. Ghana Country Study. In: World Bank Washington, DC, USA.

World Health Organization. (2006). *Air quality guidelines: global update 2005: particulate matter, ozone, nitrogen dioxide, and sulfur dioxide*. World Health Organization,.

World Health Organization. (2018a). *Air pollution and child health: Prescribing clean air*.

World Health Organization. (2018b). *Ambient (outdoor) air pollution*. Retrieved Nov 7 from [https://www.who.int/news-room/fact-sheets/detail/ambient-\(outdoor\)-air-quality-and-health](https://www.who.int/news-room/fact-sheets/detail/ambient-(outdoor)-air-quality-and-health)

World Health Organization. (2018c). *WHO global air quality guidelines: Particulate matter (PM_{2.5} and PM₁₀) and ground-level ozone*.



- World Health Organization. (2021). Review of evidence on health aspects of air pollution: REVIHAAP project: technical report. In *Review of evidence on health aspects of air pollution: REVIHAAP project: technical report*.
- World Health Organization. (2022). *Global health observatory data: Air pollution and health*.
- Wu, R., & Xie, S. (2017). Spatial distribution of ozone formation in China derived from emissions of speciated volatile organic compounds. *Environmental science & technology*, 51(5), 2574-2583.
- Wu, Y., Ge, X., Wang, J., Shen, Y., Ye, Z., Ge, S., Wu, Y., Yu, H., & Chen, M. (2018). Responses of secondary aerosols to relative humidity and photochemical activities in an industrialized environment during late winter. *Atmospheric Environment*, 193, 66-78.
- Xu, J., Chen, Y., Li, W., Liu, Z., Tang, J., & Wei, C. (2016). Understanding temporal and spatial complexity of precipitation distribution in Xinjiang, China. *Theoretical and Applied Climatology*, 123, 321-333.
- Xu, M., Guo, Y., Zhang, Y., Westerdahl, D., Mo, Y., Liang, F., & Pan, X. (2014). Spatiotemporal analysis of particulate air pollution and ischemic heart disease mortality in Beijing, China. *Environmental health*, 13, 1-12.
- Xu, X., Wang, G., Ding, F., & Chen, G. (2019). Age-specific associations between air pollution and respiratory diseases. *Environmental Health Perspectives*, 127(12).
- Yang, D., Zhang, S., Niu, T., Wang, Y., Xu, H., Zhang, K. M., & Wu, Y. (2019). High-resolution mapping of vehicle emissions of atmospheric pollutants based on large-scale, real-world traffic datasets. *Atmospheric Chemistry and Physics*, 19(13), 8831-8843.



- Yang, X., Zhao, C., Zhou, L., Wang, Y., & Liu, X. (2016). Distinct impact of different types of aerosols on surface solar radiation in China. *Journal of Geophysical Research: Atmospheres*, 121(11), 6459-6471.
- Yuan, B., Shao, M., Lu, S., & Wang, B. (2010). Source profiles of volatile organic compounds associated with solvent use in Beijing, China. *Atmospheric Environment*, 44(15), 1919-1926.
- Zafeiratou, E., Katsouyanni, K., & Dimakopoulou, K. (2021). Mortality risk related to heatwave and air pollution interactions in Mediterranean regions *International journal of environmental research and public health*, 18(1), 543.
- Zalakeviciute, R., Vasquez, R., Bayas, D., Buenano, A., Mejia, D., Zegarra, R., Diaz, V., & Lamb, B. (2020). Drastic improvements in air quality in Ecuador during the COVID-19 outbreak. *Aerosol and Air Quality Research*, 20(8), 1783-1792.
- Zhang, J., Wei, Y., & Fang, Z. (2019). Ozone pollution: a major health hazard worldwide. *Frontiers in immunology*, 10, 2518.
- Zhang, L., Wang, F., & Chen, J. (2017). Emissions from waste burning: Implications for urban air quality. *Journal of Air and Waste Management*, 67(9), 1032-1045.
- Zhang, Q., Liu, C., Xu, C.-y., Xu, Y., & Jiang, T. (2006). Observed trends of annual maximum water level and streamflow during past 130 years in the Yangtze River basin, China. *Journal of hydrology*, 324(1-4), 255-265.
- Zhang, R., Wang, G., Guo, S., Zamora, M. L., Ying, Q., Lin, Y., Wang, W., Hu, M., & Wang, Y. (2015). Formation of urban fine particulate matter. *Chemical reviews*, 115(10), 3803-3855.

Zhang, S., & Routledge, M. N. (2020). The contribution of PM2. 5 to cardiovascular disease in China. *Environmental Science and Pollution Research*, 27(30), 37502-37513.

Zhang, Y., Li, Y., & Chen, C. (2020). PM2.5 and humidity levels: A study of asthma hospitalizations in urban areas. *Environmental Research Letters*, 15(10), 104097.

Zhang, Z., Zhang, X., Gong, D., Quan, W., Zhao, X., Ma, Z., & Kim, S.-J. (2015). Evolution of surface O3 and PM2. 5 concentrations and their relationships with meteorological conditions over the last decade in Beijing. *Atmospheric Environment*, 108, 67-75.

Zhao, Y., & Hu, D. (2017). Air quality monitoring and public perception: A review of emergency response strategies. *Environmental science & technology*, 51(8), 4410-4420.

