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Prediction of climate-sensitive respiratory diseases in West Africa using climate information: case of asthma in northern (Savanes region) and southern part (Grand-Lomé region) of Togo

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Dedication

To my family, for their unwavering love and constant support!!!

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ACRONYMS AND ABBREVIATIONS

ADA	Americans with Disabilities Act
AI	Air Index
ANAMET	National Meteorological Agency
ANGE	National Agency for the Environment
BMBF	German Federal Ministry of Education and Research
CBRS	Health Research Ethics Committee
CHU	University Hospital Center
CO	Carbon Monoxide
COPD	Chronic Obstructive Pulmonary Disease
DGMN	General Directorate of National Meteorology
DHIS-2	District Health Information System, version 2
DHS	Demographic and Health Survey
GAVI	Global Vaccine Alliance
GINA	Global Initiative for Asthma
GIZ	Deutsche Gesellschaft für Internationale Zusammenarbeit
INHMR	National Institute of Health and Medical Research
INHMR	National Institute of Health and Medical Research
INSEED	National Institute of Statistics, Economic and Demographic Studies
IPCC	Intergovernmental Panel on Climate Change
ITRA	Institut de Recherche Agronomique du Togo
Kfw	Kreditanstalt für Wiederaufbau
METOP	Meteorological Operational Satellite Program
MSE	Mean Squared Error
NCA4	Fourth National Climate Assessment
NDVI	Normalized Difference Vegetation Index
NHDP	National Health Development Plan

NO2	Nitrogen Dioxide
O3	Ozone
OECD	Organization for Economic Co-operation and Development
OLS	Ordinary Least Squares
PCA	Principal Component Analysis
PNDS	National Health Development Plan
PRM	Polynomial Regression Model
R^2	Coefficient of Determination
RFM	Random Forest Model
RH	Relative Humidity
RMSE	Root Mean Squared Error
SDG	Sustainable Development Goal
SNIS	National Health Information System
SO2	Sulphur Dioxide
UL	University of Lomé
UNDP	United Nations Development Programme
UNFCCC	United Nations Framework Convention on Climate Change

CHAPTER 1: INTRODUCTION

1.1. Background of study

Climate change has a significant impact on various factors related to public health, including the availability of clean drinking water, air quality, secure housing, and food supply. According to the 2020 World Health Statistics Report from the World Health Organization (WHO), it is anticipated to result in approximately 250,000 additional annual fatalities between 2030 and 2050. The primary causes of these additional deaths are expected to be heat stress, malaria, malnutrition, and diarrhea. The consequences of climate change encompass both direct effects, such as extreme weather events, droughts, floods, landslides, and rising sea levels, particularly affecting densely populated megacities and coastal slums. Additionally, there are indirect effects, including poor water quality and malnutrition due to crop failures, which can lead to an increase in communicable diseases like diarrheal diseases and dengue fever, as well as mental disorders and non-communicable diseases like cardiovascular and respiratory illnesses (WHO, 2018).

Recent years have seen a notable increase in obstructive respiratory diseases, with asthma being a prominent example. This can be attributed, in part, to environmental changes characterized by the rising presence of chemical triggers such as particulate matter and gaseous components like nitrogen dioxide and ozone, as well as biological triggers like aeroallergens in the atmosphere. Aeroallergens can sensitize the airways in individuals with allergies, leading to symptoms of bronchial asthma (WHO, 2020).

Asthma, a condition characterized by reversible airway obstruction and bronchospasm that affects the lungs, results from a combination of genetic and environmental factors. It manifests common symptoms like wheezing, coughing, and shortness of breath and primarily affects genetically predisposed individuals exposed to environmental risk factors. The onset of asthma is influenced by genetic predisposition and environmental factors, including climate conditions, air pollution, allergens, and airborne chemical irritants (Kristeen, 2021). With global impact, asthma affects approximately 300 million people and leads to 250,000 deaths annually, as reported by Global Initiative for Asthma (GINA) in 2011. In 2019, an estimated 262 million individuals suffered from asthma, with 455,000 related deaths. Projections from the Global Initiative for Asthma (GINA, 2016) suggest that the number of asthma patients may reach 400 million by 2025, with an annual death toll of 250,000 people worldwide. The prevalence of asthma has been steadily increasing on a global scale in recent decades, posing a significant public health challenge, especially in the context of a growing world population and the challenges posed by adverse climate changes (Kassebaum et al., 2016).

Respiratory diseases, including asthma, rank as the second leading cause of death in Togo National Health Development Plan (NHDP, 2023). The Grand-Lomé and Savanes regions, like other parts of the world, are also susceptible to the effects of climate change, significantly contributing to increased respiratory illness and mortality among asthma patients. This results in elevated rates of asthma attacks, hospitalization, and mortality, all of which negatively impact the well-being of communities, productivity, and the economies of countries.

While there is currently no cure for asthma, it can be effectively controlled and managed, reducing the risk of asthma attacks and related fatalities. Although genetics play a crucial role in the development of asthma, the observed increase over the past few decades cannot be solely attributed to genetic factors Americans with Disabilities Act (ADA, 2016). Identifying the risk factors for asthma is essential in implementing effective strategies for its management.

Considering these circumstances, it is imperative to identify the climatic and environmental factors that trigger asthma and its adverse effects, and to gain insights into how these factors may evolve in the future within the study areas. This study aims to contribute to a deeper understanding of the relationship between climate and asthma in two distinct regions of Togo.

1.2. Statement of research problem

A clean environment is essential for human health and well-being. According to the Articles 34 and 41 of the Constitution of the Republic of Togo, the State recognizes citizens's right to health and everyone has the right to a healthy environment, and he works to promote it (Constitution of Republic of Togo, 1992). To this constitution, people must have access to a healthy environment at any time and every place they are to keep their health safe and especially for those who are suffering from respiratory disease like Asthma with environment like triggering and exacerbating factors. In addition, avoiding environmental allergens and irritants is one of the primary goals of good asthma management. Despite its decisive role for living beings, the environment in Savanes region like everywhere in the world, is prone by climate change effect and pollution. These changes in climate and air quality substantially increase respiratory morbidity and mortality for patients with common chronic lung diseases such as asthma. This increases asthma high crisis, hospitalization and mortality rates affecting human resource development, productivity and economy. It also tends to haunt a patient for the rest of their life. Therefore, Asthma remains a greater problem with the continuous increment of population and climate change adversely. This issue is escalating at an alarming rate as households in Savanes region increase rapidly leading to a high demand of living place, transportation, generation of waste which are not managed effectively coupled with increasing of greenhouse emission gases, poverty, poor implementation of environmental sanitation policies, weak enforcement of environmental laws and adaptation plans, and insufficient education on climate change impact on health.

Wheezing, coughing, and shortness of breath are common asthma symptoms caused by a combination of genetic and environmental conditions (Boinet and Leroy, 2021). In other words, asthma is caused by genetically susceptible individuals being exposed to environmental risk factors. The occurrence of asthma is influenced by genetic predisposition, environmental influences such as climatic parameters, air pollution, allergens, and airborne chemical irritants.

While genetics play a significant role in asthma growth, the increase observed in the last two decades cannot be explained merely by genetic changes. Therefore, understanding the asthma risk factors is crucial to avoiding or reducing the severity of the symptoms of the disease.

This call for the identification of climatological and environmental factors of Asthma triggering in these increasing adverse effects of climate variability and its probable evolution in the future on asthma in Togo.

1.3. Research questions

This thesis project focuses on the main research question: How do climatic factors influence the incidence and severity of asthma, and what strategies can be implemented to enhance asthma monitoring and health management in response to climate variability?

Specific questions:

How do climate and environmental factors affect asthma dynamics in these regions?

How do health practitioners and asthmatics perceive the influence of climate and environmental factors on their asthma symptoms and crises?

How can climate and weather data be used to generate a predictive model to forecast future asthma trends?

1.4. Objectives of the study

This study aims to contribute to a better understanding of the link between climate and environmental variability and asthma to improve its monitoring as well as its health management in Togo.

The specific objectives pursued by this study are:

- to identify asthma dynamics in the Savanes and Grand-Lomé regions. This involves studying variables such as asthma, temperature variations, humidity levels, rainfall patterns, and their seasonal and interannual variability.
- to assess the perceptions of individuals affected by asthma and health practitioners regarding climate and environmental triggers that exacerbate asthma crises in the study areas. This objective seeks to capture qualitative insights into how climate-related factors such as air quality, pollen levels, and weather changes are perceived to impact asthma episodes.
- to generate prediction models of asthma cases according to climatic and environmental parameters of the study area. These models aim to support early warning systems, improve asthma management strategies, and inform public health interventions.

1.5. Significance of the study

In terms of Sustainable Development Goal (SDG), this study falls under target 3.9: combatting diseases and controlling social and environmental determinants, which targets Sustainable Development Goal (SDG) 13.3: Improving education, awareness, and individual and institutional capacities regarding climate change adaptation, mitigation, and impact reduction, and early warning systems. Additionally, it falls under axis 4 of Togo's new National Health Development Plan (NHDP, 2023-2027): Responses to epidemics and other public health emergencies, which targets SDG 3.d: Strengthening the capacity for early warning, risk reduction, and management of national and global health risks. Therefore, the significance of this study in the Savanes and Grand-Lomé regions of Togo is multifaceted:

- **Public health impact**: By elucidating the intricate linkages between climate variables and asthma dynamics, the research contributes to improving the monitoring and management of asthma in Togo. This knowledge can lead to more effective public health interventions and policies aimed at mitigating asthma exacerbations triggered by climate-related factors.
- **Climate adaptation strategies**: Understanding how climate variability affects respiratory health, particularly in vulnerable populations in the Savanes and Grand-Lomé regions, informs adaptive strategies. This includes better preparedness for climate-related health risks and integrating climate information into healthcare planning and decision-making processes.
- **Scientific contribution and future research directions:** By laying the groundwork for understanding climate-health interactions in West Africa, particularly in Togo, this study serves as a catalyst for future research endeavors. It encourages further exploration into the broader impacts of climate change on respiratory health and promotes interdisciplinary collaborations across climate science, public health, and environmental studies.
- **Community and stakeholder engagement**: The study engages with local communities, health practitioners, and policymakers to ensure that research findings are translated into actionable insights. It fosters dialogue, builds capacity for climate adaptation in healthcare settings, and empowers communities to address climate-related health challenges proactively.

In summary, this study aims to make a significant impact by enhancing the understanding and management of asthma as influenced by climate factors in the Savanes and Grand-Lomé regions of Togo. It underscores the importance of integrating climate science with public health strategies to promote resilience, improve health outcomes, and support sustainable development in a changing climate.

CHAPTER 2: LITERATURE REVIEW

This chapter specifies the theoretical framework of the study. It briefly describes previous work conducted in the context of bioclimatology. Initially, it will provide a brief overview of the definitions and terminologies related to bioclimatology and epidemiological modelling. Subsequently, it will present a general view on asthma and climate change. Finally, it will address the Climate-Health existential relationships and provide information on epidemiological modelling.

2.1. Definition of concepts

- **Bioclimatology**

Bioclimatology is the study of the effects of climate and microclimates on the development of all living organisms and ecosystems by extension (Sané De Parcevaux and Huber, 2007). Bioclimatologie: Concepts et applications. Éditions Eyrolles.). It is also referred to as human bioclimatology. The foundations of this science emerged during the development of Terjung's comfort indices in 1966.

Initially, bioclimatology focused on studying human behavior ("human bioclimatology") based on climatic conditions and their temporal variations. It was initially studied by physicians and later expanded to include other organisms. Hence, we also discuss Animal Bioclimatology (which studies the distribution of fauna across the Earth's surface, hibernation, sexual behavior, migration, etc.) And Plant Bioclimatology (which focuses on the relationship between plants and climate and provides information on the geographical distribution of plants).

- **Climate**

According to the World Meteorological Organization (WMO), climate refers to the statistical description of all meteorological conditions for a specific location over a period of several decades. It is based on average values and variations of parameters such as temperature, rainfall, sunshine duration, as well as information on winds and their direction, which identify dominant conditions.

- **Health**

In the WHO Constitution adopted in 1948, health is defined as a state of complete physical, mental, and social well-being, not merely the absence of disease or infirmity.

As health is considered a fundamental human right, the Ottawa Charter mentions certain prerequisites for health, including peace, sufficient economic resources, adequate food and housing, a stable ecosystem, and sustainable resource use. Considering these prerequisites highlight the inextricable links between social and economic conditions, the physical environment, individual lifestyles, and health. These links are key to a comprehensive understanding of health, which is an essential element of the definition of health promotion.

- **Public health**

Public health is a social and political concept. It aims to improve health, extend life expectancy, and enhance the quality of life for entire populations through health promotion, disease prevention, and other types of health interventions (WHO, 2018).

- **Ecological public health**

The concept of ecological public health has also emerged in literature. It aims to address the evolving health issues and their interaction with new global environmental problems. These include global ecological risks such as ozone layer depletion, uncontrolled air and water pollution, and global warming. These new developments have significant effects on health, often escaping simple models of causality and intervention.

- **Social determinants**

Health determinants are personal, social, economic, and environmental factors that determine the health status of individuals or populations. Factors influencing health are multiple and interrelated. Health promotion fundamentally involves action and awareness necessary to address all potentially modifiable health determinants, not only those related to individual actions such as health behaviors and lifestyles, but also factors such as income and social status, education, employment and working conditions, access to appropriate health services, and physical environments. Together, these elements create different living conditions that affect health. Achieving changes in these lifestyles and living conditions, which determine health status, is considered an intermediate health outcome (WHO, 2021).

- **Epidemiological model**

A model is by nature a simplification of more complex systems. In this sense, an epidemiological model is generally defined as a mathematical and/or logical representation of the epidemiology of disease transmission and related processes (Armstrong, 2006).

- **General Overview on asthma**

Asthma is a chronic lung condition that affects people of all ages. It is caused by inflammation and constriction of the muscles around the airways, making breathing difficult (Lancet, 2020). Asthma can be a serious condition; however, it can be managed with appropriate treatment. Individuals experiencing asthma symptoms should consult a healthcare professional.

- **Symptoms**

Asthma symptoms can vary from person to person and can sometimes worsen significantly, leading to an "asthma attack". Common asthma symptoms typically include:

  - Persistent coughing;
  - Wheezing during expiration and sometimes during inspiration;
  - Shortness of breath or difficulty breathing, sometimes even at rest;
  - Chest tightness, making deep breathing difficult.

- **Causes**

Several different factors are associated with an increased risk of asthma, but it is often difficult to pinpoint a direct and singular cause (Boinet and Leroy, 2021). The likelihood of having asthma is higher if other family members are affected by the disease, especially close family members such as a parent or sibling.

Asthma is more common in people with other allergic conditions such as eczema and hay fever. Urbanization is associated with an increased prevalence of asthma, likely due to several lifestyle-related factors. Early-life events affect developing lungs and may increase the risk of asthma. These events include low birth weight, prematurity, exposure to tobacco smoke and other sources of air pollution, as well as viral respiratory infections. Exposure to various allergens and environmental irritants also increases the risk of asthma, including exposure to indoor and outdoor air pollution, dust mites, molds, and exposure to chemicals, smoke, or dust in the workplace. Overweight or obese children and adults are more susceptible to asthma.

2.2. Climate change

The United Nations Framework Convention on Climate Change (UNFCCC) defines climate change as any change in climate that is directly or indirectly attributable to human activity altering the global atmospheric composition and adding to observed climate variability over comparable periods (UNFCCC, 1992). Thus, in the synthesis note of its Sixth Assessment Report (IPCC, 2022), the Intergovernmental Panel on Climate Change (IPCC) mentions that human activities have already caused global warming of about +1°C since the pre-industrial era. This warming has already brought about many changes in the functioning of the climate system, including an increase in extreme events (heatwaves, droughts, torrential rains, etc.). These trends are expected to intensify with the continued rise in global temperature. At the current rate of 0.2°C per decade, the +1.5°C threshold could be reached between 2030 and 2052. Furthermore, it argues that a world at +1.5°C is a world with more extreme climate events and significant impacts on ecosystems, societies, and economies. These include more frequent extreme heatwaves, especially in most tropical regions, increasingly intense rainfall, probable increases in cyclone intensity, increased droughts, and water stress in the driest regions (sub-Saharan Africa and South Asia).

2.3. Theoretical approach of bioclimatology

Bioclimatology, defined as a science dealing with the link between climate and all living organisms, is increasingly sought after by decision-makers, populations, and businesses due to the negative repercussions of climate change on health.

Infact, numerous studies have revealed that climate change affects ecosystems and promotes the emergence and re-emergence of many diseases. According to WHO (2016), climate disruption influences the social and environmental determinants of health such as air quality, safe drinking water, sufficient food, and housing security. WHO (2016) also states that heatwaves directly contribute to mortality through cardiovascular or respiratory diseases, particularly among the elderly. For example, during the summer heatwave of 2003 in Europe, more than 70,000 additional deaths were recorded. According to the IPCC (2021) report on climate change, the coming decades are expected to see intensified heatwaves, floods, droughts, and storm winds. These phenomena have serious consequences on the health of the population. Balbus and Malina (2009) propose the idea that population vulnerability (demographic structure, prevalence of pre-existing medical conditions, acquired factors such as immunity, and genetic factors) or vulnerability of an area is the sum of all risks and protective factors that ultimately determine whether a group or region experiences adverse health issues. Zweifel et al. (2004) estimate that if health were a good that could be produced, its production would be seen as an investment that compensates for the consumption of capital due to lifestyle and aging. They also argue that specifying health production functions determines how to allocate limited resources among other health inputs to produce the highest possible increase in health levels. This concept is also supported by Oliveria et al. (2003), who argued that a health production function demand shows how health inputs interact to produce a particular level of health and how health status changes if health inputs used and their combination change. Fayissa and Gutema (2005) estimated that health investment is achieved by providing curative medical services and their own efforts, especially preventive efforts. In the same logic, Ettner (1996) said that improving health investments results in greater labor productivity due to improved physical and mental condition and reduced number of productive days lost due to illness. Grossman (2000) considered in his health capital model that individuals respond both as consumers and producers of health. He assumed that health production occurs through a health production function where health is determined by the consumption of medical care and other goods where health inputs act as investments that influence the rate of depreciation of health stock. Similarly, the author believed that rational individuals maximize the utility of their health state by optimizing the management of their health stock over their lifetime.

2.3.1. Direct impacts of climate change on health

emperature is the most direct factor influencing the effects of climate change on health. The elationship between mortality and temperature is generally described as a U-shaped relationship, with high mortality at both low and high temperatures for most causes of death (Armstrong, 2006). These temperature effects on mortality differ from city to city, from population to population over a given period, thus demonstrating the phenomenon of adaptation of certain societies (Gasparrini et al., 2015). The threshold at which the risk of death increases, known as the thermal optimum (ranging between 15 and 25°C), varies among populations. For example, Southern European populations are more sensitive to the effects of cold than those in the north, and those in the north are more sensitive to heat. Studies focus on the risks that climate change poses to homeless populations, who are most exposed to high temperatures during extreme weather events and are also more vulnerable due to frequent chronic illnesses, social isolation, and lack of mobility. The effects of high temperatures on mortality among socially disadvantaged populations have been studied (Borrell et al., 2006).

The American study by Gasparrini and Armstrong (2011) shows that beyond the immediate effect of high temperature on mortality on the same day, an additional effect related to the duration of the heatwave could be detected after four consecutive days of heat. The slower decrease in temperatures in urban centers compared to surrounding areas after a heatwave or during the night explains the amplification of health effects observed in urban heat islands, which becomes concerning in a context where 68% of the global population will live in urban areas by 2050 (United Natif). It is also important to examine the impact of successive heatwaves since, with climate change, the hot season will start earlier and end later (Baldwin et al., 2019).

In addition to dehydration and hyperthermia, more direct biological effects also concern the cardiac, respiratory, endocrine, immune, and nervous systems. Adverse impacts of high temperatures on mental health have been identified (Tong et al., 2022), with the most consistent associations found for suicide rates in numerous studies across different continents (Burke et al., 2018). An effect of high temperatures on violent behaviors has also been documented, which may be partly linked to disruptions in sleep and the endocrine system (Anderson and De Lisi, 2011). While evolution has equipped organisms with heat reaction mechanisms, these have limited efficiency and generally fatigue the body. More chronically, current research highlights that an increase in temperature combined with ultraviolet radiation could additively or synergistically enhance the development of skin cancers rates (Fischer et al., 2013).

2.3.2. Indirect impacts of climate change on health

Indirect effects of climate change are generally related to the animal and plant worlds, the consequences of extreme climate change events, air pollutants, and rising sea levels. Thus, the expected health impact of climate change is linked to the modification of the geographical distribution of vector-borne diseases. Some diseases, such as malaria, have not reached consensus among researchers regarding the effect of climate change on the rate of transmission or its geographical spread (Hayes et al., 2012). However, for other diseases like Lyme disease, a bacterial disease transmitted by ticks whose habitat is expanding, the contribution of climate change is probable. This is also the case of Chikungunya virus (Fischer et al., 2013) and Zika virus (Ali et al., 2017) remain probable, for which climate change will extend the transmission area. On another note, ocean warming favors the proliferation of certain bacteria, thus altering the geographical distribution of cholera epidemics (Escobar et al., 2015).

The plant kingdom also remains a factor in the health impact of climate change. High temperatures and extreme climate events such as floods and droughts, on the other hand, cause a decrease in agricultural yields, leading to problems of malnutrition and stunting in children in heavily agricultural communities. An increase in carbon dioxide concentration in the atmosphere negatively affects the micronutrient composition of various cereals (Grattan et al., 2016) on one hand, and on the other hand, it enhances the proliferation of algae containing food toxins, with decomposition releasing toxic gases (Gobler, 2020). Furthermore, ocean acidification linked to anthropogenic carbon dioxide absorption threatens marine fauna and flora, affecting zooplankton that form the basis of large parts of the food chain, and risking destabilization of communities and countries heavily dependent on fishing (Doney, 2006). It is also noted that the tripling of pollen allergies over the past twenty years in France is due to early springs that lead to increased pollen quantities, while allergenic plants like ragweed see their distribution area expanding.

With the interaction between climate and pollutant dispersion and chemical reactions between atmospheric compounds, climate change will also impact the atmospheric concentration of certain pollutants influencing human health. Climate change increases ozone concentration in polluted regions, especially in urban areas, and besides their immediate health impact, increasingly common wildfires emit atmospheric pollutants and are likely to become a significant source of particle emissions and growth (Jacob and Winner, 2009). The heatwave in the summer of 2010 in Moscow exemplified a heatwave episode occurring in conjunction with a peak in suspended particle concentration generated by wildfires around the city.

Finally, rising sea levels will cause flooding and have negative consequences on megacities at sea level, hosting more than 10 million inhabitants, especially with current projections anticipating a sea level rise of 26 to 82 cm by the end of the present century (Cao et al., 2021). The World Bank asserts that this sea level rise, combined with reduced agricultural production and water shortages, will lead to significant climate migration, with hygiene problems and transmission of infectious diseases, potentially leading to conflicts (Anderson and Lisi, 2011).

2.4.Empirical approach of bioclimatology

Climate change constitutes a fundamental threat to human health. It affects the physical environment as well as all aspects of natural and human systems, including socio-economic conditions and the functioning of healthcare systems. It is therefore a "threat multiplier," potentially undermining decades of health efforts and progress (WHO, 2020). The Intergovernmental Panel on Climate Change's Sixth Assessment Report estimates that up to 3.6 billion people live in highly vulnerable conditions to the impacts of climate change. Low-income countries, lower-middle-income countries, and small island developing states face the most severe health consequences of climate change, despite contributing the least to historical global emissions (WHO, 2018). Multiple scientific assessments have highlighted the diverse and substantial effects of climate change on human health and well-being, and various data suggest that measures aimed at reducing climate change have beneficial effects on public health (Haines et al., 2017). These overall findings have led two separate Lancet commissions to conclude that climate change represents the greatest threat to global health, and the greatest global health opportunity of the 21st century (Costello et al., 2009). Ongoing research continues to attract researchers' attention to quantify the current and future effects of climate change on human health.

Consistent with previous research, survey participants largely understood that climate change is occurring and caused by humans, consider a significant and growing cause of health damage in their countries, and feel responsible for educating the public and policymakers about the consequences of these changes. Dhimal et al. (2021) assesses the impact of climate change on the health and well-being of populations in the Hindu Kush Himalayan region. The study's results show that climate change exacerbates infectious diseases, non-communicable diseases, malnutrition, and trauma. Therefore, urgent adaptation and mitigation measures for climate change are needed to protect vulnerable populations in the Dhimal et al. (2021) region. They also demonstrates that the expanded spatial distribution and increased incidence of Chikungunya and dengue over the past decades in the Hindu Kush Himalayan region are due to climate change. Similarly, the drastic increase in confirmed cases of Japanese encephalitis in the high plateaus of the Himalayas, which were previously only reported in the southern plains, has been a consequence of climate change (Burke et al., 2018). In China, the relationship between climate change and infectious diseases, showing a clear relationship between rising temperatures and malaria cases in the southwestern mountainous region of the country. Cardwell et al. (2013) conducted in-depth semi-structured interviews with 22 residents of the Golden Horseshoe region in southern Ontario, between August 2010 and January 2011, regarding individual and community health, climate change, as well as facilitators and barriers to behavior change, to assess the effect of climate change on community health. Few participants recognized the role of the environment in the context of individual and community health. However, when asked about health concerns specific to their community, environmental issues were frequently mentioned. The health effects as possible impacts of global environmental change were mentioned by 77% of participants when asked, but this link was not described in very detail or in the context of the impact on their communities or themselves. Brubaker et al. (2011) examine the relationships between climate impacts and health effects and provide examples of community-scale adaptation measures currently being implemented in northwest Alaska. The results show that climate change increases vulnerability to injuries, diseases, mental stress, food insecurity, and water insecurity. Northwest communities apply adaptation approaches that are both specific and appropriate. Simane et al. (2016) assess the current situation in Ethiopia regarding environmental, climate change, and health issues. The research was conducted through a comprehensive review of available secondary data and interviews with key informants from various national organizations involved in climate change adaptation and mitigation activities. The findings reveal that climate change-related health issues such as mortality and morbidity due to floods and heatwaves, vector-borne diseases, waterborne diseases, meningitis, and respiratory diseases linked to air pollution are increasing in Ethiopia. Sensitive systems such as agriculture, health, and water have been affected, and the effects of climate change are expected to escalate without appropriate adaptation and mitigation measures.

Curtis et al. (2017) studies the impacts on health and social protection systems in the UK from extreme weather events under conditions of climate change. Extreme weather events considered include heatwaves, cold spells, and floods. Using a structured review method, the authors examine evidence regarding the current observed and anticipated future impacts of extreme weather conditions on health and social protection systems, as well as the potential of preparedness and adaptation measures to enhance resilience. They highlight several general conclusions likely to have international relevance, despite the focus of the review being on the UK. Extreme weather events impact the operation of healthcare services due to their effects on built, social, and institutional infrastructures supporting health and healthcare, as well as changes in service demand due to the impact of extreme weather events on human health. Through a quantitative survey of 130 households in Ziguinchor city, sought to analyze the impacts of climate change. Among the findings were floods during the rainy season and an increase in temperature. These factors contribute to increased morbidity from malaria, acute respiratory infections, hypertension, and diarrheal diseases. Deng et al. (2020) sought to estimate the links between childhood diarrhea and climatic factors in rural and urban settings in the health district of Mbour, western Senegal. The data used included monthly records of diarrhea cases among children under five years old from 24 establishments, along with climatic data (daily temperature, nighttime temperature, and rainfall) spanning from 2011 to 2014. They employed a binomial regression method. Their findings indicate that the effects of high average temperatures of 36°C and above, and monthly cumulative rainfall of 57 mm and above, have stronger impacts on diarrhea in rural areas compared to urban areas.

Tran et al. (2023) study the impact of climate change on age-standardized mortality rates (ASMR) of chronic obstructive pulmonary disease (COPD) and asthma at the national level. They used Global Burden of Disease data on age-standardized mortality rates of COPD and asthma between 2000 and 2018. Climate change index was represented by the percentage deviation of temperature and relative humidity, calculated based on 19-year averages of temperature and humidity. Annual temperatures, relative humidity, and levels of fine particulate matter in 185 countries/regions were obtained from ERA5 and OECD Environmental Statistics Database. Generalized linear mixed-effects models were used to examine associations between climate change and the logarithm of ASMR for COPD and asthma. After adjusting for annual PM2.5 levels, smoking prevalence, and a 0.26% increase in temperature deviation percentage, decreases of 0.016, 0.017, and 0.014 per 100,000 population in ASMR for COPD, and 0.042, 0.046, and 0.040 per 100,000 population in ASMR for asthma were associated for both sexes. A 2.68% increase in relative humidity deviation percentage was associated with increases of 0.009 and 0.011 per 100,000 population in ASMR for COPD. Finally, a negative association between temperature deviation percentage and ASMR for COPD was observed among men and women.

2.5. Modelling climatic and environmental determinants of asthma

Asthma is a chronic inflammatory disorder of the airways affecting people of all ages worldwide. Chronic inflammation is associated with airway hyperresponsiveness leading to recurrent episodes of wheezing, breathlessness, chest tightness, and coughing, particularly at night or early in the morning. The condition is prevalent across all age groups (GINA Global Initiative for Asthma, 2016) and affects approximately 300 million people globally, causing 250,000 deaths annually (GINA, 2016). Environmental factors such as allergens, air pollution, or climate change, as well as infectious factors like viruses and bacteria (GINA, 2016), can exacerbate the disease. When uncontrolled, asthma can severely limit daily life and occasionally be fatal. Chronic respiratory diseases (CRDs), primarily asthma and chronic obstructive pulmonary disease (COPD), are influenced by a broad range of environmental, climatic, and socioeconomic factors (Andersen et al., 2023). Epidemiological studies have convincingly explained the association between CRD morbidity and various individual-level risk factors such as particulate matter, temperature, and poverty. Indeed, Kumarihami and Tripathi (2019) examine spatial associations between asthma/COPD morbidity and their determinants using Ordinary Least Squares (OLS) and Geographically Weighted Regression (GWR). Patient records from secondary and tertiary care hospitals in Kandy from 2010 to 2014 were considered as the dependent variable. Potential risk factors (explanatory variables) were identified across four distinct classes: 1) meteorological factors, 2) direct and indirect factors of air pollution, 3) socio-economic factors, and 4) physical environmental characteristics. All possible combinations of candidate explanatory variables were assessed through exploratory regression. A comparison between regression models was also explored. The best OLS regression models revealed approximately 55% variation in asthma and 62% variation in COPD, while GWR models yielded 78% and 74% respectively in variations of asthma and COPD occurrences. Relative humidity, proximity to roads (0 to 200 m), road density, use of wood fuel as a combustion source, and altitude play essential roles in predicting asthma and COPD morbidity. Local and global regression models are important for evaluating spatial relationships between asthma and COPD. However, local models exhibit better predictive capability for assessing non-stationary relationships between asthma and COPD than global models. On the other hand, assess the relationship between hospital admissions for asthma and several environmental variables across mainland Portugal using spatial data from remote sensing and spatial modelling. A set of five environmental variables were considered: near-surface air temperature (Ta) from the temperature profile of the Moderate Resolution Imaging Spectroradiometer (MODIS); relative humidity (RH) from interpolated meteorological station data by kriging; vegetation density from the Normalized Difference Vegetation Index (NDVI) MODIS; and spatio-temporal estimates of nitrogen dioxide (NO2) and particulate matter less than 10 µm (PM10), both from Land Use Regression (LUR) models based on air quality station data. Districts were grouped into three categories based on their urban coverage percentage, and the municipality was chosen as the sampling unit to evaluate the relationship between hospital admission rates for asthma and environmental variables by season for the years 2003-2008. In the most urbanized group, Ta, NDVI, and NO2 had consistent relationships with asthma across all seasons (Pearson correlation coefficients ranging from 0.351 to 0.600, -0.376 to -0.498, and 0.405 to 0.513, respectively). Associations in other groups were very weak or non-existent. Urban coverage percentage influences the relationship between environment and asthma. Results suggest that asthmatic individuals living in highly urbanized areas with sparse vegetation are at greater risk of suffering from severe asthma attacks leading to hospitalization. Hu et al., (2022) examine the risk factors associated with asthma at the age of 7 in a high-risk cohort participating in a randomized controlled trial on primary prevention of asthma. Indoor exposures were characterized before birth and at 2 weeks, 4, 8, 12, 18, and 24 months after birth and again at 7 years. Nasal scrapings for respiratory viruses were performed at the same intervals during the first 2 years. At age 7, children were evaluated by a pediatric allergist and underwent allergy skin testing. A logistic regression analysis was conducted to assess the effect of exposures on asthma for the entire cohort with adjustment for group allocation. In addition to the lower asthma risk in the intervention group, a higher prevalence of asthma at age 7 was found in males, those with positive asthma history in mother, father, or older siblings, and children residing in Winnipeg. After adjustment for group assignment and baseline factors, significant environmental risk factors during the first year included dog ownership and respiratory syncytial virus infection detected at 12 months, while maternal smoking was protective. Owning a dog was a significant risk factor during the second year but strongly correlated with dog ownership in the first year. Indoor environmental exposures at age seven were not associated with asthma at age 7. Maternal smoking at age seven was associated with reduced risk of asthma at age 7. Early life exposures were more significant determinants than those in later years. There is a "window of opportunity" for implementing intervention measures.

Breiman (2001), through their study, examine the relationship between the prevalence of asthma symptoms among adolescents living in urban centres in Latin America and socio-economic and environmental determinants measured at the ecological level. Prevalence of asthma symptoms was obtained from Phase III of the International Study of Asthma and Allergies in Childhood (ISAAC). A hierarchical conceptual framework was defined, and explanatory variables were organized into three levels: distal, intermediate, and proximal. Weighted linear regression models were conducted between asthma prevalence and selected variables. Asthma prevalence was positively associated with the Gini index, water supply, and homicide rate, and inversely associated with the Human Development Index, overcrowding, and adequate sanitation. This study provides evidence of the potential influence of poverty and social inequalities on current wheezing among adolescents in a complex social context such as Latin America.

Denguezli et al., (2020) aim to identify socio-economic, environmental, psychosocial, familial, and lifestyle factors associated with self-reported asthma symptoms among Brazilian adolescents. This was a cross-sectional study using data from the 2012 National School-Based Health Survey (pense) on a sample of 109,104 adolescents. They analyzed variables including socio-economic conditions, demographic characteristics, lifestyle, family context and dynamics, psychosocial indicators, smoking, and exposure to violence. The outcome variable was self-reported asthma symptoms in the last 12 months. The prevalence of wheezing was 22.7% (21.5–23.9). After adjustment for sex, age, and higher-level hierarchical variables, exposure to violence (feeling unsafe at school, frequently being bullied, being involved in fights with firearms) and physical aggression from an adult family member showed the strongest associations with self-reported asthma symptoms. For psychosocial indicators of mental health and social integration, feelings of loneliness and sleep problems were most significant, and among individual behavioral factors, the strongest associations were found for tobacco consumption. The authors' findings were consistent with previous studies, showing an association between self-reported asthma symptoms and socio-economic status, family context and dynamics, psychosocial indicators of mental health, exposure to violence and social integration, as well as sedentary lifestyle and smoking. Cole & Jacobs, (2021) delve into examining the association between asthma and ultraviolet radiation by adding variables of temperature, relative humidity, and rainfall. An ecological study was designed to investigate meteorological factors associated with asthma prevalence in England.

Data from the 2005 Quality Outcomes Framework were used to determine asthma prevalence in primary care in England. This information was complemented by obesity and smoking indicators from general practice and population (by age and sex), deprivation, and ethnic origin at the Lower Super Output Area level from the 2001 and 2011 censuses. They employed multiple linear regression to examine individual and multiple climate factors using principal component analysis and tested association with asthma prevalence, accounting for spatial autocorrelation of data.

The prevalence of asthma in general practice surgeries in England was 5.88% (95% CI: 5.83 to 5.92). In the highest quartile of ultraviolet radiation weighted by pre-vitamin D action spectrum (2.12 to 2.50 kj/m2/day), asthma prevalence was reduced by 5% compared to the lowest quartile here (0.95 (95% CI: 0.92 to 0.98)). Similar reductions were observed at the highest temperature (0.93 (95% CI: 0.90 to 0.96)). Conversely, higher relative humidity was associated with increased asthma prevalence (1.09 (95% CI: 1.05 to 1.12)). A combination of high temperatures and UV highlighted postal districts in southeast England with a climate conducive to lower asthma prevalence. Southwest England exhibited a climate showing both beneficial and adverse associations with asthma development. Climate is associated with asthma prevalence in England.

Kanannejad et al., (2023) study the effects of climatic and geographical variability on asthma hospitalizations among an adult population living in the Fars province, southwest Iran, during the period 2016 to 2019. Effects of geographical factors including temperature, rainfall, humidity, evaporation, number of rainy and frost days, slope of land cover, were evaluated on hospitalization of asthmatic adults using a geographic information system. Data were analyzed using binary and multivariate logistic regression. A total of 349 patients were recruited, including 157 men and 192 women. The age of the sample ranged from 19 to 98 years. Asthmatic patients came from a total of points including villages, towns, and cities. Through univariate analysis, urban environment and average annual rainy days were identified as factors associated with increased asthma hospitalizations, while average annual temperature, evaporation, and slope had a negative effect on asthma hospitalizations. The urban environment was considered the only significant factor in multivariate analysis. The main areas at risk for acute asthma in adulthood in southwest Iran were urban areas and areas with higher rainy days, lower temperatures, and evaporation on lower slopes. Climate change is a reality that, according to recent projections, will worsen in the coming years. Climate change poses a massive threat to respiratory health, directly promoting or exacerbating respiratory diseases, increasing exposure to respiratory disease risk factors. Climate change increases the amount of pollen and allergens produced by each plant, the proliferation of molds and concentrations of outdoor ozone and ground-level particles. The main worrying diseases are asthma, rhinosinusitis, chronic obstructive pulmonary disease (COPD) and respiratory tract infections. The most exposed groups to the effects of climate change include individuals with pre-existing cardiopulmonary diseases or disadvantaged individuals (D'amato et al., 2016).

Changes in meteorological parameters significantly increase respiratory morbidity and mortality in adults with common chronic lung diseases, such as asthma, and other serious lung diseases (WHO, 2018). Some of the deaths observed are since, due to an extreme event, people with a lung disease died a few weeks earlier than expected (what is called the "harvesting effect"). Respiratory diseases also increase in children during heatwaves (Xu et al., 2014). Cyclones have also been linked to asthma. Cold weather, by increasing exposure to cold, will increase overall respiratory infections in underlying persons. The Aphekom project (www.aphekom.org), considering individual addresses, calculated the number of cases of child asthma caused by living near a road with high traffic-related pollution and episodes of acute asthma related to urban air pollution in 10 European cities. Exposure to high traffic-related roads, an indicator of traffic-related pollution, accounted for 14% of all asthma cases in the study. Assuming a causal relationship between traffic-related pollution and asthma, 15% of all asthma symptom episodes were attributable to air pollution. However, without this assumption, only 2% of asthma symptoms would be attributable to air pollution. There is evidence that, during the pollen season, thunderstorms can be associated with allergic asthma exacerbations in patients with pollen allergies (Connolly et al., 2021). During the first phase of a thunderstorm, patients with pollen allergy can inhale a high concentration of allergen material, such as biological antigenic aerosols dispersed in the atmosphere, which can cause asthmatic reactions (severe) in some cases (Jacquemin, 2009). Thunderstorms can trigger severe asthma attacks and, under certain circumstances, are a frequent cause of asthma exacerbation epidemics requiring emergency department visits (Katsouyanni et al., 2001). A study conducted in New South Wales, Australia, found that storm exits were detected in 33% of epidemics, compared to 3% of non-epidemic days (Chen et al., 2018). Moreover, 48% of epidemic days in late spring and summer were associated with storm exits (development of a system).

Conclusion

The world is increasingly vulnerable to the impacts of climate change in terms of food security and health. This is particularly true due to inherent issues in geography, population pressure, and limited infrastructure. As climate change impacts intensify, issues related to food security and health will also escalate unless effective adaptation programs are implemented. To date, interventions appear to have had limited success while continuing to be a topic of significant concern among researchers and policymakers.

Given the rapidly accumulating evidence of the numerous significant health risks posed by climate change, our review clearly highlights the relative lack of research on the subject in developing countries in general and specifically in Togo. Furthermore, while the healthcare sector in Africa is also vulnerable and affected by climate change, disease modeling appears to be underdeveloped, rendering early warning systems for climate-sensitive diseases, especially respiratory diseases, either nonexistent or ineffective.

Considering these findings, this study, which aims to forecast climate-sensitive respiratory diseases in West Africa using climate information and models, focusing on asthma in northern and southern Togo, aims to be a contribution to decision-making tools. Specifically, this study will: (i) Identify the profile and variability of typical climate and meteorological environment associated with asthma dynamics in both regions; (ii) Assess the perceptions of asthma patients and healthcare professionals regarding climate and environmental triggers of asthma attacks; and (iii) Generate prediction models for asthma cases based on climate and environmental parameters.

This conclusion summarizes the discussion on the vulnerability of food security and health to climate change and emphasizes the need for more research and effective adaptation strategies, particularly in developing countries like Togo. The study aims to fill gaps in climate-sensitive disease modeling, focusing on asthma, to aid decision-making and improve early warning systems.

CHAPTER 3: METHODOLOGY

Our study, focused on the Savanes region in the northern Togo and Grand-Lomé region in the southern Togo, was based on a literature review, remote and in-situ environmental and climatical data analysis and a field survey.

3.1. Study area

3.1.1. Presentation of the Grand-Lomé region

Located in the extreme southwest of the country along the Gulf of Guinea coastline, the Grand-Lomé region is home to the capital city (Figure 1). With an estimated population in 2022 of 2,188,376 inhabitants (INSEED, 2023), Grand-Lomé experiences a Guinean climate characterized by two rainy seasons. The main rainy season starts in april and ends around july, followed by a second, less pronounced season from september to late november. The average maximum temperature under shelter reaches about 30 °C in the afternoon, while the average minimum temperature is around 23 °C in the morning. During december to february-march, the Harmattan wind occasionally blows from the Sahara, bringing dry conditions that can lower the morning temperature to 19 °C (Afidegnon, 2003). The region receives an annual rainfall of approximately 900 mm.

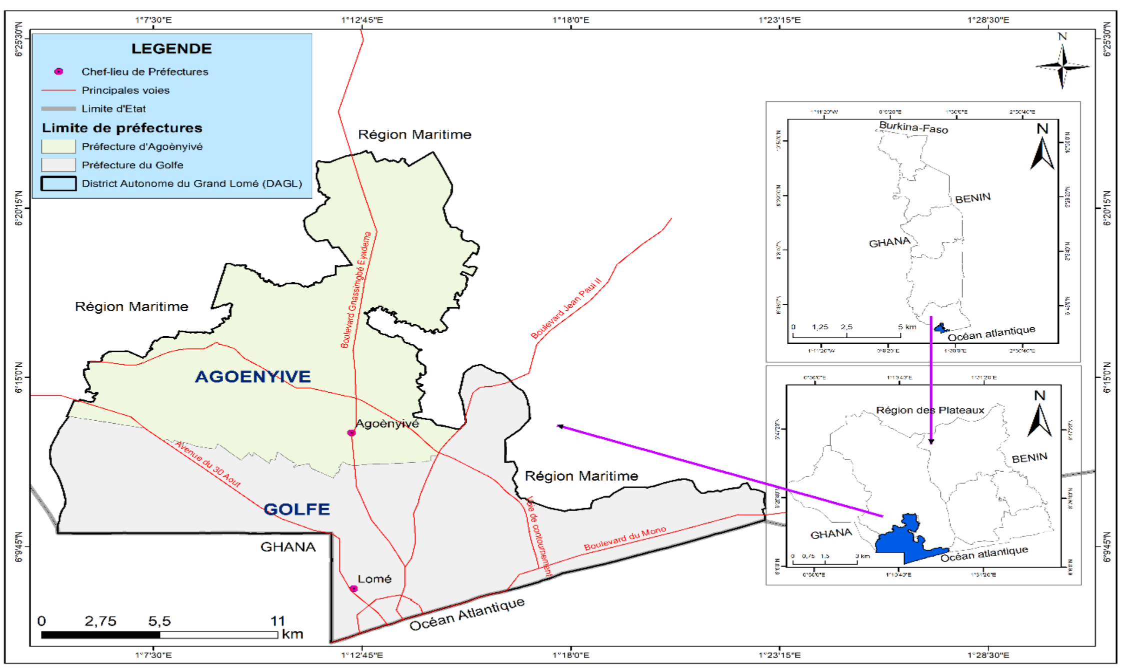

Figure 1 : Study area (Grand-Lomé region)
Source*: Passike, 2023, based on Inseed data*

3.1.2. Presentation of Savanes region

Located between 0°10' and 1°00' East longitude and 9°55' and 11°05' North latitude, the Savanes region, with an estimated population of 1,143,520 in 2022 (INSEED, 2023), is the northernmost region of Togo (Figure 2). It covers an area of 8,533 km², accounting for 15% of the national territory (INSEED, 2023). The region experiences a Sudanian climate, characterized by a rainy season from June to September and a dry season from october to may (DGMN, 2018). The average annual rainfall is approximately 1050.0 mm, while the average annual maximum temperatures are around 34°C. The average annual minimum temperatures are about 23°C. Relative humidity varies between 50% and 70% (Afidégnon, 2003). The average wind speed is approximately 2m/s, and the average daily sunshine duration is about 7 hours (DGMN, 2018).

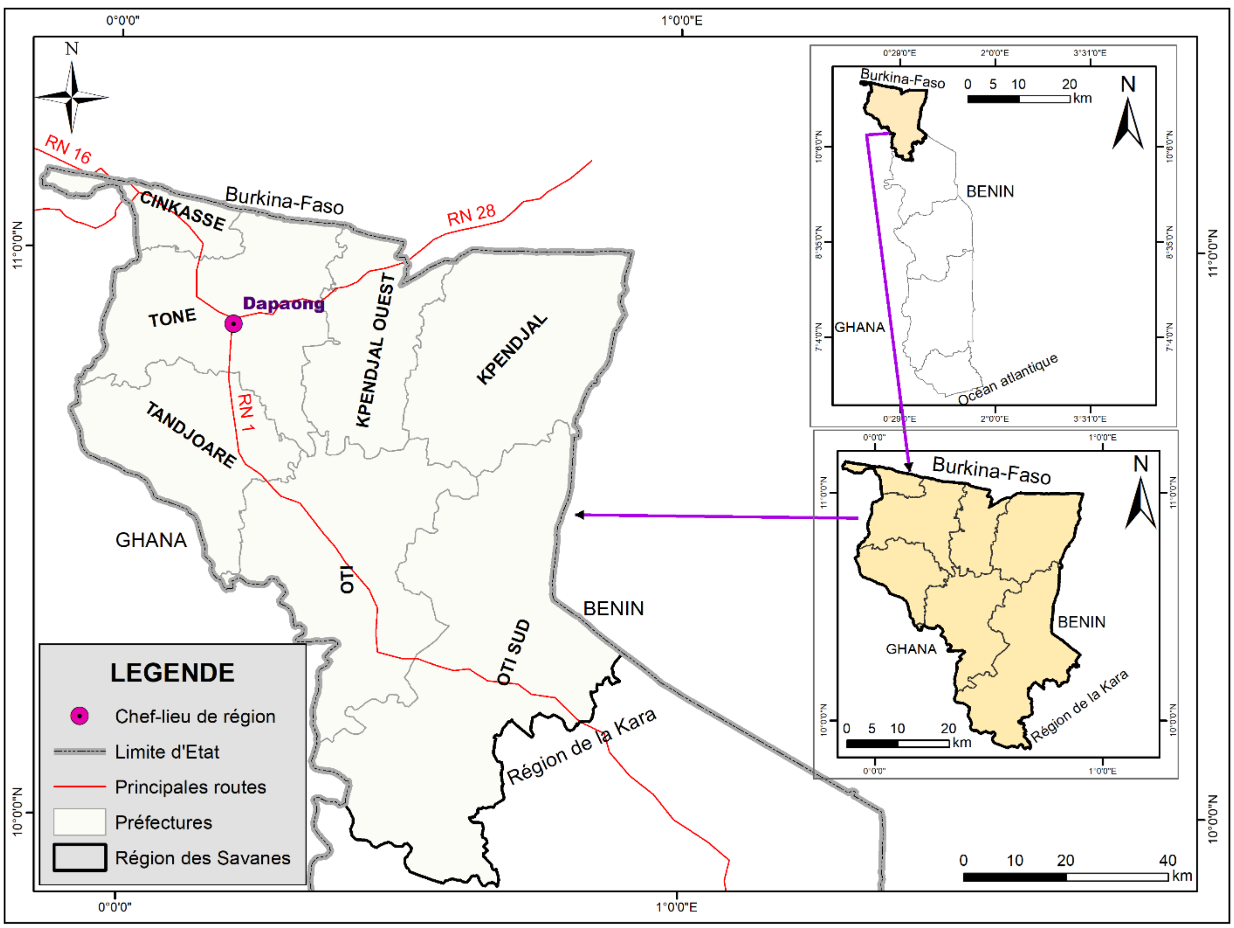

Figure 2 : Study area (Savanes Region)
Source*: Passike, 2023, based on Inseed data*

3.1.3. Justification of the choice of study area

The selection of the Savanes and the Grand-Lomé area as study zones for asthma prediction based on climatic variables is particularly relevant due to their starkly contrasting environmental, climatic, socio-economic, and security-related characteristics.

The Savanes region, located in northern Togo, is characterised by a dry tropical Sudanian climate, with a long dry season dominated by the Harmattan, a dusty wind known to exacerbate respiratory illnesses. In contrast, Grand-Lomé, situated in the south of the country, enjoys a more humid sub-equatorial climate, with relatively high annual rainfall and milder average temperatures. This region is also highly urbanised, industrialised, and equipped with more advanced healthcare infrastructure, which facilitates the diagnosis and management of chronic conditions such as asthma.

This climatic and environmental contrast provides an ideal framework for studying the various forms of exposure to asthma-triggering factors. While the northern region is more exposed to natural allergens such as dust and pollen, Grand-Lomé is more affected by atmospheric pollution of anthropogenic origin. Moreover, the disparity in access to healthcare also allows for the evaluation of how health infrastructure influences asthma detection and management. It is also important to highlight the security dimension: the Savanes region faces growing instability due to cross-border security threats, which can hinder access to care and affect the quality of health data, unlike Grand-Lomé, which remains relatively calm and stable. Consequently, a comparative analysis of these two areas will not only help identify the most influential climatic variables in the onset or worsening of asthma but also enable the development of predictive models and tailored recommendations based on local contexts. This approach will contribute to a better understanding of the relationship between climate and respiratory health in Togo, with strong potential for informing public health policy.

3.2. Overview of Togo health context

3.2.1. Administrative health organization in Togo

The organizational structure of the Ministry of Health is defined by Decree No. 2012-006/PR of 07 March 2012, which outlines the organization of ministerial departments. This was supplemented by Order No. 0021/2013/MS/CAB of 27 February 2013, which details the organization of the Ministry of Health's services, including the creation of a General Secretariat and two General Directorates. Thus, the Ministry's services comprise the Minister's Office, the services attached to the Minister's Office, the central administration, external services, and affiliated institutions and organizations.

According to the provisions of Order No. 171/2020/MSHP/CAB/SG of 19 June 2020, which governs the administrative organization of health regions, the health divisions are aligned with the administrative divisions provided by laws on decentralization. There are three categories of health areas: health regions (6), health prefectures or districts (39), and health communes (117). At the decentralized level, there are the intermediate level (regional health directorates led by regional health management teams) and the local/peripheral level (prefectural health directorates led by district health management teams).

3.2.2. Organization of health service delivery and healthcare in Togo

In Togo, healthcare is provided to the population through both public and private facilities (including associative, religious, and private establishments). The healthcare organization is hierarchical and divided into three levels: the first (peripheral), the second (intermediate), and the third (central).

Primary level care is structured around three tiers: (i) the Community Health Worker (CHW) who provides delegated care at the family and community level and acts as an interface between the community and health services; (ii) the Peripheral Health Unit (PHU), which serves as the base of the healthcare system and from which proximity activities are conducted both at fixed sites and towards the populations; (iii) the District Hospital (DH), which constitutes the first level of referral. The second level of referral is managed by regional hospitals (Regional Hospital Centers - RHC) and some regional specialties. Tertiary healthcare is provided in three University Hospital Centers (UHC) and specialized reference hospitals.

The number of healthcare facilities increased from 1,297 in 2019 to 1,320 in 2021, according to the results of the health map update conducted in 2021, and further to 2,152 in 2022 (Table I).

Table I: Distribution of Healthcare Facilities by type and region in 2022

Types of Health Facilities	Grand-Lomé	Maritime	Plateaux	Centrale	Kara	Savanes	Total
UHC	2	0	0	0	1	0	3
RHC	1	1	1	1	1	1	6
Specialized reference hospitals	1	1	1	0	0	1	4
Hospital II	9	3	9	3	4	4	32
Hospital I	70	13	11	3	5	5	107
PHU II	252	40	62	24	36	19	433
PHU I	671	219	260	113	130	97	1490
Nursing Home	29	4	10	9	9	7	68
Total	1035	281	354	153	186	134	2143

Source*: NHDP, 2023*

3.2.3. Human resources for health

The number of healthcare professionals trained in educational institutions has significantly increased. These efforts have been accompanied by the recruitment of a total healthcare workforce equivalent to 72% of the required human resources for health (HRH). However, all these advancements still fall short of the WHO recommended standard. According to the WHO, to optimally reduce the burden of maternal and under-five mortality, the country must have 2.5 healthcare providers (doctors, nurses, midwives) per 1,000 inhabitants. In 2021, Togo had a total of 2,514 doctors, nurses, and midwives for an estimated population of 7,976,000 inhabitants. This corresponds to a ratio of 2.5 healthcare providers per 7,932 inhabitants, clearly illustrating the significant need for qualified personnel. Moreover, this is also reflected in the coverage of healthcare personnel needs at the primary care level, which declined from 62.4% in 2015 to 42.1% in 2021. Additionally, besides the issue of workforce numbers, significant weaknesses persist. These include the lack of equity in the distribution of qualified personnel across the national territory, with concentration in urban areas. Furthermore, various weaknesses characterize career management for staff. A gender analysis of the staff of the Ministry of Health, Public Hygiene, and Universal Health Access on the state budget shows a disparity. In 2021, female staff comprised

37%, revealing a predominance of males in the healthcare system despite the existence of professions exclusively reserved for women, such as midwives and auxiliary midwives, as well as professions predominantly dominated by women (support hospital staff).

3.2.4. National health information system

The data collection for the National Health Information System (SNIS) is carried out using the District Health Information System, version 2 (DHIS-2) platform, which is governed by an operational procedures manual (MOP) detailing the data collection and reporting processes. This platform is used in all health districts. The completeness and promptness rates of periodic reports still vary significantly from year to year. This variability is illustrated by the completeness rate, which fluctuated from 91% in 2017 to 89.20% in 2021, with a peak of 96.50% in 2018. Overall, there is good proficiency in using the tools and data quality control system by the various actors. These advancements have enabled the regular production of the health statistics yearbook, providing quality data disaggregated by health districts.

3.2.5. Health research

To guide interventions in health research, Togo developed a national strategic health research plan covering the period 2015-2020, considering the international commitments to which Togo has subscribed. The implementation of this plan was suboptimal due to poor national coordination of health research activities. Additionally, there is a lack of a national plan outlining health research guidelines, limited research coverage of health system areas and health determinants, the absence of research promotion by hospitals, institutions, and specialized centres, and the low utilization of health research results. Nevertheless, some actions have been taken since 2008 that should be capitalized on. These mainly include the creation by ministerial decree of the health research ethics committee (CBRS), revised in May 2019 to enhance its functionality.

3.2.6. Health statuts of the population

- **Maternal health**

Data from Demographic and Health Survey (DHS)-III 2013-2014 place the maternal mortality ratio at 401 deaths per 100,000 live births. This ratio, estimated by United Nations agencies in 2021, remains high at 399 deaths per 100,000 live births despite ongoing efforts. These deaths are mainly due to direct obstetric causes, namely hemorrhages (47%), eclampsia (24%), and infections

(13%). The magnitude and severity of these problems are linked to: (i) limited access to quality health care and services, particularly prenatal care, assistance during delivery, and immediate postpartum care, (ii) insufficient progress in operationalizing sites offering obstetric care, resulting in an inability to provide adequate management of obstetric complications nationwide, (iii) the malfunctioning of the referral and counter-referral system, (iv) the low availability of essential medicines and blood products to save the lives of mothers and children, (v) the weakness of family planning services, (vi) the limited financial accessibility to healthcare services, and (vii) the low continuous use of prenatal care.

- **Neonatal and child health**

According to the NHDP 2017–2022 evaluation report, child health has significantly improved in recent years, as evidenced by the reduction in infant and under-five mortality rates. These rates decreased from 49 to 42 deaths per 1,000 live births from 2014 to 2017 for infant mortality and from 88 to 71 deaths per 1,000 live births for under-five mortality over the same period. During this period, neonatal mortality remained stable at 27 per 1,000 live births, while it contributed to 35% of under-five mortality. Despite progress, these rates still indicate significant mortality attributable to the burden of diseases, characterized by malaria, acute respiratory infections, diarrheal diseases, injuries, and trauma for under-five mortality, and prematurity, asphyxia, and severe infections for neonatal mortality. This high mortality is partly due to: (i) the poor quality of care and follow-up for children with diseases such as malaria, pneumonia, diarrhoea, and severe acute malnutrition, (ii) low vaccination coverage rates, (iii) limited access to proper hygiene conditions, clean drinking water, and sanitation, and (iv) deficiencies in both the prevention of mother-to-child transmission of HIV and the care of children living with HIV.

- **Adolescent and youth health**

The health of adolescents and youth is significantly affected by: (i) early pregnancies and their consequences, (ii) sexually transmitted infections (stis), including HIV/AIDS, (iii) various forms of violence, (iv) mental health issues, and (v) infectious and non-infectious diseases. Additionally, they are particularly vulnerable to substance abuse and various traumas. In recent years, adolescent and youth health indicators have shown little improvement, such as the adolescent birth rate, which decreased from 85‰ in 2010 to 79‰ in 2017. Regarding HIV/AIDS, the prevalence among youth aged 15–24 decreased from 0.70% in 2019 to 0.64% in 2021. Given the significant influence of men on sexual matters, this slight progress may partly be due to better HIV/AIDS knowledge among boys (34.8%) compared to girls (25.7%), according to the MICS6 survey results. However, regardless of gender, young people have a low knowledge of HIV/AIDS, which continues to spread within this age group.

- **Elderly health**

The elderly population is very vulnerable socio-economically. Health-wise, they face a double burden of communicable and non-communicable diseases. Their specific health problems include osteoarthritis, multiple pathologies, dementia, visual and hearing impairments. Regarding non-communicable diseases, Hypertension (HTN) accounted for 68.4% and 57.07% of hospitalizations for cardiovascular diseases at the Sylvanus Olympio University Hospital Centre (CHU-SO) in 2017 and 2018, respectively. Additionally, in the same year, 67.3% resorted to self-medication, and 20-40% used functional foods or traditional medicine for treatment in Lomé. The elderly often suffer from a range of health issues associated with compromised immune systems, making them less able to cope with certain environmental risks, such as air pollution, and more susceptible to serious insect-borne and waterborne diseases. Their limited mobility increases their risk of exposure.

3.2.7. Determinants of health

- **Sources of drinking water supply and basic sanitation**

The sources of drinking water supply and basic sanitation conditions are critical environmental determinants of health. According to UNICEF 2021 report on water sanitation, the sources of drinking water consumed in households are distributed as follows: boreholes (26.7%), the public water supply network by the Togolese Water Company “TDE” (25.8%), wells (24.1%), surface water (15.6%), other sources (4.1%), and rainwater catchment (3.7%). It is noteworthy that 52.3% of households utilise drinking water sources likely to provide potable water (TDE and boreholes). For all other sources, the water quality is not assured. This is particularly true for surface water, which is inherently unfit for consumption. They account for 15.6% of households. In this context, the MICS 2017 survey results indicate that 69.1% of households consume drinking water contaminated with E. Coli. This contamination is more prevalent in rural areas, affecting 80.2% of households, compared to 49.1% in urban areas.

Regarding household access to basic sanitation facilities, according to the same report, 27.0% of households had no latrines; 47.1% had latrines in good condition, and 25.5% in poor condition. The absence of latrines in households effectively necessitates the practice of open defecation. Limited access to potable water, the use of latrines in poor condition, and the practice of open defecation (OD) indicate precarious living conditions. This situation at least partly explains the high frequency of epidemic peaks of diarrheal diseases regularly recorded in the country (NHDP, 2023).

Furthermore, floods and droughts (manifestations of climate change) can compromise the quality of water and soil. Floods cause sewage overflows and contamination of drinking water, while droughts lead to reduced water supply and increased use of contaminated water sources. The convergence of these factors results in an increase in diarrheal diseases.

3.2.8. Other determinants of health

There is limited data on air quality, the impact of chemicals, protection against radiation, safety, and health in workplaces and living environments, despite their importance as determinants of human health. The consumption of tobacco and alcohol, physical activity, and various environmental factors also significantly impact health. Data from the STEPS Togo 2021 survey show that, on average, the prevalence of tobacco use in the general population is 5%. This consumption is more prevalent among men (10%) compared to women (0.4%). Approximately 3.3% smoke daily, with an average starting age of daily smoking at 21.4 years. For 92.8% of these individuals, this involves the consumption of industrial tobacco.

3.2.9. Justification of the choosen disease

According to the 2021 Health Statistics Yearbook, malaria is the leading reason for consultations, both among children under 5 years old (65.3%) and in the general population (60.6%). Acute respiratory infections follow, accounting for 15.8% of cases among children under 5 and 11.5% in the general population. Gastroenteritis and colitis of unspecified origin rank third, representing 4% of cases among children (Figure 3).

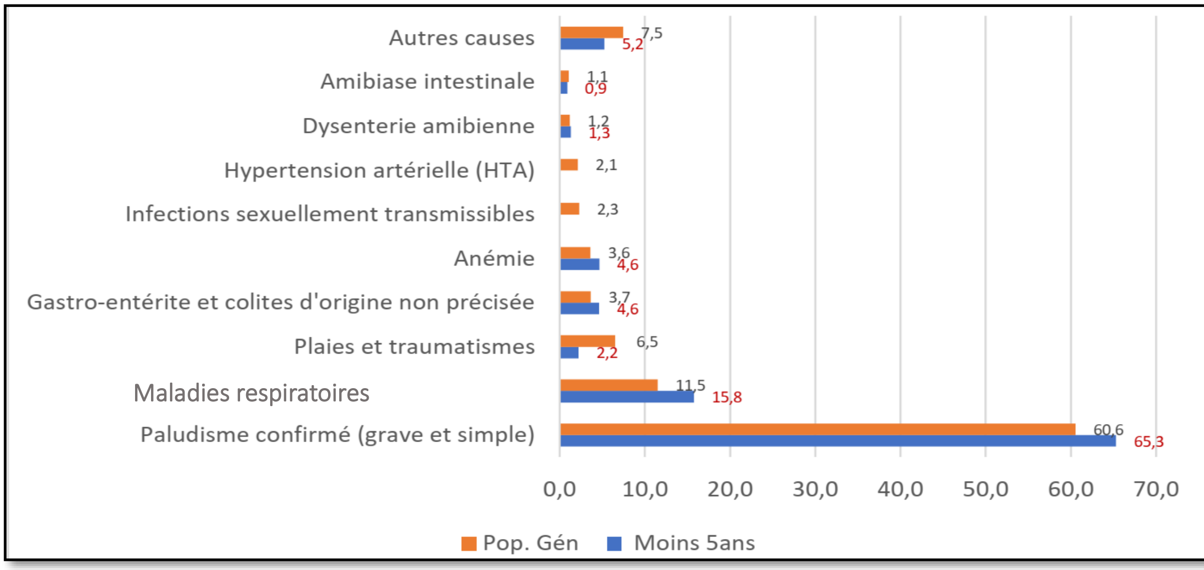

Figure 3 : Leading cause of consultation in Togo in 2021

Source: Health Statistics Yearbook, 2021

3.3.Stakeholders involved in the study

This thesis is the result of collaboration between several stakeholders:

i) The Direction Générale de la Météorologie Togolaise (DGMN)

The DGMN provided essential in-situ and remote climatic data, including daily rainfall, temperature, humidity, wind speed, and insolation, which were crucial for analyzing the impact of climatic conditions on asthma incidence.

ii) The Ministry of Health

The moh contributed health data on asthma cases through its District Health Information Software (DIHS2) databases. This data was vital for understanding the prevalence and distribution of asthma in the study regions.

iii) The Institut de Recherche Agronomique du Togo (ITRA)

ITRA supplied environmental data, particularly vegetation indices (NDVI) from the Meteorological Operational Satellite Program (METOP) databases, which supported the analysis of environmental factors affecting asthma.

iv) WASCAL-Ghana

WASCAL-Ghana provided remote data on air quality mainly (AI, CO, SO, NO2, O3) which was essential for evaluating the impact of air quality on asthma prevalence. This data helped in understanding the broader environmental influences on respiratory health.

v) Hospitals and healthcare centers

These healthcare facilities facilitated data collection through retrospective and prospective surveys of asthma patients and healthcare professionals. Their involvement ensured comprehensive and accurate health data for the study.

vi) Asthmatic patients

The participation of asthmatic patients was essential for collecting primary health data. Their contributions through surveys and interviews provided valuable insights into the lived experiences and health challenges associated with asthma, ensuring that the study's findings were grounded in real-world experiences.

vii) Ethics committees

Ethical considerations were overseen by relevant ethics committees, ensuring that the study adhered to principles of confidentiality, informed consent, and responsible handling of health information. The approval number was ***"Avis N° 011/2023 CBRS du 16 mars 2023"***.

viii) WASCAL-Togo

WASCAL-Togo provided academic support, including access to research facilities and expertise in data analysis and interpretation.

These collaborations were instrumental in gathering, analyzing, and interpreting the data, ultimately contributing to a deeper understanding of the relationship between climate variability and asthma in Togo.

3.4. Methodological approach

The present thesis project is structured around three main axes. It was designed to comprehensively examine the impact of climatic variability on asthma incidence in Togo, specifically in the Savanes and Grand-Lomé regions.

3.4.1. Approach for axis 1: Characterization of climate and health patterns

To address the aim of this axis, this study had been a retrospective, descriptive, and analytical investigation carried out from 2018 to 2022.

Climatic data, including daily rainfall (RR), minimum and maximum temperatures (TMIN and TMAX), relative humidity (UMAX and UMIN), wind speed, and insolation (Inso), were sourced from the meteorological stations of Dapaong and Mango (for the Savanes region) and Lomé-Aero (for the Grand-Lomé region) from Direction Générale de la Météorologie Nationale (DGMN).

Health data focused on monthly recorded asthma cases across all age groups, obtained from the Ministry of Health's District Health Information Software (DIHS2) databases. Environmental data on vegetation indices (NDVI) were collected every ten days from the Meteorological Operational Satellite Program (METOP) databases at the Institut de Recherche Agronomique du Togo (ITRA). The period 2018 to 2022 was choosen because of the limitations of health data which are only available from 2018.

The data analysis encompassed three main components: the analysis of seasonal variability in climatological and health parameters using monthly graphical representations, the determination of asthma prevalence (equation 1) by region with standardized data to ensure fair comparisons:

Prevalence = ((Number of existing cases of the disease in the population) / (Total size of the study population)) x 100000 **(*1*).**

In addition, there were the calculation of the correlation (equation 2) to quantify the strength relationship between variables. The correlation coefficient (r) quantifies the strength of the linear relationship between two variables, as described by Equation 2. This coefficient ranges between -1 and 1, with values closer to the extremes (-1 or 1) indicating a stronger correlation (either inverse or direct). Conversely, a correlation of 0 suggests that the variables being studied are linearly independent:

$$r = \frac{Cov(X,Y)}{\sigma X \, \sigma Y} \qquad (2)$$

Where :

- *Cov(X,Y) denotes the covariance of the variables X and Y ;*
- *and σX σY are their standard deviations.*

3.4.2. Approach for axis 2: Perception assessment

To achieve the objective of the second axis, two studies were conducted. The first study conducted from may to august 2023, targeted asthmatics using retrospective and prospective searches. The retrospective search examined the registry of asthmatics with available contact details, while the prospective search surveyed asthmatics presenting for consultation at pulmonology, pediatrics, and internal medicine departments. Questionnaires (hardware and online form via kobocollect and Gform) were shared to a sample of asthmatic patients, with the population size determined using the SCHWARTZ formula (Equation 3):

$$\boldsymbol{n = \frac{z^2 * p(1-p) * N}{z^2 * p(1-p) + (N-1)e^2}} \quad \textbf{(3)}$$

Where :

- *n is the minimum sample size to survey for obtaining significant results;*
- *z is the confidence level, i.e., the 95th percentile of the normal distribution (z=1.96);*
- *N: size of the target population*
- *p = Initial level of proportion for a population characteristic (p =0.5);*
- *e = the margin of error, typically set at 5%.*

Thus, by substituting the values into the formula with N=575, we find n=230 asthmatics to survey. Due to non-responses, we increased this number to a total of 275. The data collected focused mainly on several essential aspects of asthma management among patients. These included educational background, perceptions and environmental triggers of asthma attacks, and the types of domestic energy sources used. The study also seeks patients' access to healthcare services.

Ethical considerations were addressed, focusing on privacy, informed consent, and the disclosure of potential health problems. Confidentiality was maintained, with securely stored recordings and no names included. Respondents were informed about the interview contents and procedures, and their full approval was obtained. Informed consent was sought from each respondent, with interviews conducted privately after explaining the consent form.

The second study from October to December 2023, focused on healthcare professionals treating asthma patients in healthcare centers. The sample size was determined using statistical principles to ensure reliability and representativeness. Thus, with N=1141we found n=287.58 which rounds up to 288 individuals to survey. Due to non-responses, we have increased this number to a total of

350 healthcare professionals. Participants included doctors, medical assistants, and nurses working in pulmonology, pediatrics, and internal medicine departments. This selection aimed to minimize biases and improve the generalization of results. Ethical considerations were also paramount, addressing privacy rights, the necessity of informed consent, and responsibilities in disclosing potential health issues. Confidentiality was strictly maintained, with securely stored recordings that did not include any names. Respondents were fully informed about the interview contents and procedures and gave their full approval. Informed consent was obtained from each participant, with consent forms explained and read to them before the interviews, which were conducted in private. The data collected mainly focused on several key areas related to climate and respiratory health. These included knowledge and training on climate change, as well as the general understanding of air pollution among healthcare professionals. The study also explored perceptions of the link between climate and health, particularly in relation to asthma. Specific attention was given to identifying the periods and environmental factors that trigger asthma attacks. Additionally, the integration of climate considerations into healthcare practices was assessed. Finally, the research examined the awareness and relevance of national documents and health policies in addressing climate-related health issues. Statistical analyses were conducted using R software version 4.2.1.

3.4.3. Approach axis 3: Development of prediction models

To develop prediction models for asthma cases based on climatic, environmental, and pollution parameters, this study utilizes monthly data from 2018 to 2022, which includes both climatic and environmental parameters. The dependent variable is asthma registered cases, while the explanatory variables encompass environmental and pollution metrics, such as carbon monoxide (CO), the air quality index (AI), sulphur dioxide (SO_2), ozone (O_3), nitrogen dioxide (NO_2), and climate parameters including precipitation (Rainfall), minimum (Tmin), maximum (Tmax), and average (Tmoy) temperatures, relative humidity (Umin, Umax, Umoy), sunshine (Inso), wind speed (windspeed), and the Normalized Difference Vegetation Index (NDVI).

The modelling process begins with variable selection, where an initial exploration data analysis was conducted to understand the dataset. This was followed by Principal Component Analysis

(PCA), which was used to reduce data dimensionality. PCA played a crucial role in identifying key variables that captured the major variations within the dataset, thereby enhancing the interpretability of the final model. For the model construction phase, two techniques were employed: the Random Forest Model (RFM) and the Polynomial Regression Model (PRM). The RFM (Equation 4) was selected for its strength in capturing complex, non-linear relationships, its robustness to correlated variables, and its resilience to missing data and outliers. The prediction in the RFM is defined by the equation:

$$\mathbf{Y} = \mathbf{1/N \sum_{i=1}^{N} Ti(X)} \tag{4}$$

where :

- *Y is the predicted output,*
- *N is the number of trees in the forest,*
- *Ti(X) is the prediction from the i-th decision tree for the input X.*

On the other hand, the PRM (Equation 5) was used due to its capacity to model non-linear relationships through the inclusion of higher-order terms. It offers a good balance between flexibility and interpretability. The polynomial regression model is expressed as:

$$\mathbf{Y = \beta_0 + \beta_1 X + \beta_2 X^2 + \beta_3 X^3 + ... + \beta_h X^h + \varepsilon} \tag{5}$$

where :

- *Y is the dependent variable,*
- *X is the independent variable,*
- *β_0 is the intercept,*
- *β_1 ... β_h are the coefficients for each term in the polynomial,*
- *ε is the error term.*

In the final stage, model performance evaluation was conducted using two criteria: statistical performance and seasonal validation. For statistical assessment, metrics such as the Coefficient of Determination (R^2), Mean Squared Error (MSE), and Root Mean Squared Error (RMSE) were used to evaluate the models' explanatory power and accuracy. Additionally, seasonal validation was carried out to test how well the models replicated seasonal trends in asthma case incidence, including identifying peak periods and fluctuation patterns.

An Asthma impact chain was also developed to capture the complex interactions between climatic, environmental, and socio-economic factors influencing asthma in Northern and Southern Togo based on the Climate Risk Sourcebook (GIZ, 2023). The process involved defining the geographical and temporal scope of the study and identifying primary climatic hazards like temperature variations, humidity fluctuations, air pollution, and dust storms. Non-climatic drivers (e.g., urbanization, indoor pollution, and limited healthcare access) were incorporated to provide a comprehensive understanding of asthma risk factors. Vulnerable populations (children, elderly, individuals with pre-existing conditions) and healthcare system capacity were central to this analysis, alongside environmental and socio-economic vulnerabilities.

CHAPTER 4: RESULTS AND DISCUSSION OF AXIS 1

4.1. Results

4.1.1. Characterization in Grand-Lomé

4.1.1.1. Characterization of climate patterns

4.1.1.1.1. Interannual evolution of rainfall from 1990 to 2022

Analysis of the interannual evolution of rainfall in the Greater Lomé region from 1990 to 2022 shows significant variation in annual rainfall accumulation, ranging between 423.9 mm and 1416.7 mm, with an average of 827.60 mm (Figure 4). Over the thirty-three years observed, 18 years recorded above-average rainfall (1991, 1997, 1999, 2002-2004, 2006-2012, 2014, 2018, and 2019) compared to 15 years with below-average rainfall (1990, 1992-1996, 1998, 2000, 2001, 2005, 2013, 2015, 2016, 2017, and 2020). The wettest years were 2010 and 2019, with 1416.7 mm and 1333.6 mm, respectively. Conversely, severe rainfall deficits were observed in 1998 and 2000, with 442.6 mm and 423.9 mm, respectively. There is an upward trend, though not statistically significant according to the Mann-Kendall test (p-value = 0.17765). The Pettit test identifies 2002 as a change point, though not significant with a p-value of 0.1527 > 0.05. The mean difference between the two periods (1990-2002) and (2002-2022) is 181.86 mm, with the first period averaging 715.63 mm compared to 897.49 mm in the second period.

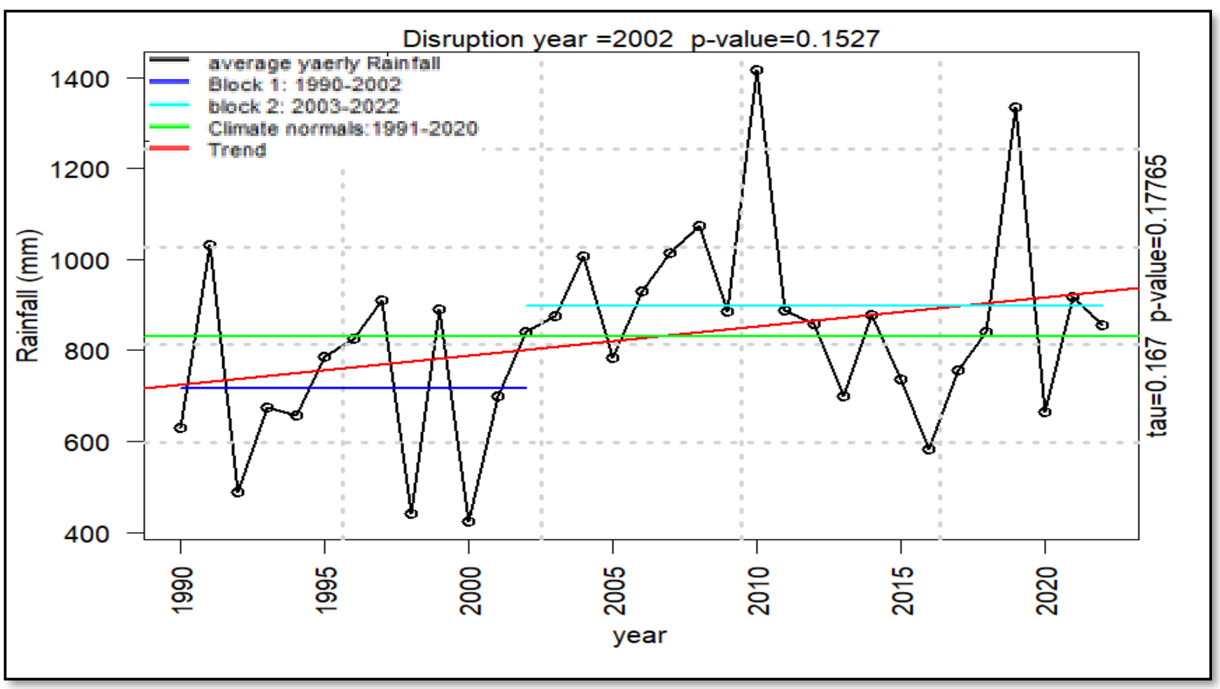

Figure 4 : Interannual evolution of rainfall from 1990 to 2022 in the Grand-Lomé Region

4.1.1.1.2. Rainfall anomalies from 1990 to 2022

The Standard Precipitation Index (SPI) reveals significant variability in the Grand-Lomé region (Figure 5). Based on the figure, four distinct periods can be identified: two dry periods (one long and one short) and two wet periods (one long and one short). Dry periods account for approximately 45% compared to 55% of the wet period in the time series under consideration.

The long dry period spans from 1990 to 2001, with 1998 and 2000 being the driest years in the series, with indices of -1.7 and -1.8 respectively. However, the short dry period extends from 2013 to 2017, with 2016 marked as the driest year with an index of -1.1. Nevertheless, both dry periods include some wet years such as 1991, 1997, and 1999 for the long dry period, and 2014 for the short dry period.

Regarding wet periods, the long-wet period covers from 2002 to 2012, with 2010 considered the wettest year with an index of +2.9. The short-wet period spans from 2018 to 2022, with 2019 identified as the wettest year with an index of +2.5.

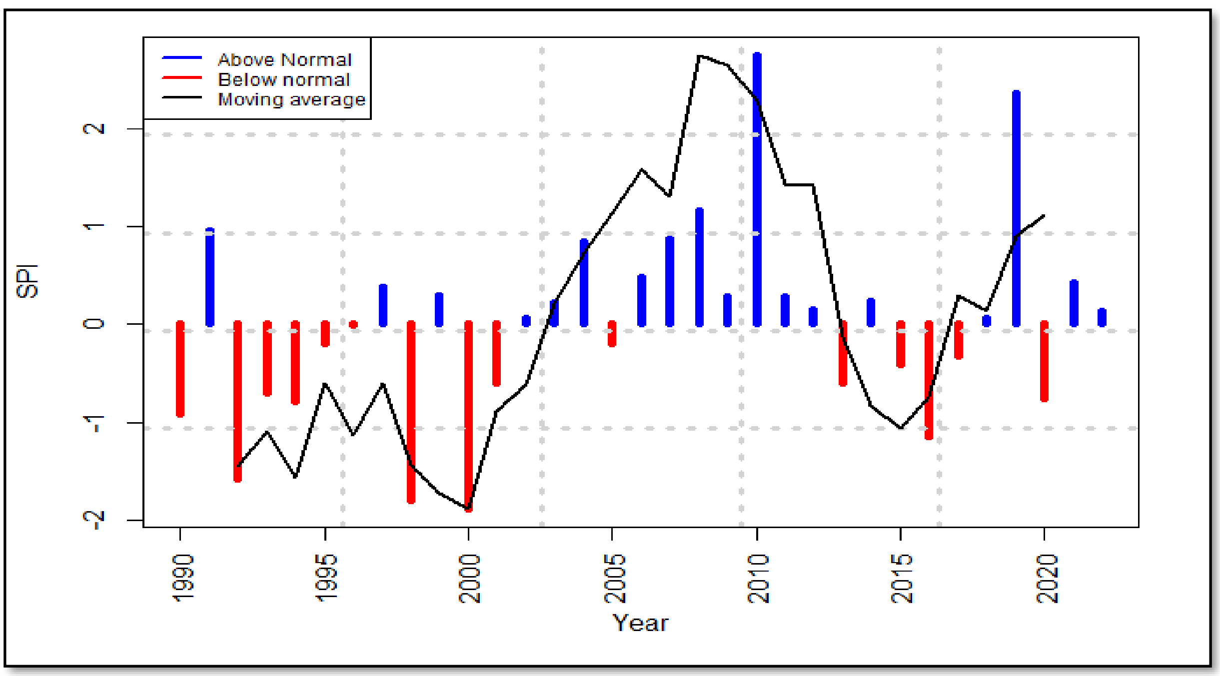

Figure 5 : Rainfall anomalies from 1990 to 2022 in Grand-Lomé region

4.1.1.1.3. Seasonal evolution of rainfall from 1990 to 2022

The rainfall pattern in the Grand Lomé region exhibits a bimodal regime with four distinct seasonal types characterized by monthly average rainfall below 200 mm (Figure 6). There are two dry seasons (a major and a minor) and two rainy seasons (a major and a minor).

During the major rainy season from April to June, monthly average rainfall heights exceed 100 mm, with a peak of 176 mm observed in June. The cumulative rainfall during this season amounts to 423 mm out of the annual average of 827 mm, representing 51%. In contrast, the minor rainy season from September to October, with a secondary peak of 98 mm in October, accounts for an annual average of 175 mm out of 827 mm, which is 21%. Together, the two rainy seasons contribute 72% of the annual average cumulative rainfall, totaling 598 mm, with a total of 53 rainy days 34 days during the major rainy season and 19 days during the minor rainy season. Maximum rainy days were observed in June (14 days) and September (10 days).

Regarding the dry seasons, the major dry season spans from December to March, characterized by very low rainfall totals amounting to 100 mm over the four months. The minor dry season covers the months of July and August, characterized by generally pleasant weather conditions.

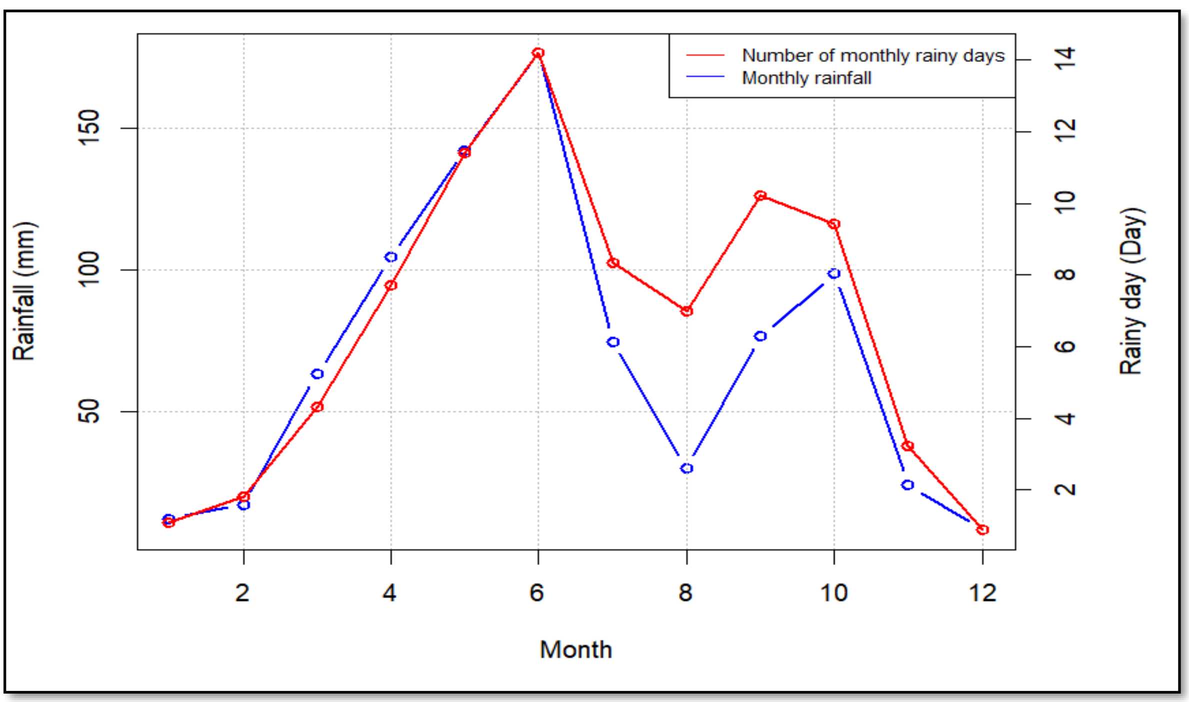

Figure 6 : Seasonal evolution of rainfall from 1990 to 2022 in the Grand-Lomé region

4.1.1.1.4. Annual evolution of rainy days from 1990 to 2022

The annual evolution of rainy days shows considerable variability (Figure 7). From 1990 to 2022, the annual number of rainy days ranged from 52 days observed in 1998 to 122 days in 2010.

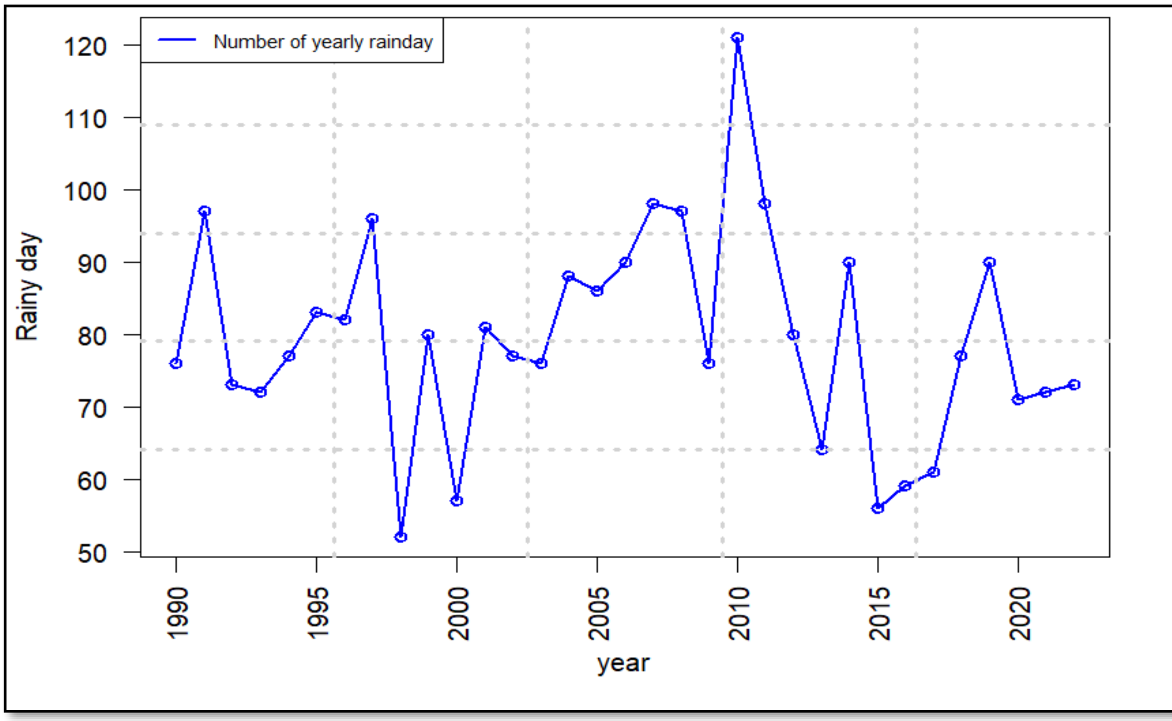

Figure 7 : Annual evolution of rainy days from 1990 to 2022 in Grand-Lomé region

4.1.1.1.5. Annual evolution of minimum temperatures from 1990 to 2022

The analysis of the annual evolution of minimum temperatures in the Grand-Lomé region from 1990 to 2022 reveals significant variation in the annual thermal regime, ranging between 23.7°C and 25.4°C with a thermal average of 24.5°C (Figure 8). Over the thirty-three years observed, 18 years were characterized as warm (2001, 2003-2010, and 2012-2022) compared to 15 cold years (1990-2000, 2002, 2011, 2013, and 2014). The warmest years were 2010 and 2016 with temperatures reaching 25.5°C, while 1999 recorded the coldest temperature at 23.6°C. There is a significant upward thermal trend according to the Man-Kendall test (p-value = 2.33 * 10^-5). The Pettitt test identifies 2002 as a significant breakpoint with a p-value of 0.0001102 < 0.05. The thermal mean difference between the two periods (1990-2002) and (2002-2022) amounts to +0.65°C.

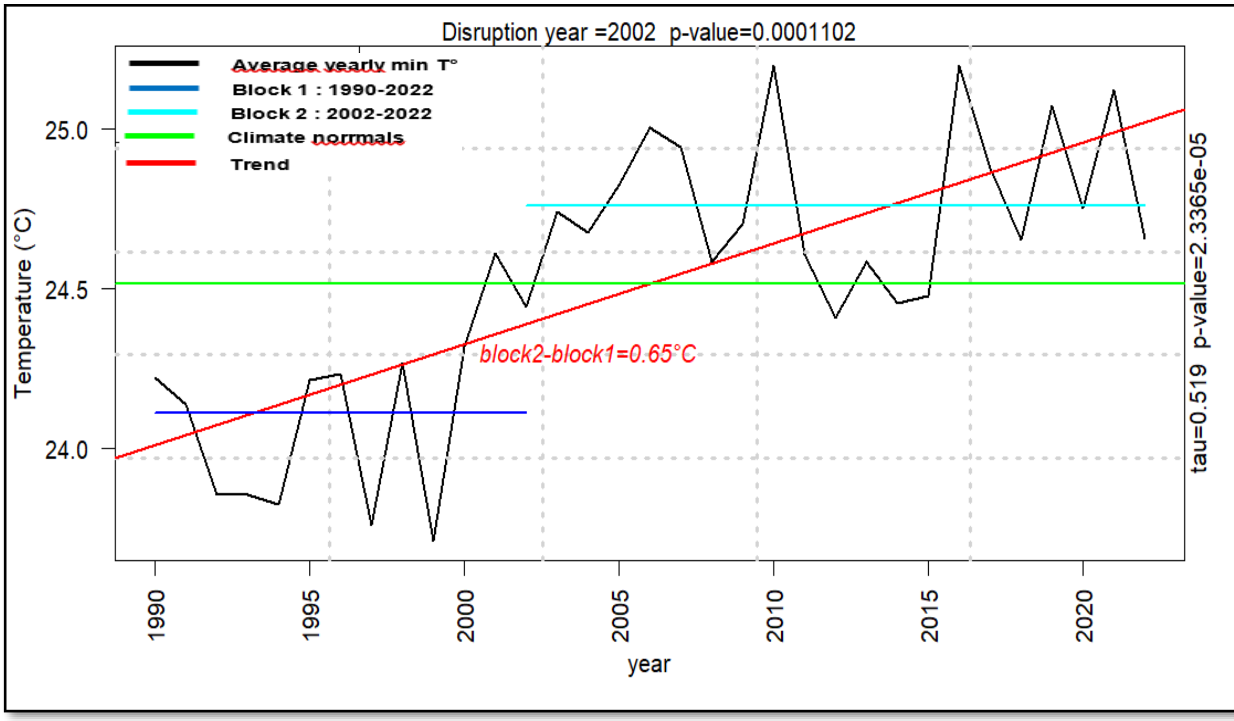

Figure 8: Annual evolution of minimum temperatures from 1990 to 2022 in the Grand-Lomé Region

4.1.1.1.6. Anomalies of minimum temperatures from 1990 to 2022

The analysis of the Standard Temperature Index (STI) reveals significant variability in minimum thermal conditions in the Grand-Lomé region (Figure 9). Examining the figure, two distinct periods emerge: a cold period from 1990 to 2002 and a warm period from 2002 to 2022. Cold years constitute 45% of the period, whereas warm years account for 55% of the considered time series.

The cold period is characterized by a sequence of cold years with anomaly indices ranging between -0.2 and -1.9, except for the anomalous year 2001, which was warm with an anomaly index of +0.25. In contrast, the warm period includes three cold years: 2012, 2014, and 2015. The warmest years during the warm period were 2010 and 2016, with thermal anomaly indices reaching +1.7.

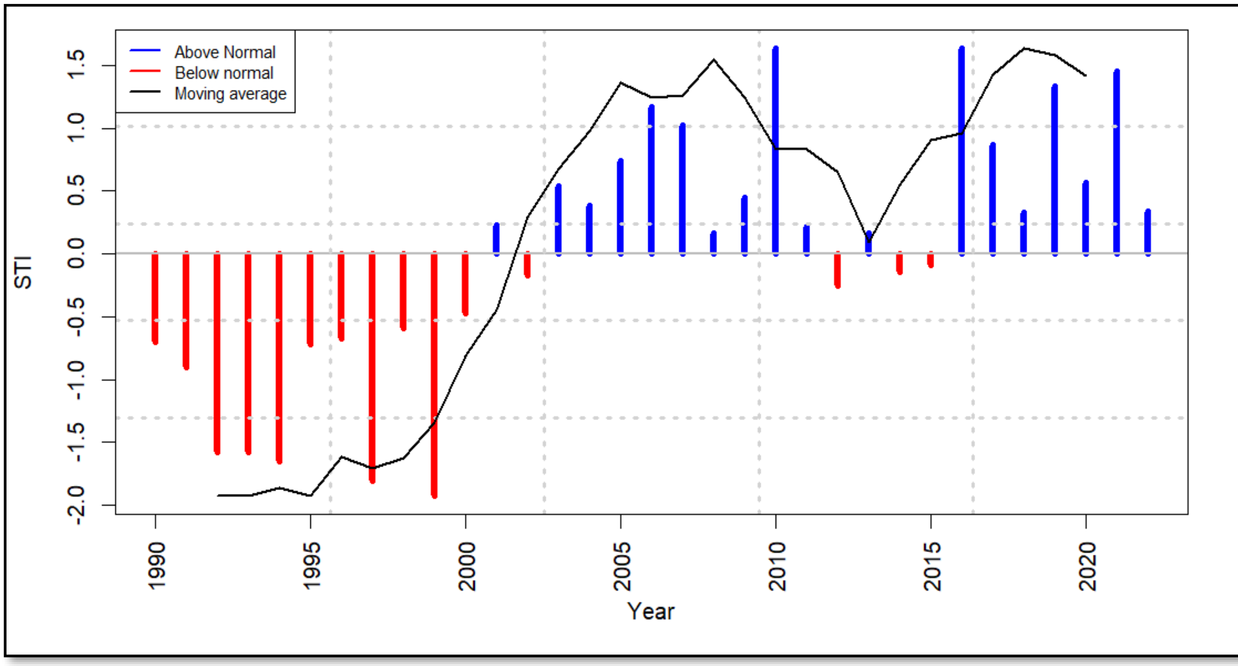

Figure 9: Anomaly of minimum temperatures from 1990 to 2022 in the Grand-Lomé region

4.1.1.1.7. Interannual variation of maximum temperatures from 1990 to 2022

The analysis of the interannual variation of maximum temperatures in the Grand-Lomé region from 1990 to 2022 reveals significant fluctuation in the annual maximum thermal regime, ranging between 30.6°C and 32.7°C, with a thermal mean of 31.7°C (Figure 10). Over the thirty-three years observed, 15 years were identified as warm (1998, 1999, 2003-2010, and 2012-2022) and 15 years as cool (1990-2000, 2007-2011, and 2013-2021). The years 1998 and 2014 are identified as the warmest, with temperatures of 32.7°C and 32.6°C, respectively. In contrast, 1992 is noted as the coldest year, with a temperature of 30.6°C. A significant upward thermal trend is observed according to the Mann-Kendall test, with a p-value of 1.192 × 10^-6. The Pettitt test indicates a significant breakpoint in 2006, with a p-value of 0.001197 < 0.05. The difference in average temperature between the two periods (1990-2006) and (2006-2022) is +0.67°C.

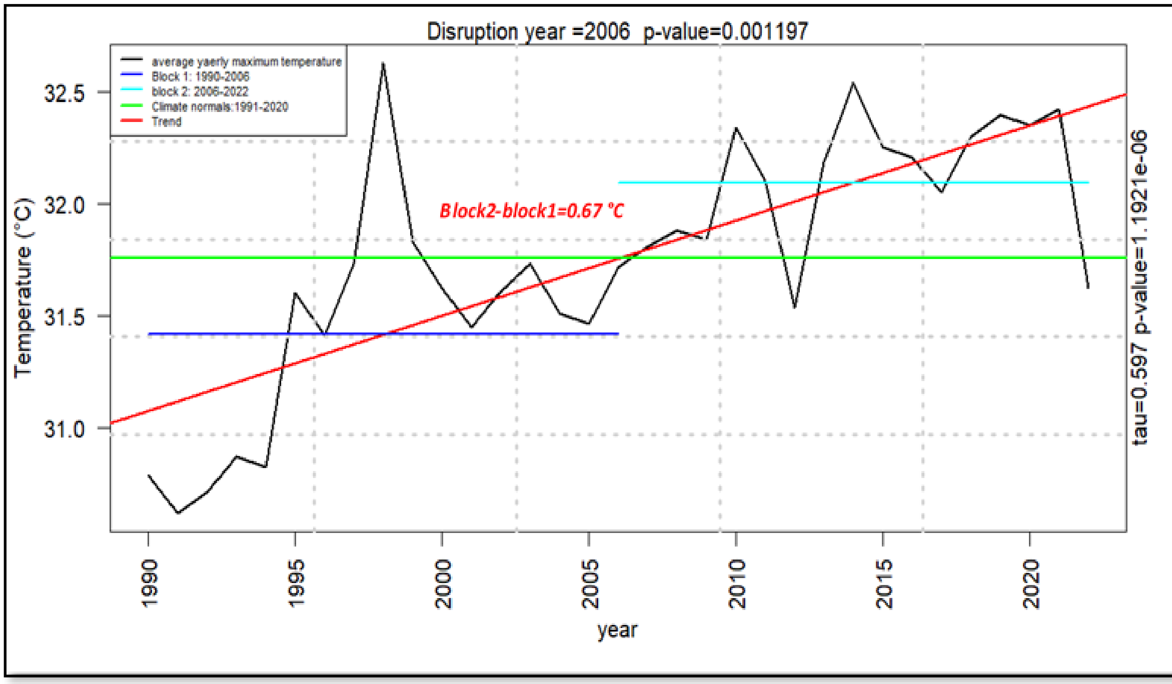

Figure 80: Interannual variation of maximum temperatures from 1990 to 2022 in the Grand-Lomé region

4.1.1.1.8. Anomalies of maximum temperatures from 1990 to 2022

The analysis of maximum temperature anomalies reveals substantial thermal variability in the Grand-Lomé region (Figure 11). The data delineates two major periods: a cold period from 1990 to 2006 and a warm period from 2007 to 2022. The cold years account for 45% of the series, while the warm years constitute 55%.

The cold period is marked by a succession of years with temperature indices ranging between -0.05 and -2.1, except for two warm years, 1998 and 1999, which have indices of +1.8 and +0.1, respectively. Conversely, the warm period includes two cold years, specifically 2012 and 2022. The warmest year in the entire series is 1998, with an index of +1.8, while 1991 is the coldest year, with an index of -2.1.

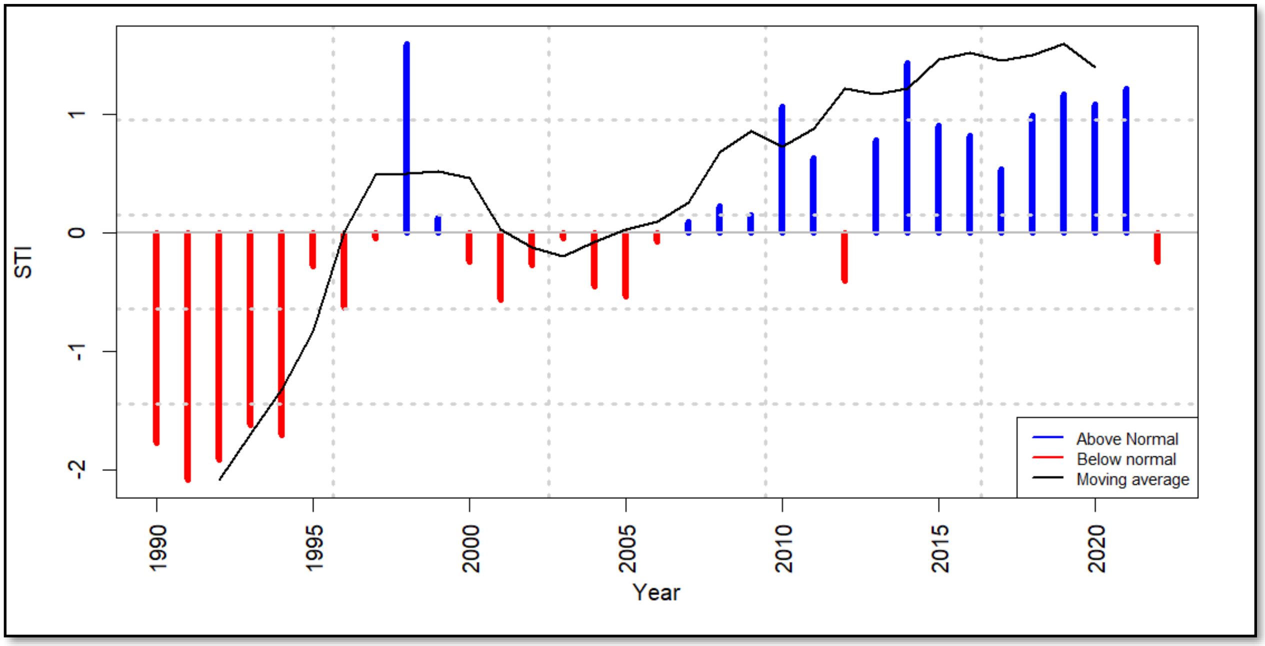

Figure 11: Anomaly of maximum temperatures from 1990 to 2022 in the Grand-Lomé region

4.1.1.1.9. Seasonal evolution of temperatures (maximum, minimum, and mean) from 1990 to 2022

The average monthly temperature variations range between 23°C and 33°C (Figure 12). The monthly averages of maximum temperatures (Tmax) fluctuate between 29°C in July and 33.45°C in February. The variations in minimum temperatures (Tmin) range from 23.3°C in August to 25.92°C in March. The mean temperatures (Tmean) vary between 26.16°C in August and 29.6°C in March. February appears to be the hottest month, with a peak observed in March, in contrast to August, which records the lowest temperatures.

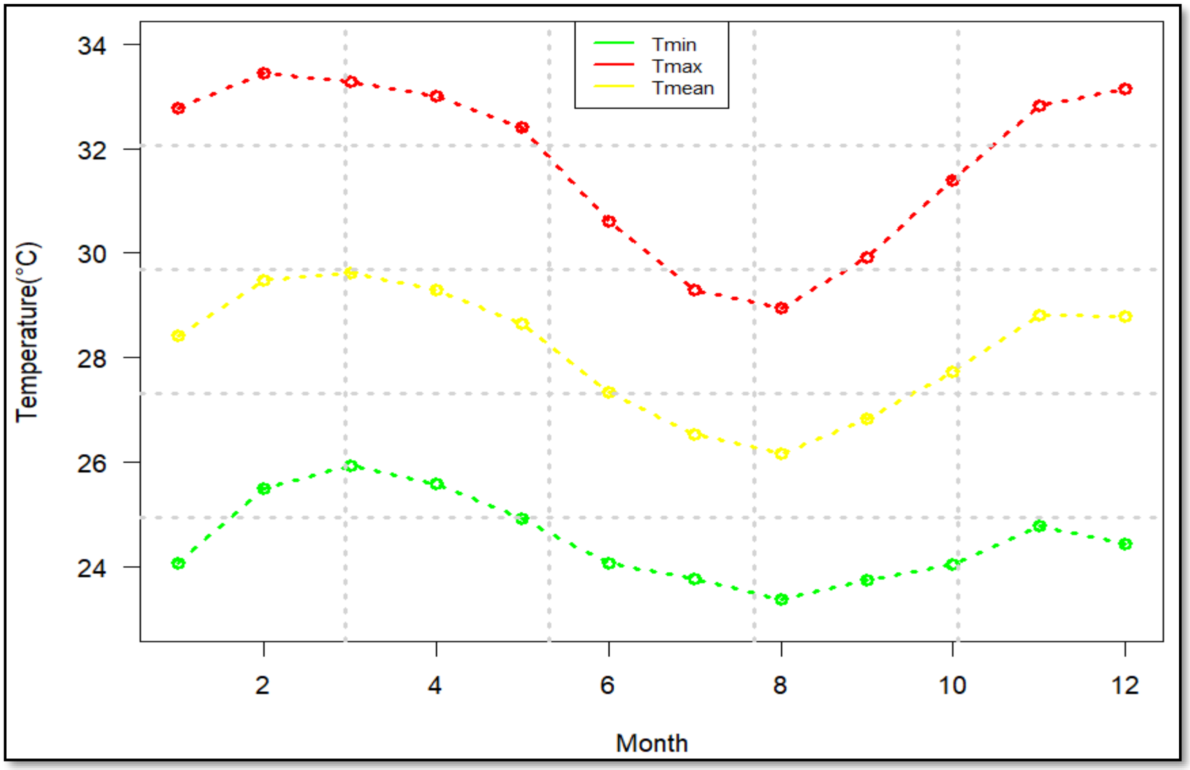

Figure 12: Seasonal evolution of maximum, minimum, and mean temperatures from 1990 to 2022 in the Grand-Lomé region

4.1.1.1.10. Seasonal changes of windspeed

Wind speed demonstrates seasonal variations (Figure 13) with typically ranging values between 2.5 m/s and 4 m/s. The months of May, October to December exhibit the lowest wind speeds, falling below 2.5 m/s. In contrast, the months of February to April and July to September register the highest wind speeds, all surpassing 3.2 m/s, with the peak, reaching 4 m/s, notably observed in August.

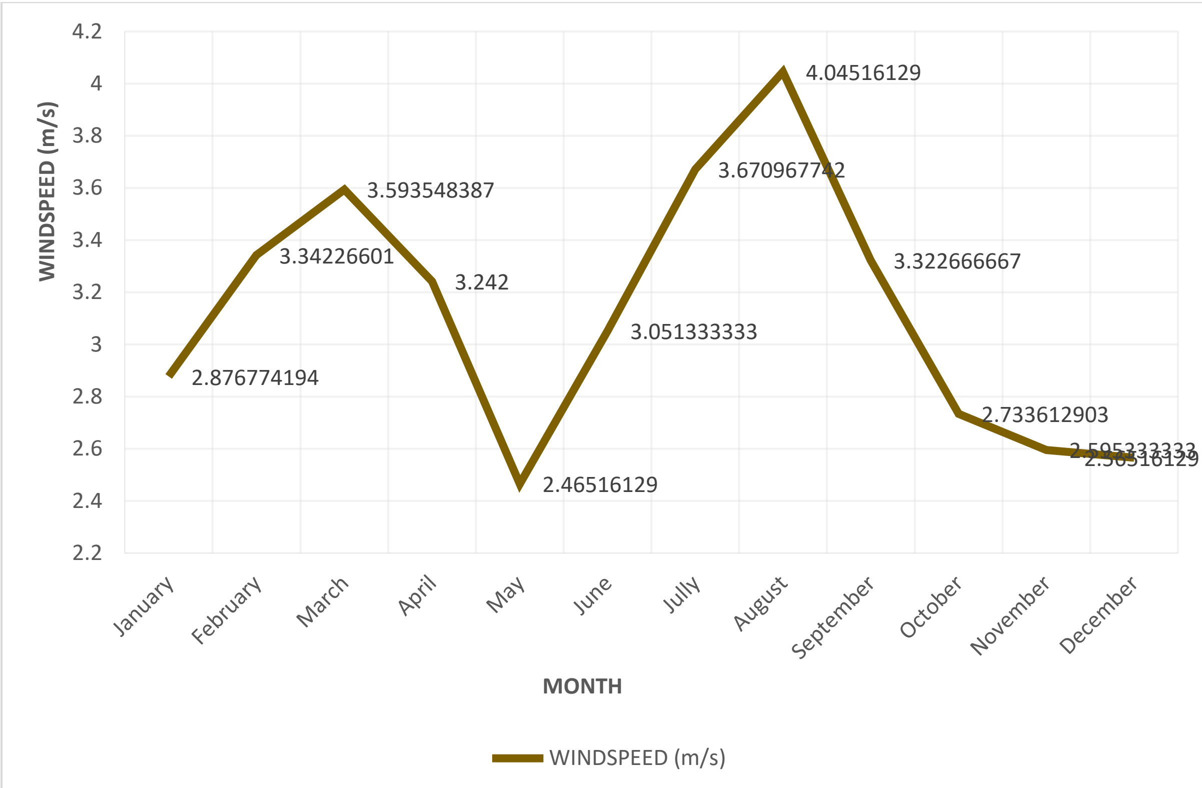

Figure 13: Seasonal changes of windspeed from 2018 to 2022

4.1.1.1.11. Seasonal trends in maximum and minimum relative humidity

Monthly relative humidities, both maximum and minimum, exhibit significant fluctuations throughout the year, typically ranging between 52% and 94% (Figure 14 et 15). The maximum relative humidity (UMAX) varies from 90% in March to 94% in October, as depicted in Figure 15. On the other hand, the minimum humidity (UMIN) shows a range from 52% in January to 73% in September, as shown in Figure 16. Consequently, humidity levels tend to be elevated during the rainy season and more frequently decrease during the dry season.

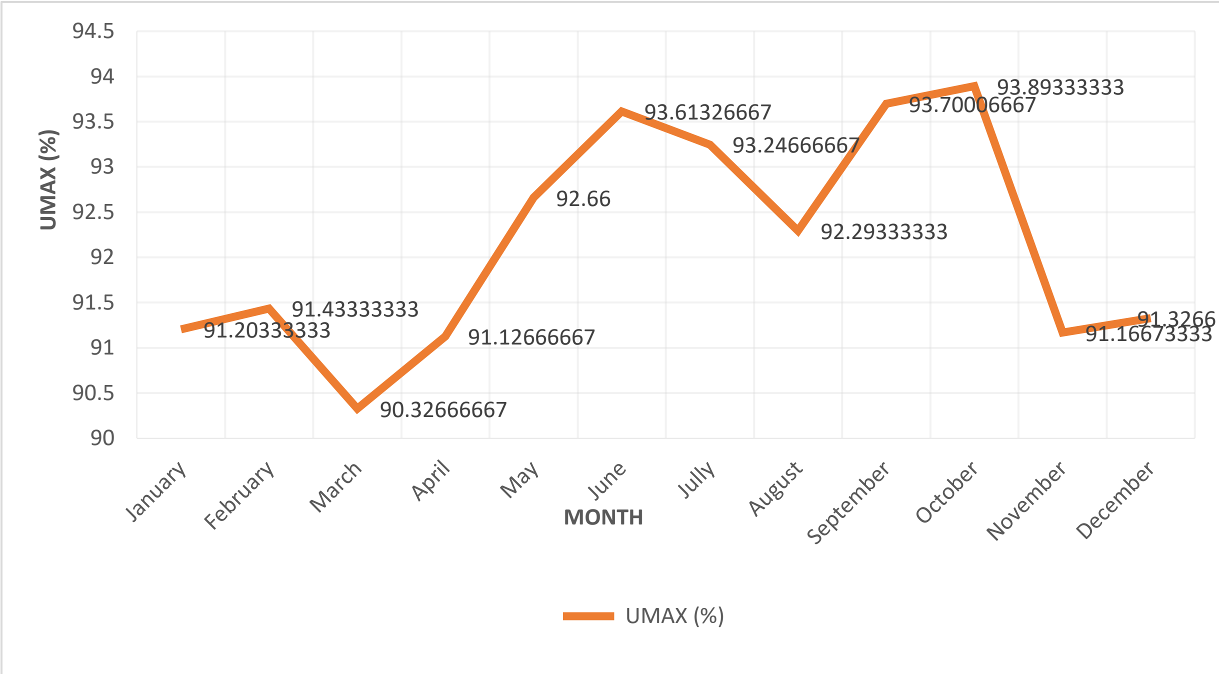

Figure 14: Seasonal trends in maximum relative humidity from 2018 to 2022

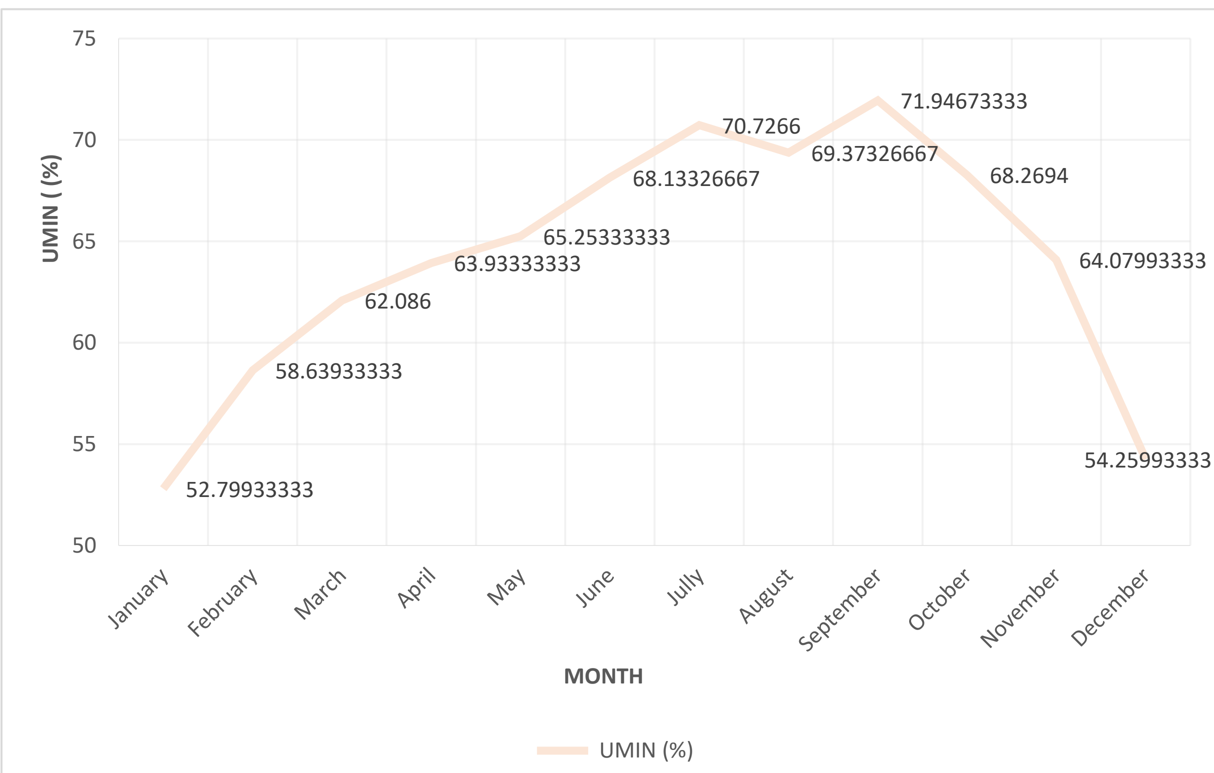

Figure 15: Seasonal trends in minimum relative humidity from 2018 to 2022

4.1.1.1.12. Seasonal evolution of the vegetation index

NDVI exhibits values ranging between 1 in February and 1.9 in May (Figure 16). Specifically, during the period from January to March, which represents the relatively arid months of the year, the vegetation index indicates relatively modest values, ranging from 1 to 1.4. This decline is attributed to cold climatic conditions and reduced sunshine, inducing plant dormancy in numerous regions, resulting in a decrease in vegetative growth. Starting from April onward, the initial rains act as a stimulus for plant growth, which is reflected in a gradual elevation of the vegetation index. From May to June, corresponding to the winter months, the vegetation index attains its pinnacle at 1.9. Favorable weather conditions, characterized by ample sunlight and rainfall, foster robust vegetative growth. Subsequently, during August to September, as the principal rainy season approaches its conclusion, the vegetation index recedes, subsequently surging once more in October with the advent of the second rainy season, only to taper off as the second dry season ensues.

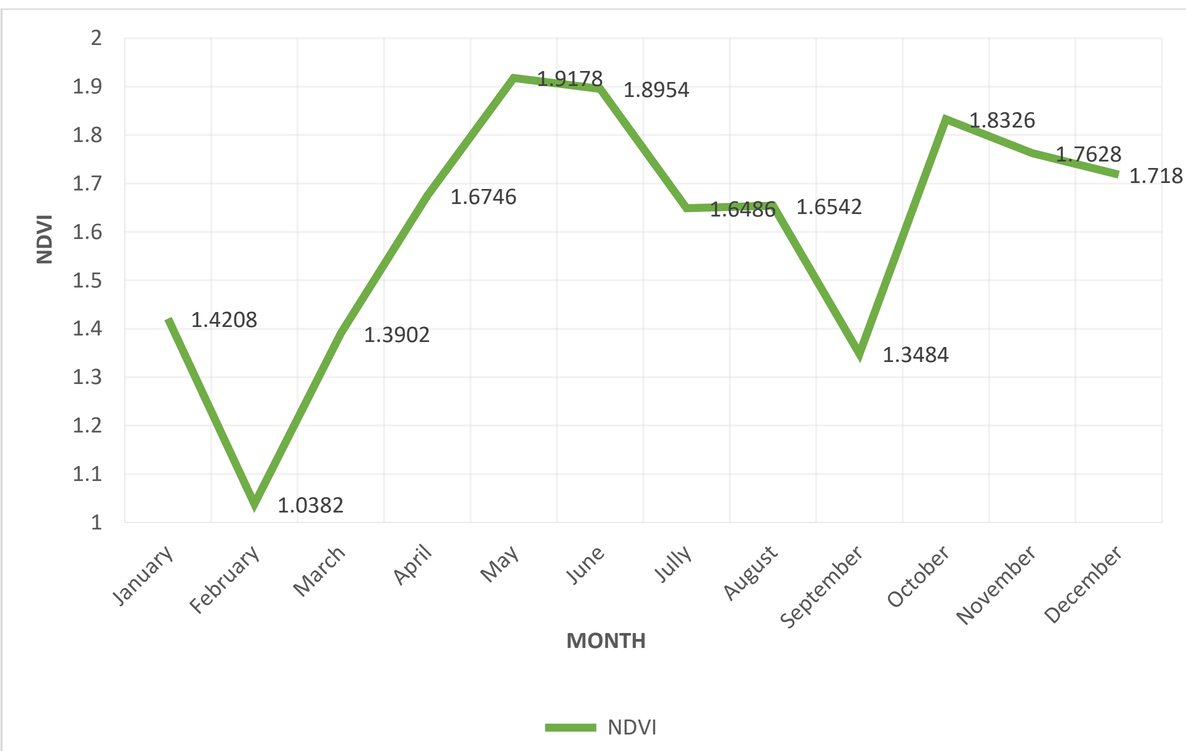

Figure 16: Seasonal evolution of the vegetation index from 2018 to 2022

4.1.1.1.13. Seasonal variation of insolation

The average monthly duration of sunshine (insolation) across the year falls within the range of 4.5 to 8 hours per day, as presented in figure 19. Notably, the peak duration occurs in November, contrasting with the lowest values recorded from June to September. These months coincide with periods characterized by substantial cloud cover, acting as an effective shield against the sun's rays.

Figure 17: Seasonal variation of insolation from 2018 to 2022

4.1.1.2.Characterization of health patterns

4.1.1.2.1. Interannual variation of asthma cases in Grand-Lomé from 2018 to 2022

Analysis of annual asthma case data from 2018 to 2022 reveals variability in this condition over the five-year period (Figure 18). There is notable fluctuation in the annual totals of asthma cases, ranging from 4,491 cases in 2020 to 6,102 cases in 2019. A slight increase of 774 cases was observed from 2018 to 2019, followed by a sharp decrease of 1,613 cases in 2020. Subsequently, the following years were marked by a significant increase in asthma cases, with an increase of 718 cases from 2020 to 2021, and 793 cases from 2021 to 2022. In total, an increase of 1,511 cases was observed between the periods 2020 to 2021 and 2021 to 2022.

It is important to note that 2020 was significantly impacted by the COVID-19 pandemic. Lockdown measures and travel restrictions likely reduced environmental exposures and respiratory infections, leading to a temporary decrease in asthma cases. In contrast, 2021 was characterized by the gradual resumption of activities and the easing of lockdown measures, leading to increased exposure to environmental factors such as air pollution, seasonal allergens, and weather conditions. This could have contributed to the observed rise in asthma cases.

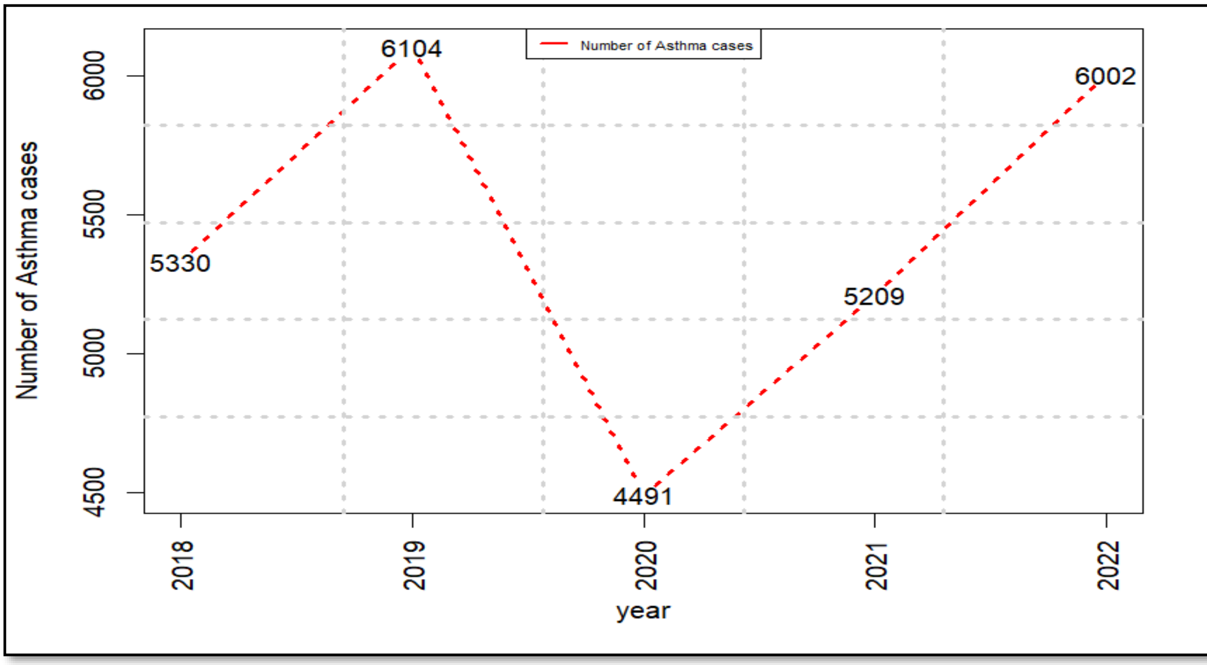

Figure 18: Interannual variation of asthma cases in Grand-Lomé from 2018 to 2022

4.1.1.2.2. Intermonthly variation of asthma cases from 2018 to 2022 in Grand-Lomé

From January 2018 to December 2022, the intermonthly variation in asthma cases exhibited notable fluctuations (Figure 19). In 2018, the months from June to July and October to December recorded asthma case numbers above the average (444 cases), with a peak of 672 cases observed in October. In 2019, the months from January to February and from June to December also experienced elevated asthma cases above the average (452 cases), with an initial peak of 550 cases in January and a second peak of 596 cases in August. In 2020, the months from January to February and from September to December showed asthma case numbers above average (374 cases). April had the lowest number of cases with 260, whereas January and December recorded peaks with 454 and 431 cases, respectively. For 2021, six months exceeded the average of 434 cases, specifically February, June, July, and October to December. This year exhibited three peaks in February, June, and December, with 512, 450, and 450 cases, respectively. Finally, in 2022, the months from April to May and from October to December had asthma case numbers above the annual average of 500 cases, with two peaks observed in April and November, with 500 and 693 cases, respectively.

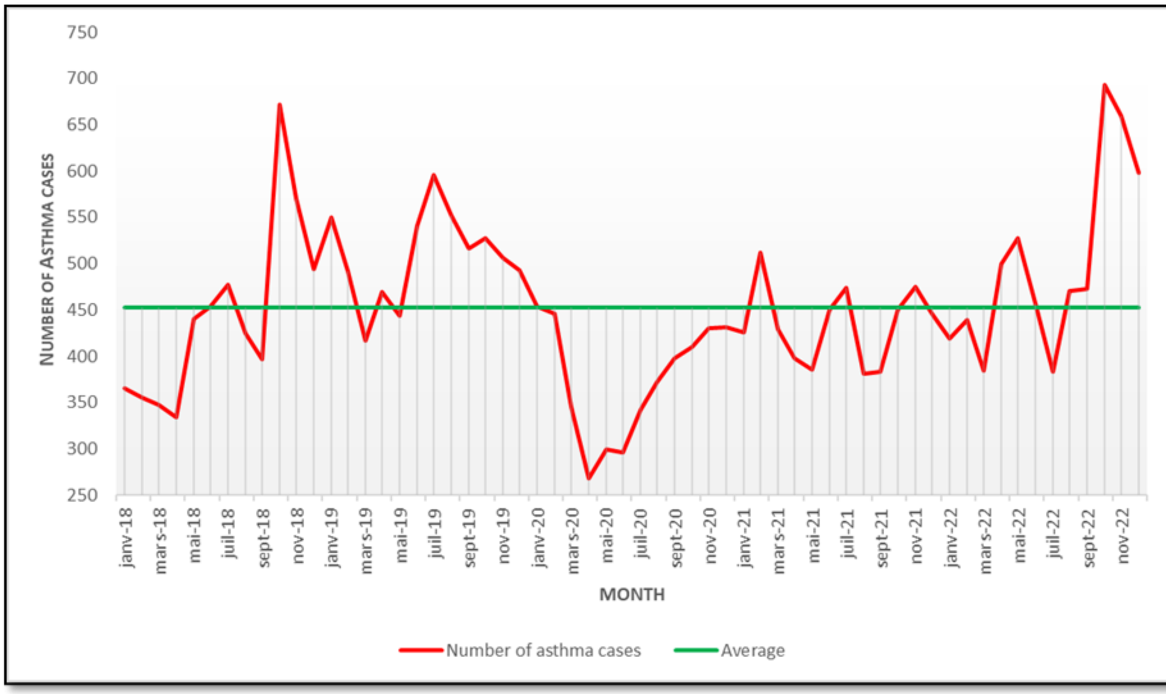

Figure 19: Intermonthly variation of asthma cases from 2018 to 2022 in Grand-Lomé

4.1.1.2.3. Seasonal variation of asthma cases from 2018 to 2022 in Grand-Lomé

The analysis of the seasonal variation in asthma cases reveals a distinct auspicious period within the year (Figure 20). There is a progressive increase in asthma cases starting from March (377 cases), reaching a peak in July (452 cases), and then slightly decreasing until September (440 cases). The number of cases then rises again, peaking in October (550 cases) before decreasing until December (458 cases). It is noteworthy that the highest asthma case numbers are recorded from October (a rainy month) to December (a dry Harmattan month), with a peak of 550 cases in October. Additionally, there is another peak of 450 cases in February. However, March (a dry month) records the lowest number of cases of the entire year, with 377 cases.

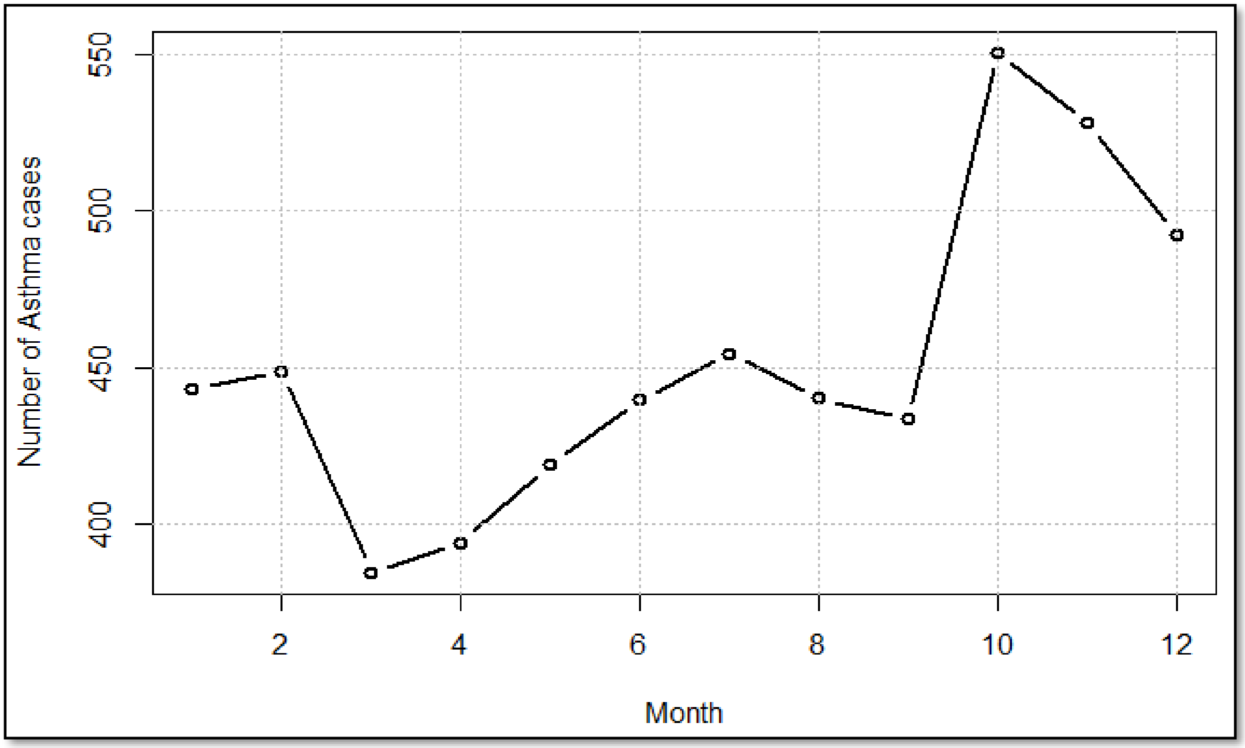

Figure 20: Seasonal variation of asthma cases in Grand-Lomé region from 2018 to 2022

4.1.2. Characterization in Savanes region

4.1.2.1. Characterization of climate patterns

4.1.2.1.1. Interannual rainfall evolution from 1990 to 2022 in Savanes region

The analysis of the interannual evolution of rainfall in the Savanes region from 1990 to 2022 indicates a significant variation in annual rainfall totals, ranging from 743.2 mm to 1383.4 mm, with an average annual rainfall of 830.20 mm (Figure 21). Over the thirty-three years observed, 16 years recorded above-average rainfall (1994, 1997, 1998, 1999, 2001, 2003, 2006, 2007, 2008, 2009, 2011, 2012, 2013, 2014, 2016, and 2020), while the remaining 17 years were below average. The year 2013 was the wettest, with 1383.4 mm of rainfall, in contrast to 1990, which was the driest year with 743.2 mm of rainfall. There is a slight, non-significant upward trend in annual rainfall according to the Man-Kendall test (p-value = 0.6727). The Pettitt test applied indicates 1996 as the year of a potential shift, although this result is not significant (p-value = 0.58761 > 0.05).

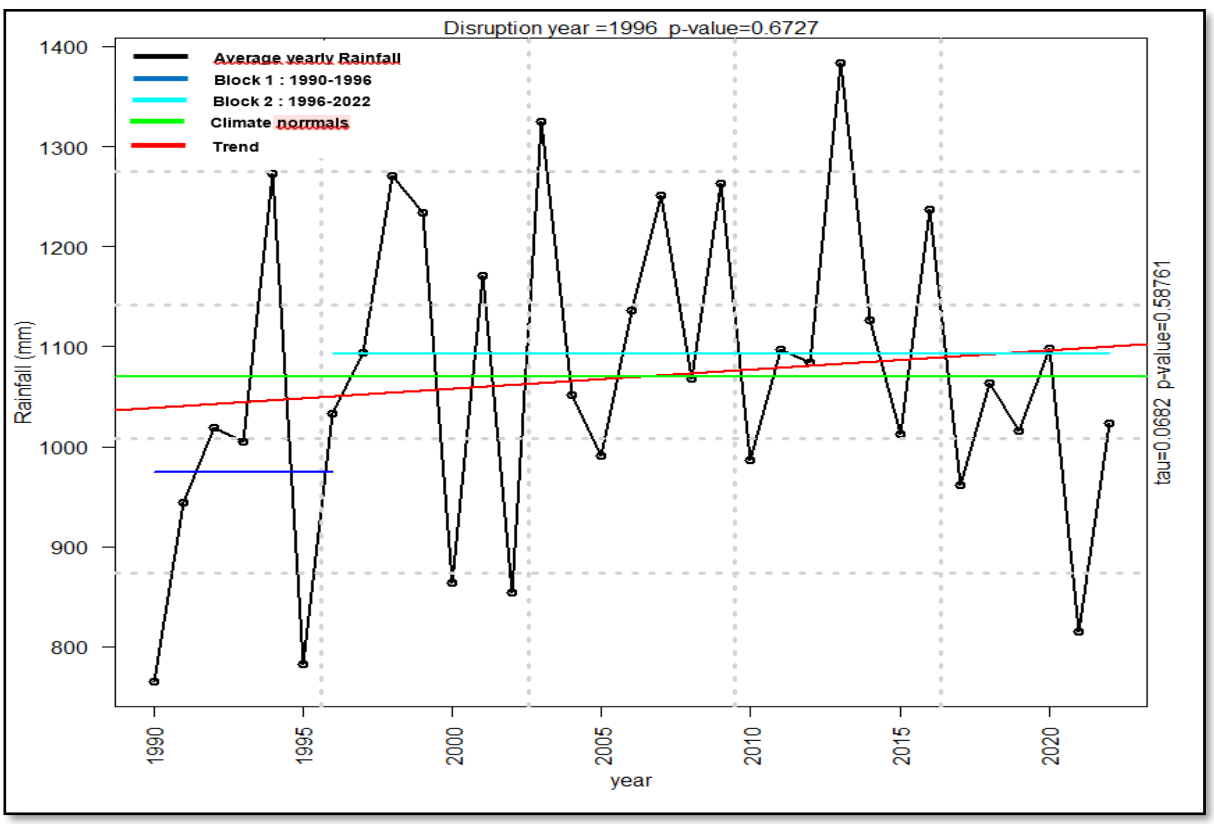

Figure 21: Interannual rainfall evolution from 1990 to 2022 in the Savanes region

4.1.2.1.2. Rainfall anomalies from 1990 to 2022

The interannual variation of rainfall reveals significant rainfall variability in the Savanes region (Figure 22). Based on the figure, three distinct periods can be identified: two short dry periods from 1990 to 1996 and from 2017 to 2022, with indices ranging between -0.01 and -1.9; and a longer wet period from 1997 to 2016, marked by a pronounced alternation of dry and wet years, with indices ranging between +0.2 and +2. Dry years account for approximately 54.54% of the time series considered. The year 2013 stands out as the wettest year, with an index of +2, in contrast to 1990, which was the driest year, with an index of -1.9.

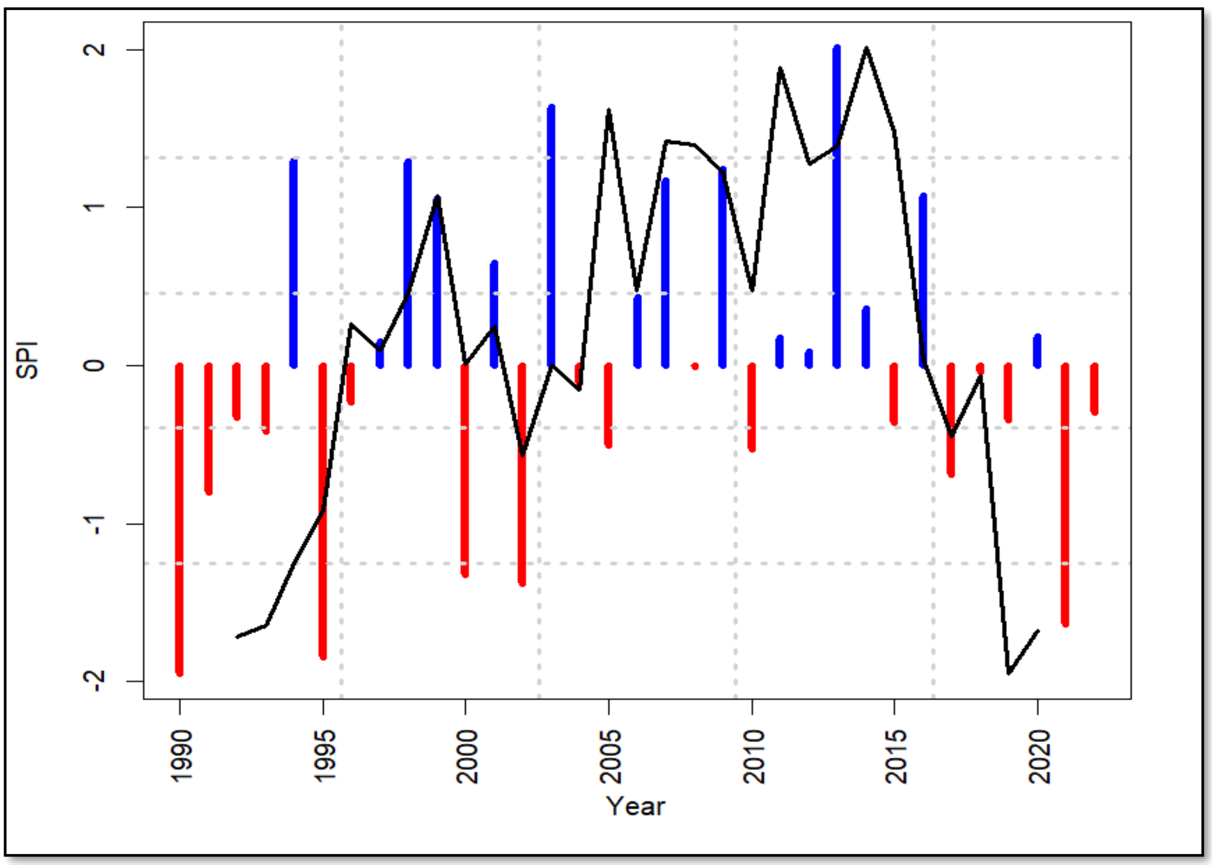

Figure 22: Rainfall anomalies from 1990 to 2022 in the Savanes region

4.1.2.1.3. Interannual evolution of minimum temperatures from 1990 to 2022

The analysis of the interannual evolution of minimum temperatures in the Savanes region from 1990 to 2022 reveals significant variation in the annual thermal regime, with temperatures ranging from 20.9°C to 23.83°C, and an average temperature of 22.8°C (Figure 23). Over the thirty-three years observed, 17 years were warmer than the climatological norm (2001, 2003-2010, and 2015-2022), while the remaining 16 years were cooler. The coldest years were 1992 and 1993, with temperatures of 20.9°C, while 2005 was the warmest year, with a temperature of 23.83°C.

A very significant upward trend in minimum temperatures is noted according to the Man-Kendall test (p-value = 0.00157095). The Pettitt test identifies 2000 as a significant year of change, with a p-value of 0.002356 < 0.05. The difference in average temperature between the two periods (1990-2002) and (2002-2022) is +0.86°C.

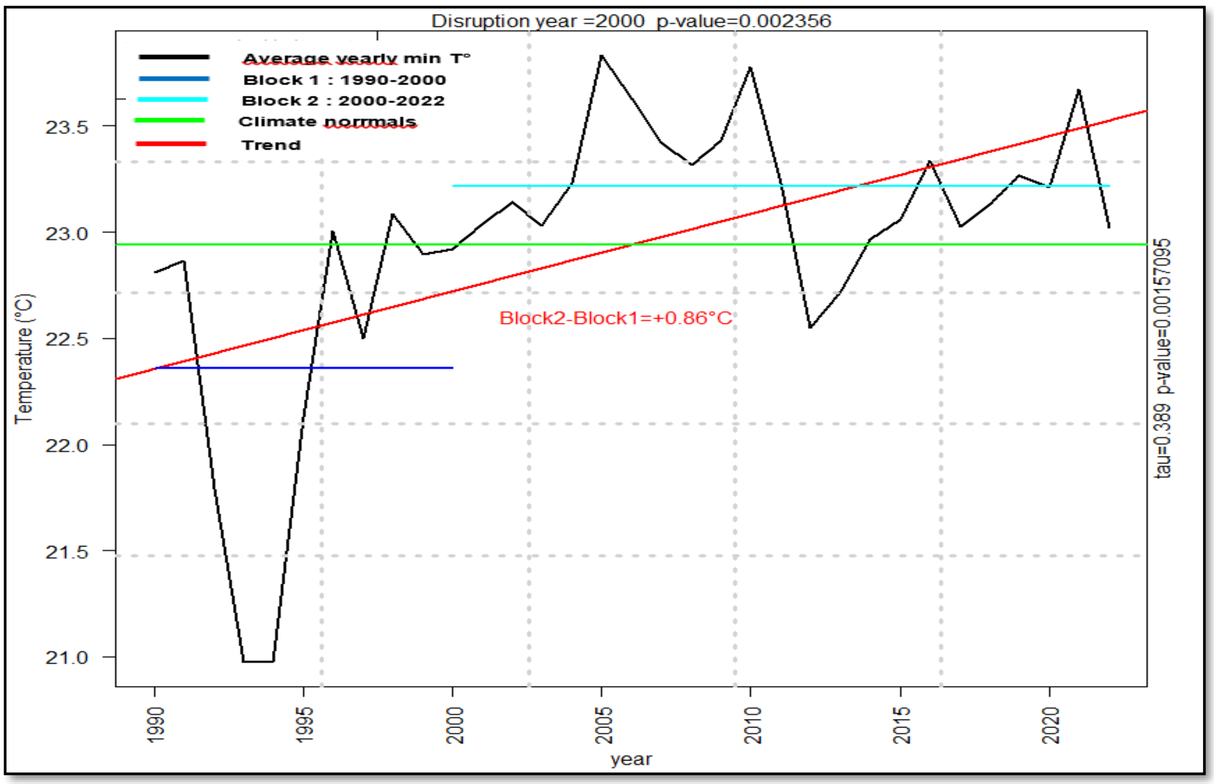

Figure 93: Interannual evolution of minimum temperatures from 1990 to 2022 in the Savanes region

4.1.2.1.4. Anomalies of minimum temperatures from 1990 to 2022

The analysis of minimum temperature anomalies in the Savanes region reveals substantial thermal variability (Figure 24). Two main periods are evident: a cold period from 1990 to 2000 and a warm period from 2001 to 2022. Warm years account for 60.6% of the time analyzed. The cold period is characterized by a succession of years with temperature anomalies ranging from -0.1 to -2.9, with the exceptions of 1996 and 1998, which show positive anomalies of +0.1 and +0.2, respectively.

Similarly, the warm period predominantly comprises warm years, with anomalies ranging from +0.05 to +1.4, with 2005 being the warmest year. However, this warm period is interspersed with two cooler years, namely 2012 and 2013.

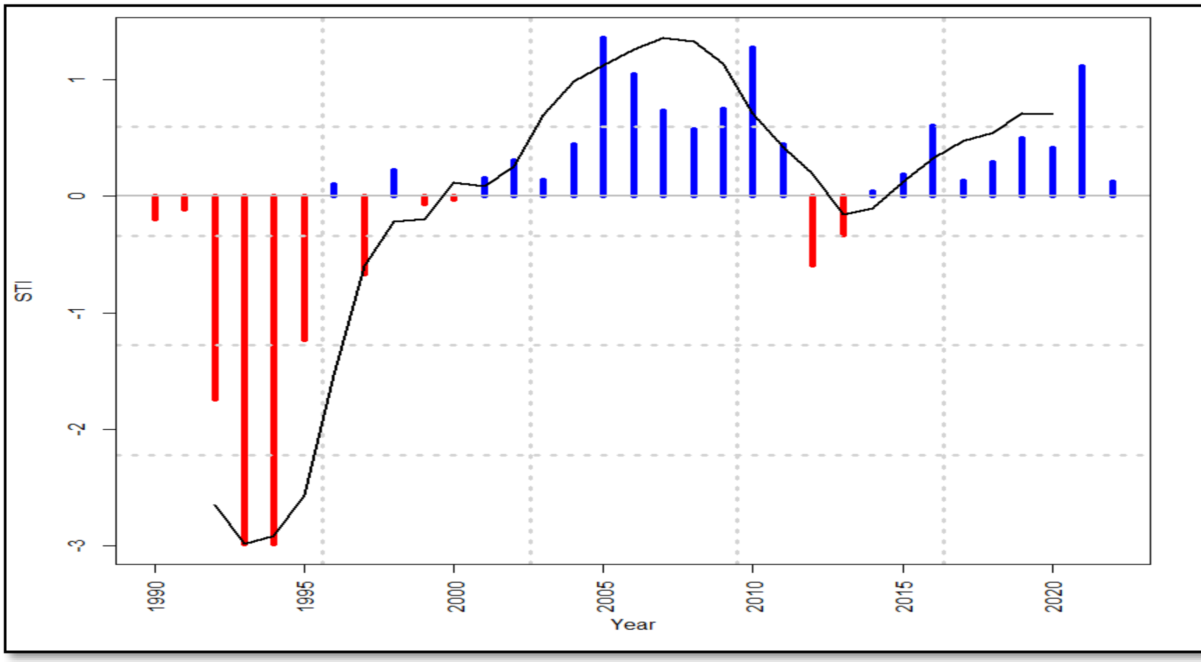

Figure 24: Anomalies of minimum temperatures from 1990 to 2022 in the Savanes region

4.1.2.1.5. Interannual variation of maximum temperatures from 1990 to 2022

The analysis of interannual variation in maximum temperatures in the Savanes region from 1990 to 2022 reveals considerable variability in the annual maximum thermal regime, ranging from 29.6°C in 1995 to 34.9°C in 2021, with a thermal norm of 33.5°C (Figure 25). There is a highly significant upward thermal trend according to the Mann-Kendall test, with a p-value of 0.00081. The Pettitt test indicates that 2012 is a year of significant change, with a p-value of 0.004497 (<5%). The difference in the average temperature between the two periods (1990-2012) and (2012-2022) is +0.98°C.

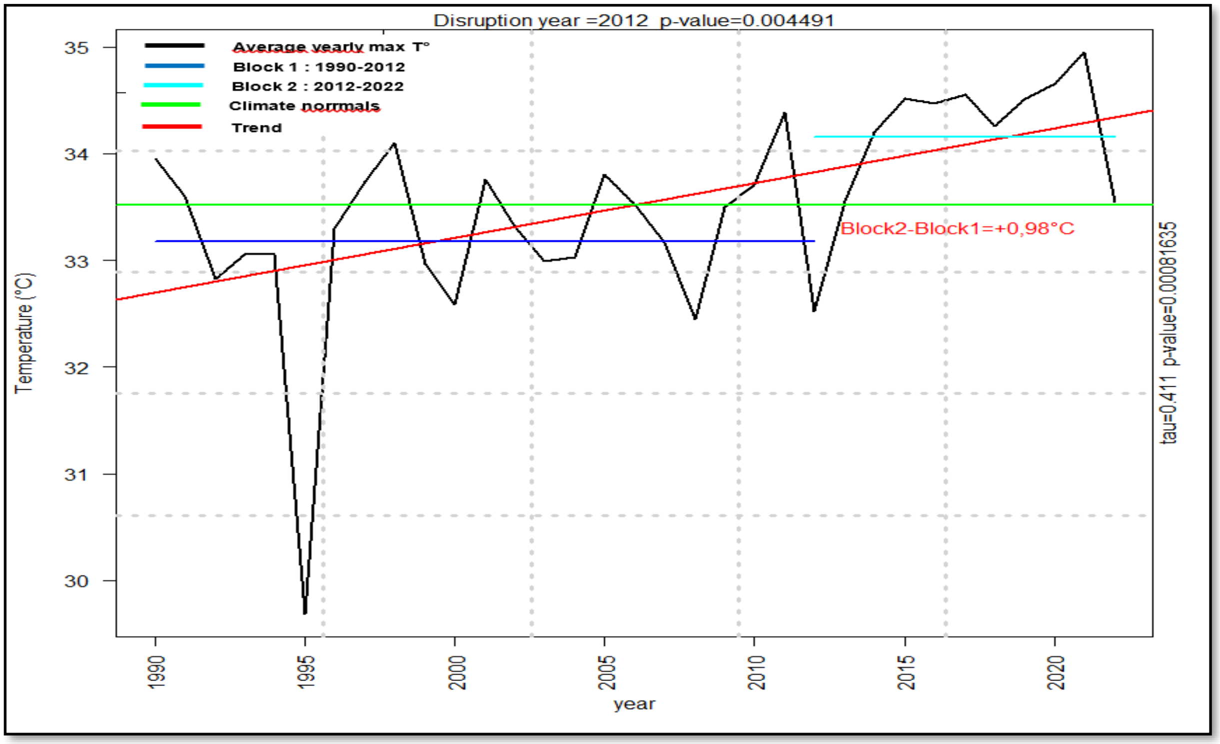

Figure 25: Interannual variation of maximum temperatures from 1990 to 2022 in the Savanes region

4.1.2.1.6. Anomalies of maximum temperatures from 1990 to 2022

The analysis of maximum temperature anomalies reveals a pronounced thermal anomaly in the Savanes region (Figure 26). Two major periods emerge: a very long cold period from 1992 to 2012 and a warm period from 2013 to 2022. The extended warm period is characterized by consistently warm years, with 80% of the indices exceeding +0.6. The year 2021 was the warmest, with an index of +1.6, while 1995 was the coldest year, with an index of -4. The cold period exhibited significant variability, marked by the intrusion of eight warm years, namely 1990, 1991, 1997, 1998, 2001, 2006, 2010, and 2011.

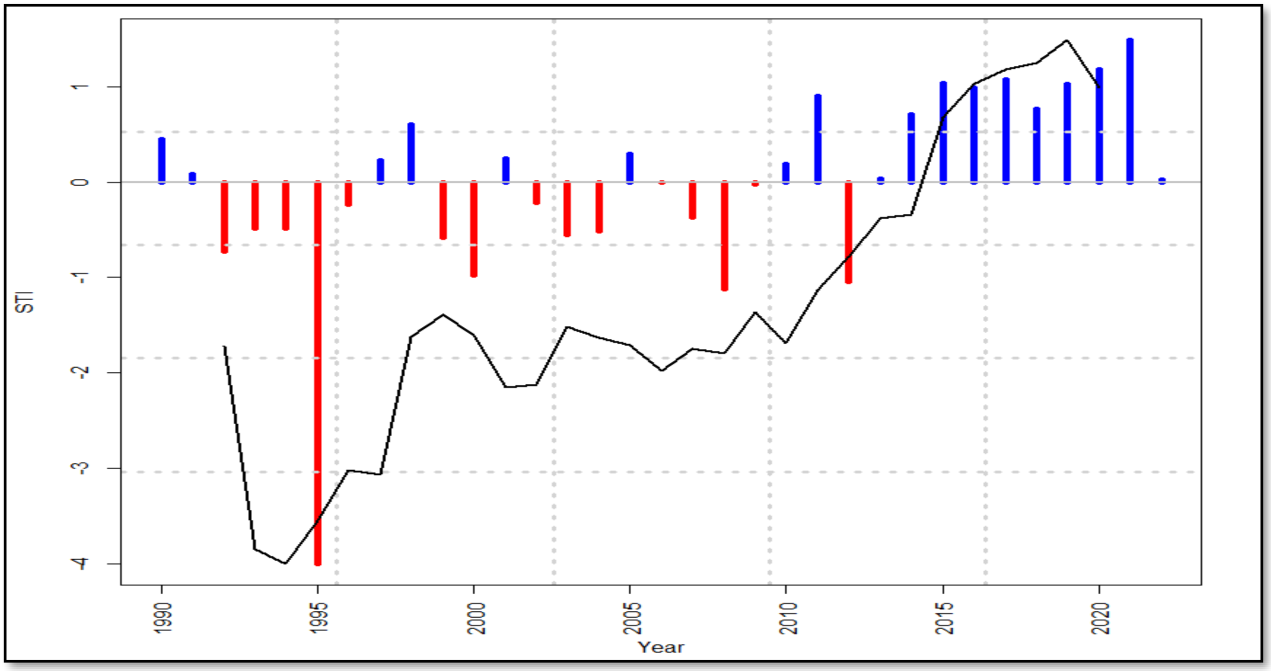

Figure 26: Anomalies of maximum temperatures from 1990 to 2022 in the Savanes region

4.1.2.1.7. Seasonal variation of rainfall from 1990 to 2022

The analysis of seasonal rainfall variation in the Savanes region reveals a unimodal rainfall regime (Figure 27). Monthly average rainfall shows significant variability throughout the year, remaining below 300 mm. The period from May to September appears to be the wettest, with average monthly rainfall exceeding 100 mm. August is the month with the highest rainfall, with average totals reaching 288 mm per month. The total rainfall for the rainy season (May to September) accounts for over 85% of the annual average total (1,000.73 mm out of 1,169 mm).

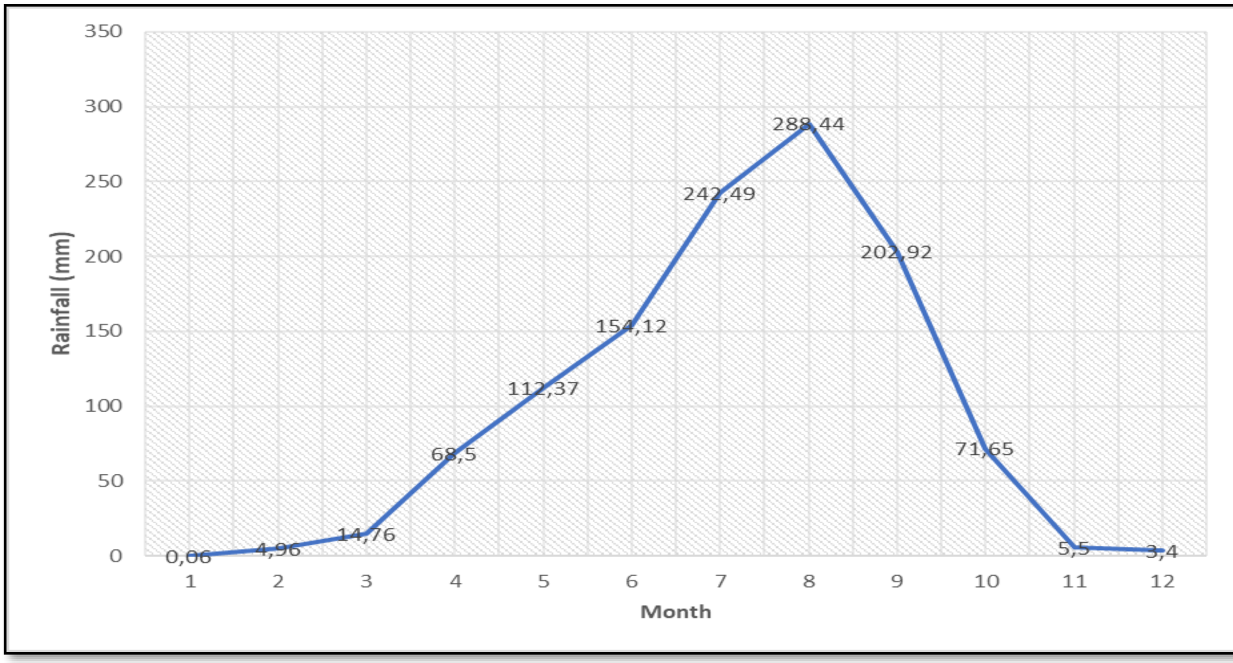

Figure 10 : seasonal variation of rainfall from 1990 to 2022 in the Savanes region

4.1.2.1.8. Seasonal variation of temperatures (maximum and minimum) from 1990 to 2022

The average monthly temperature variations range from 22.27°C to 39.19°C (Figure 28). The monthly average maximum temperatures (Tmax) range from 39.19°C in March to 29.87°C in August. Minimum temperature variations (Tmin) range from 22.27°C in August to 27°C in March. The mean temperatures (Tmean) vary between 26.16°C in August and 29.6°C in March. March appears to be the hottest month, whereas August records the lowest temperatures.

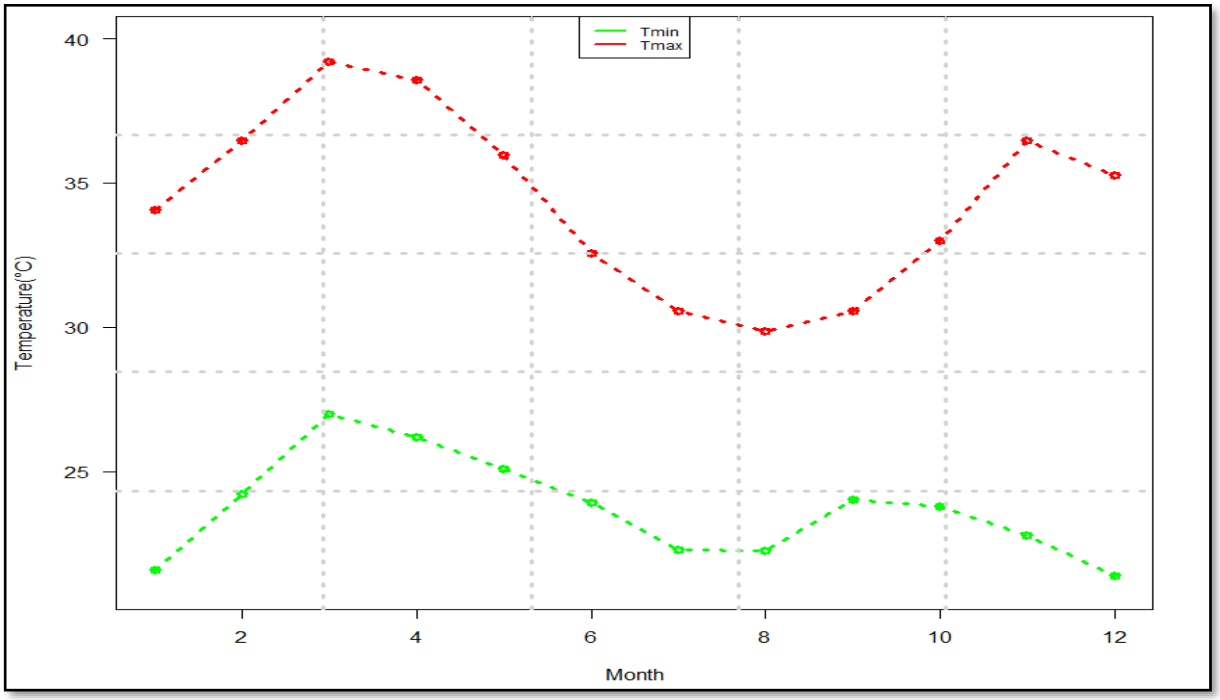

Figure 28: Seasonal variation of temperatures (maximum and minimum) from 1990 to 2022 in the Savanes region

4.1.2.1.9. Seasonal windspeed variations

Wind speed displays seasonal variations throughout the year (Figure 29), typically ranging between 1.9 m/s and 4.25 m/s. The months from September to November record reduced wind speeds, falling below 2.25 m/s, whereas January and February report the highest values, all exceeding 3.75 m/s, with a pinnacle of 4.25 m/s documented in January.

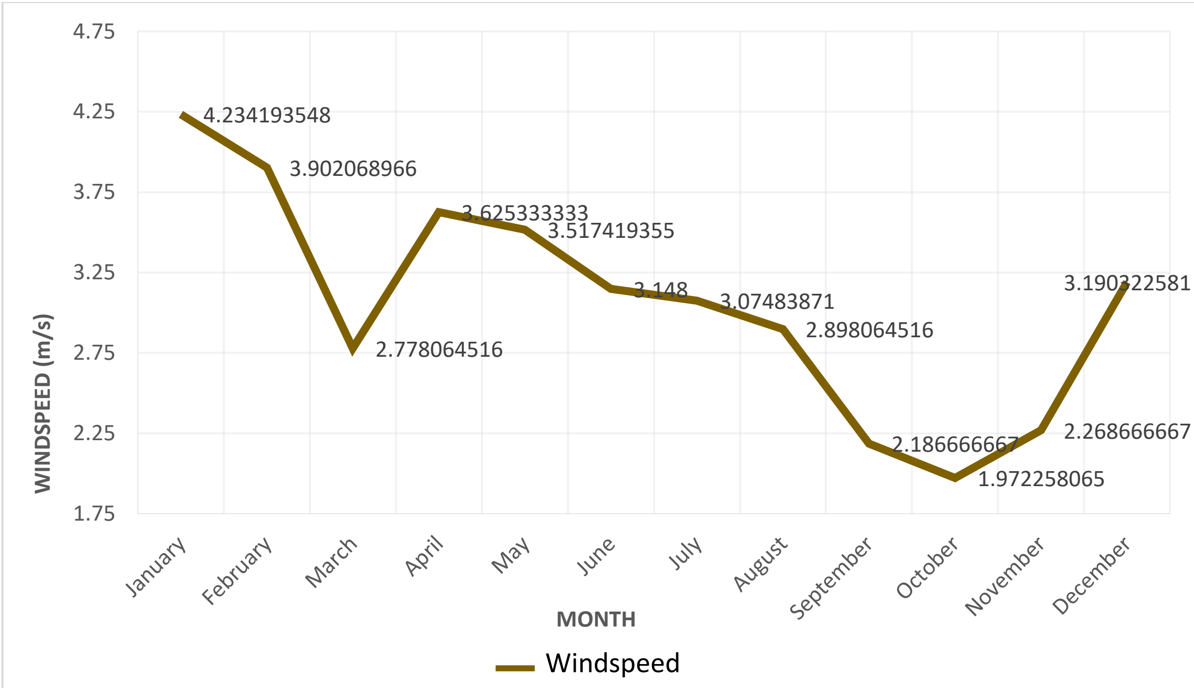

Figure 29: Seasonal Windspeed Variations from 1990 to 2022

4.1.2.1.10. Seasonal relative humidity patterns

Monthly relative humidities, encompassing both maximum and minimum values, undergo significant fluctuations over the course of the year, generally oscillating between 40% and 80% (Figure 30 and 31). The minimum relative humidity (UMIN) demonstrates a range from 40% in October to 50% in November, as depicted in figure 30. Meanwhile, the maximum humidity (UMAX) fluctuates from 67% in July to 80% in June, as portrayed in Figure 31.

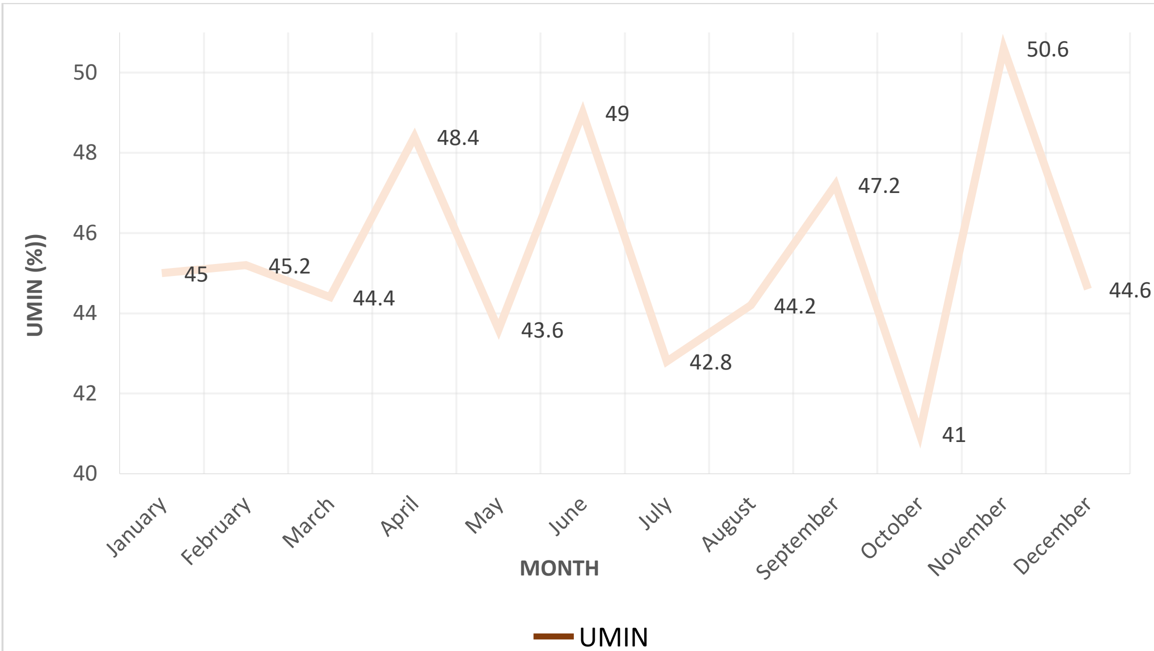

Figure 30: Seasonal minimum relative humidity variation from 1990 to 2022

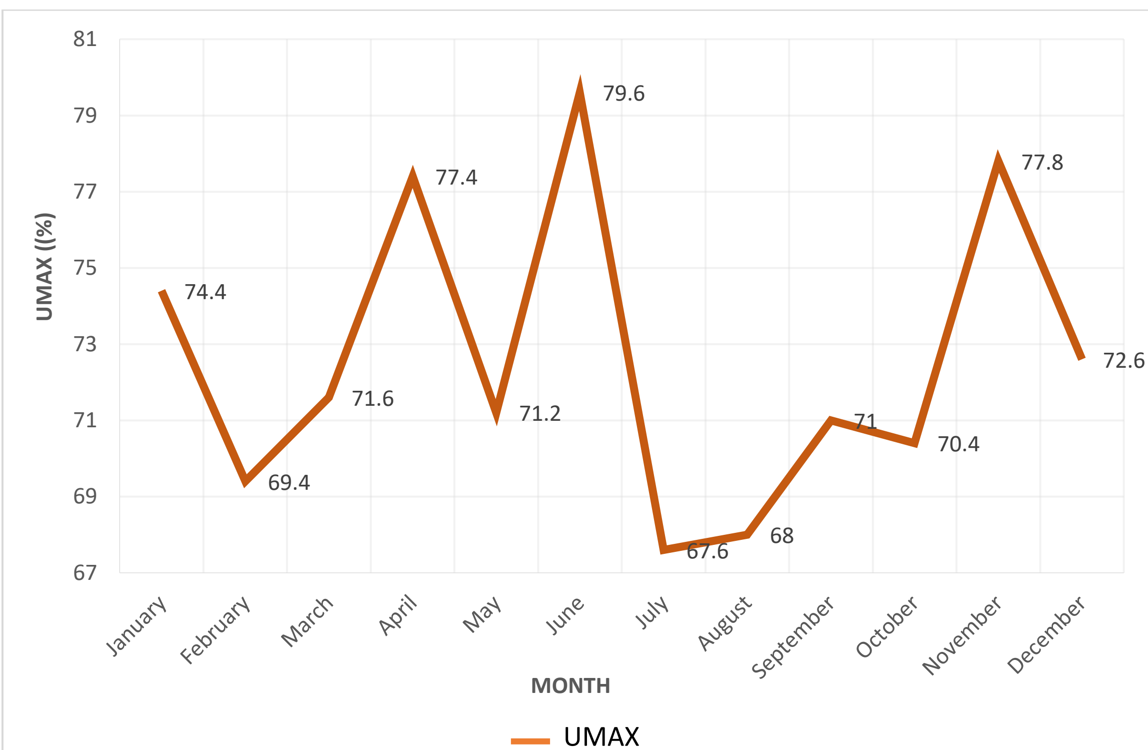

Figure 31: Seasonal maximum relative humidity variation from 1990 to 2022

4.1.2.1.11. Seasonal changes in vegetation index

The Normalized Difference Vegetation Index (NDVI) exhibits substantial variations throughout the year, typically oscillating between 0.7 and 1.9 (Figure 32). The lowest indices manifest during the arid months of January to April, all falling below 1. Vegetation growth commences from May onwards, corresponding to the onset of the initial rains of the season. Elevated NDVI values, ranging from 1.4 to 1.9, are observed during the rainy season, culminating in a peak in October, reaching 1.9.

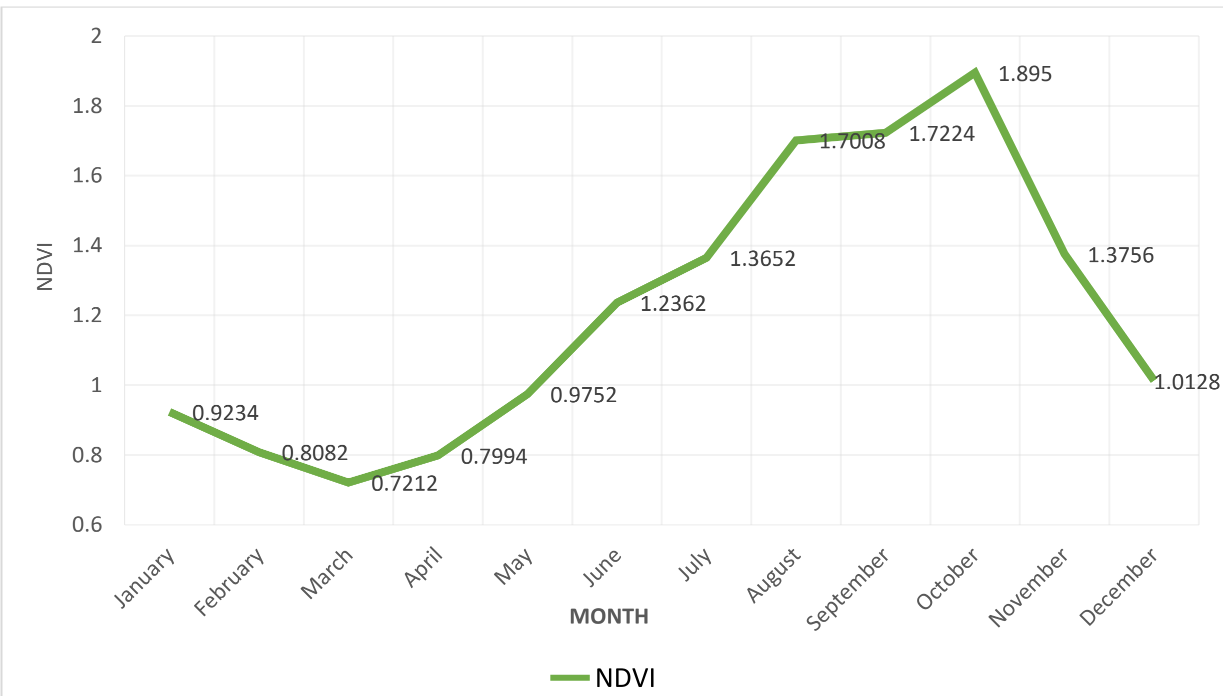

Figure 32: Seasonal variation of vegetation index from 1990 to 2022

4.1.2.1.12. Seasonal insolation variations

The average monthly duration of sunshine throughout the year fluctuates between 5.3 and 10 hours per day (Figure 33). The highest duration of 10 hours is observed in November, whereas the lowest values, less than 6 hours (specifically 5.3 hours), are recorded in July and August. These periods align with extensive cloud cover, effectively acting as a screen against the sun's rays.

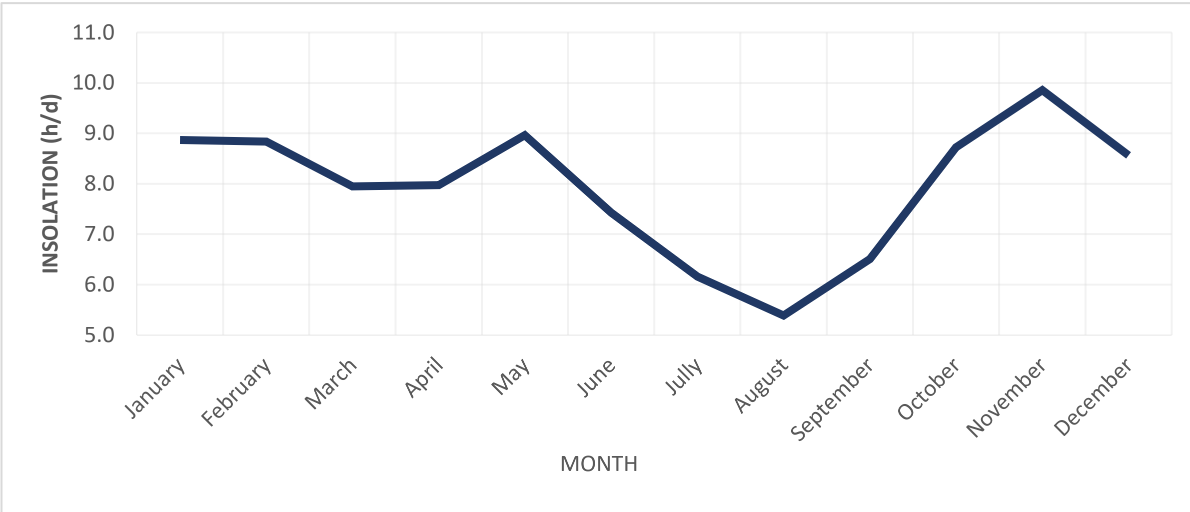

Figure 33: Seasonal variation of insolation in the Savanes region from 1990 to 2022

4.1.2.2. Characterization of health patterns

4.1.2.2.1. Interannual variation of asthma cases in Savanes from 2018 to 2022

Analysis of annual asthma case data from 2018 to 2022 reveals variability in this condition over the five-year period in the Savanes region (Figure 34). Specifically, the annual totals of asthma cases range from 621 cases in 2021 to 742 cases in 2022. There was a slight increase of 41 cases from 2018 to 2019, followed by a nearly negligible decrease of 9 cases in 2020 and 46 cases in 2021. From 2021 to 2022, a substantial increase of 121 asthma cases was observed.

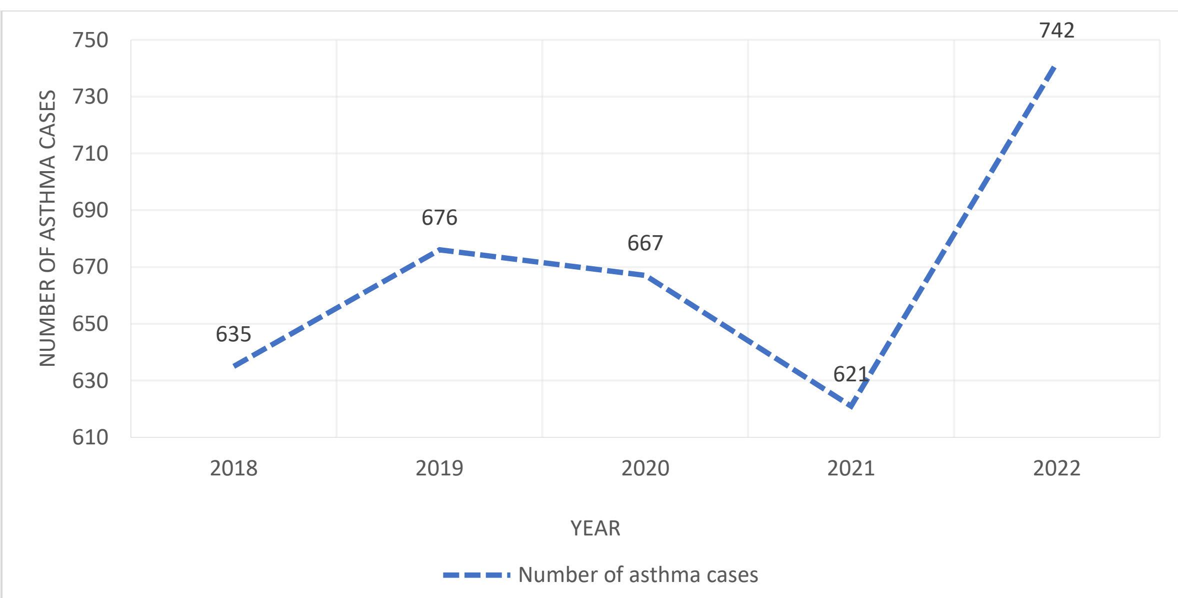

Figure 34: Interannual variation of asthma cases in the Savanes region from 2018 to 2022

4.1.2.2.2. Intermonthly variation of asthma cases from 2018 to 2022 in the Savanes region

From January 2018 to December 2022, the intermonthly variation in asthma cases exhibited notable fluctuations (Figure 35). In 2018, the months of February, August, and October to December recorded asthma case numbers above the average (53 cases), with a peak of 127 cases observed in February. January, with 20 cases, had the lowest number of asthma cases for the year. In 2019, the months from January to March, May, August, and October experienced elevated asthma cases above average (56 cases), with an initial peak of 72 cases observed in May. In 2020, the months of January, June, July, and from August to December had asthma case numbers above the average (31 cases), with November recording the highest number at 81 cases. For 2021, six months exceeded the average of 52 cases, specifically May, August, and October to December. Notably, 2021 exhibited three peaks: May with 63 cases, August with 62 cases, and November with 81 cases. Finally, in 2022, the months from June to August and from October to December had asthma case numbers above the annual average of 62 cases, with several small peaks observed during these months.

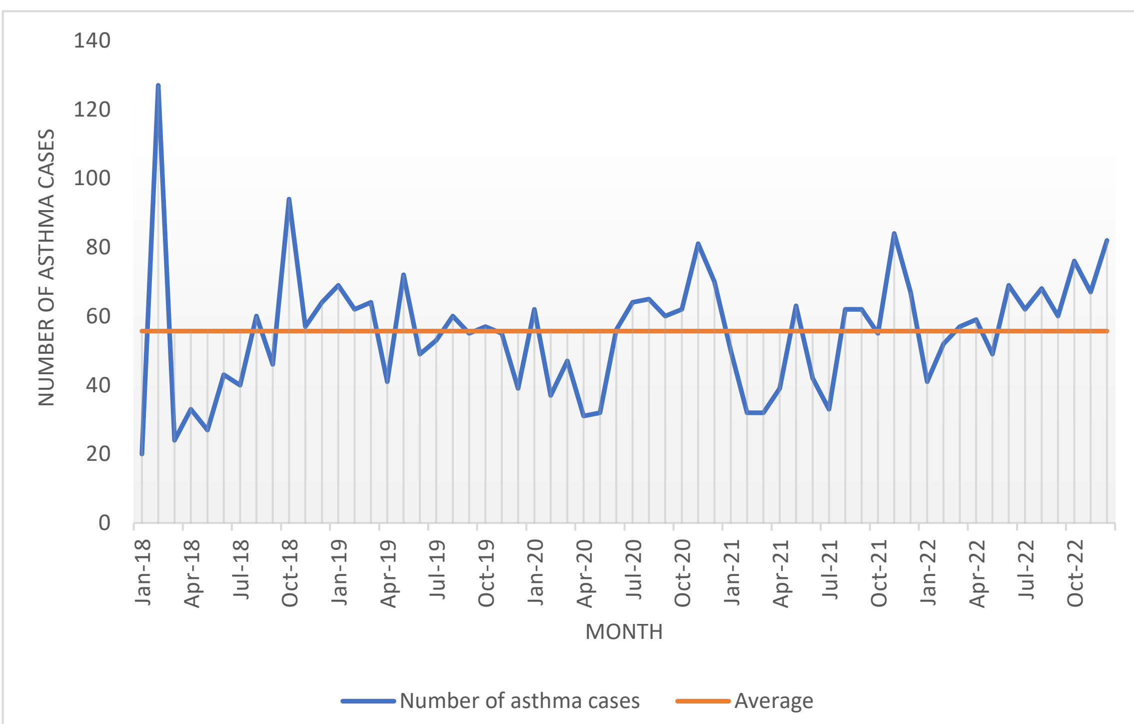

Figure 35: Intermonthly variation of asthma cases from 2018 to 2022 in the Savanes region

4.1.2.2.3. Seasonal variation of asthma cases from 2018 to 2022 in the Savanes region

The analysis of the seasonal variation in asthma cases in the Savanes region reveals significant fluctuations throughout the year (Figure 36). The highest asthma case numbers are recorded during the months of February, August, and from October to December, with the cumulative rates for these three months representing nearly 48.72% of the annual rate, and peaks observed in October and November, each with 68 cases. In contrast, the months of March and April exhibit the lowest asthma case numbers, with 40 and 45 cases respectively. The months from October to December, August, and February are identified as periods most conducive to asthma exacerbations.

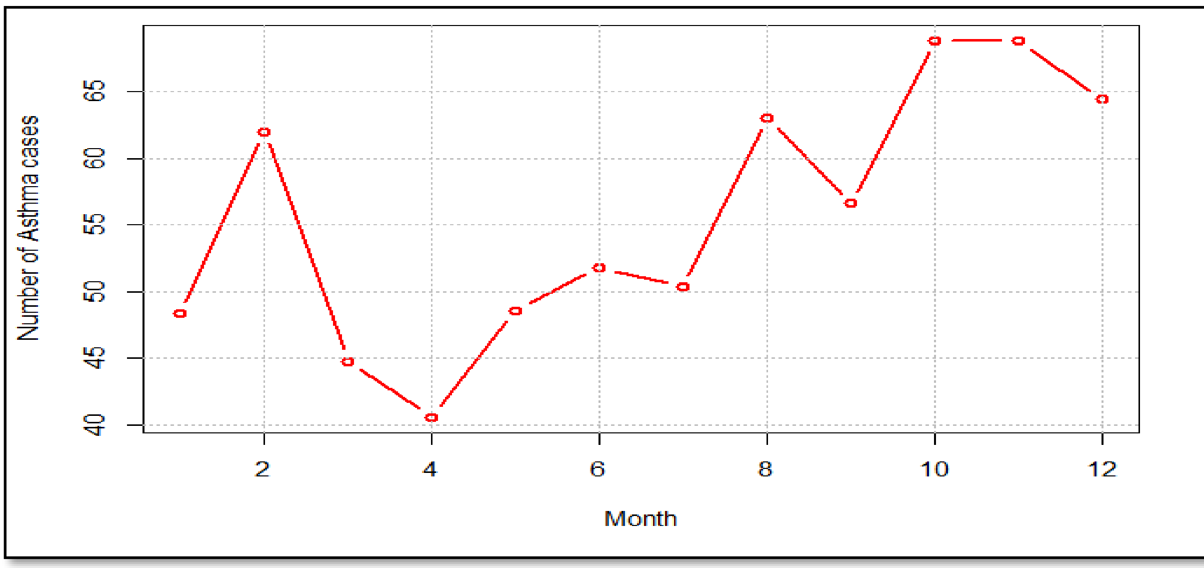

Figure 36: Seasonal variation of asthma cases from 2018 to 2022 in the Savanes region

4.1.3. Correlations between climatic and environmental parameters and Asthma

The findings underscore a robust correlation between specific climatic and environmental parameters and asthma incidence in both the Savanes and Grand-Lomé regions (Table II).

Within the Savanes region, there are three parameters, namely the Normalized Difference Vegetation Index (NDVI), minimum temperature (TMIN), and wind speed (Windspeed), exhibited statistically significant correlations with asthma at the 5% significance level. NDVI displayed a positive correlation, with correlation coefficients (r) and p-values of 0.63 and 0.02, respectively.

In contrast, TMIN and Windspeed demonstrated negative correlations with asthma, characterized by (r) values of -0.53 and 0.60, along with corresponding p-values of 0.04275 and 0.035.

In the Grand-Lomé region, only two parameters, Maximum Relative Humidity (UMAX) and insolation (Inso), exhibited significant correlations with asthma at the 5% significance level. UMAX displayed a positive correlation of 0.75, with a p-value of 0.005, while Inso exhibited an (r) of 0.66, accompanied by a p-value of 0.01.

Table II : Correlation between climatological and environmental parameters and asthma

Région	cor	TMAX	NDVI	TMIN	Windspeed	UMAX	UMIN	RR	Inso
Savanes	r	-0.31	0.63	-0.53	-0.60	-0.02	0.07	-0.04	0.14
	P-value	0.318	0.026*	0.042*	0.035*	0.943	0.805	0.886	0.656
Grand-Lomé	r	-0.02	0.30	-0.20	-0.36	0.75*	-0.03	-0.05	0.66*
	P-value	0.943	0.332	0.526	0.242	0.005	0.912	0.874	0.017

* *Significance at 5% confidence level*

4.1.3.1. Correlation between asthma and maximum relative humidity in the Grand-Lomé region

Analysis of figure 37 revealed an augmentation in maximum relative humidity corresponds to an escalation in the incidence of asthma cases. These trends both culminate in their zeniths during October and November, respectively, before experiencing a subsequent decline.

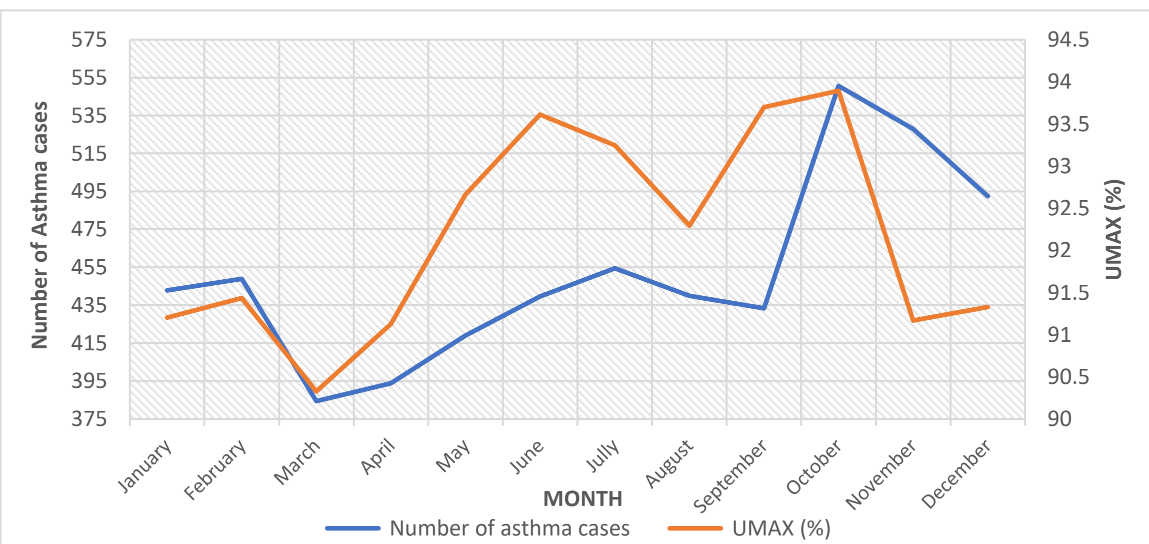

Figure 37: Correlation between asthma and maximum relative humidity in the Grand-Lomé region

4.1.3.2. Correlation between asthma and insolation in the Grand-Lomé region

The variation in the number of asthma cases mirrors a proportional relationship with the duration of insolation, except during the period from June to August when the trends deviate (Figure 38). From January to May and from September to December, the duration of sunshine parallels that of asthma cases. In contrast, from June to August, the number of asthma cases increases while the duration of sunshine appears to decrease.

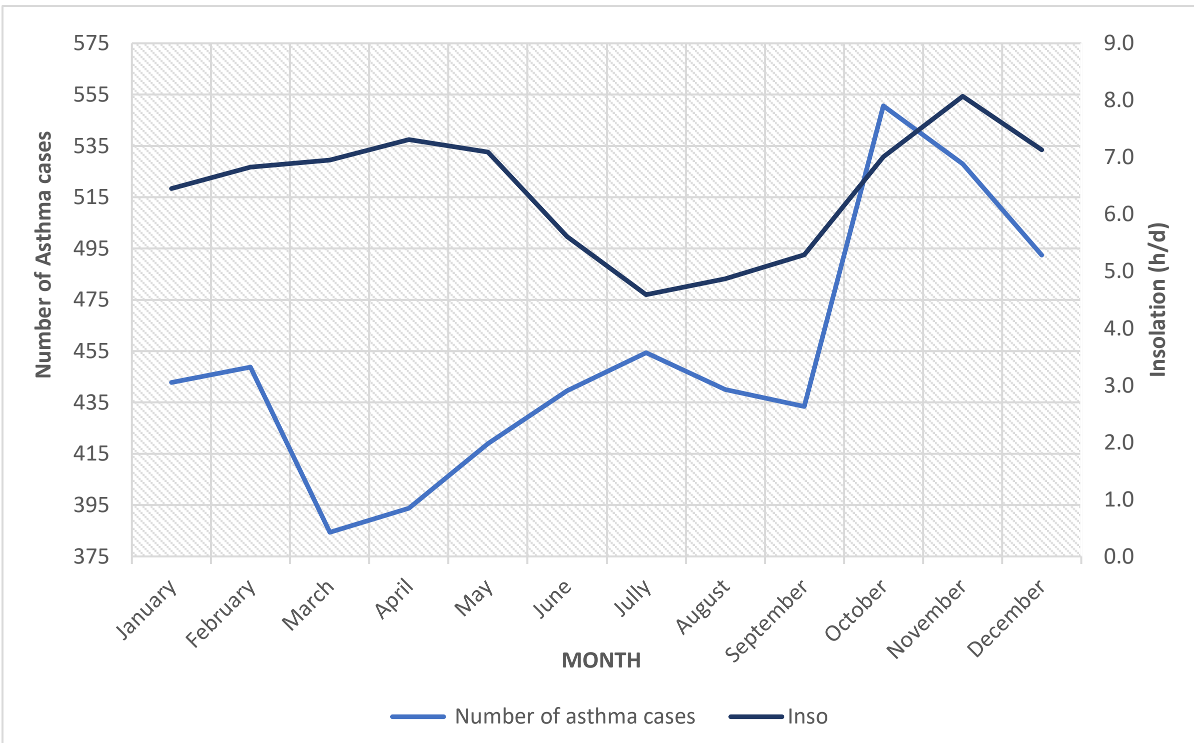

Figure 38: Correlation between asthma and insolation in the Grand-Lomé region

4.1.3.3. Correlation between asthma and vegetation index in the Savanes region

It has been observed that an increase in the vegetation index is paralleled by an uptick in the number of asthma cases from March to October, reaching their peaks during this period, and subsequently declining until December. Notably, a peculiar anomaly surfaces in January and February, where the incidence of asthma cases increases despite a decline in the vegetation index (Figure 39).

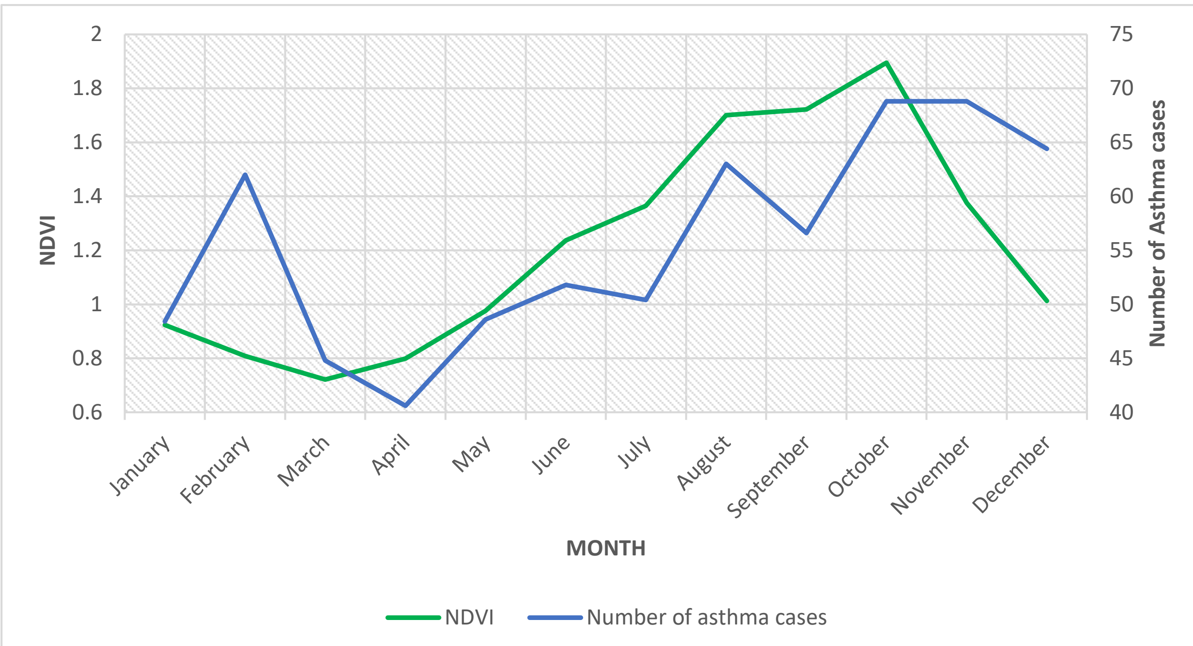

Figure 39: Correlation between asthma and vegetation index in the Savanes region

4.1.3.4. Correlation between asthma and windspeed in the Savanes region

Examination of the association between asthma cases and wind speed unveils a contrasting pattern (Figure 40). The trajectory of asthma cases appears to oppose that of wind speed throughout the year. When wind speed is relatively high, cases of asthma tend to decrease, while a decrease in wind speed coincides with an increase in asthma cases.

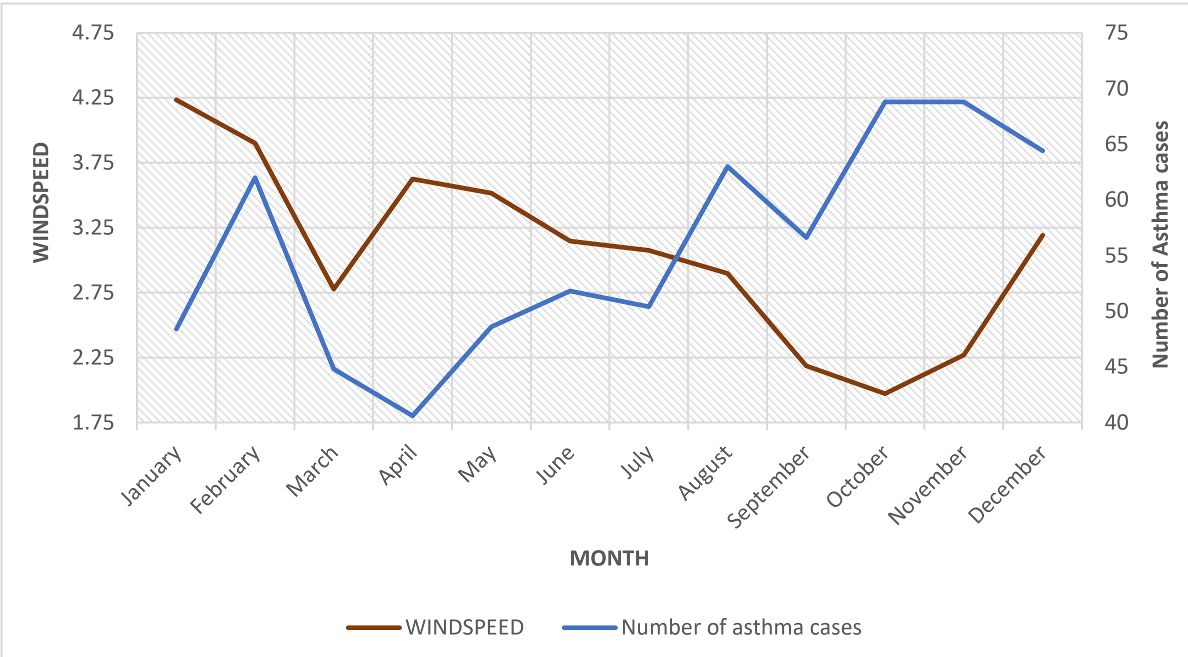

Figure 4011 : Correlation between asthma and windspeed in the Savanes region

4.1.3.5. Correlation between asthma and minimum temperature in the Savanes region

Analysis of the correlation between asthma and minimum temperature reveals a divergent trend (Figure 41). Specifically, during the period from February to July, when minimum temperatures are elevated, the number of asthma cases appears to be notably low. In contrast, from August to December, the period of relatively lower minimum temperatures, there is an increase in asthma cases.

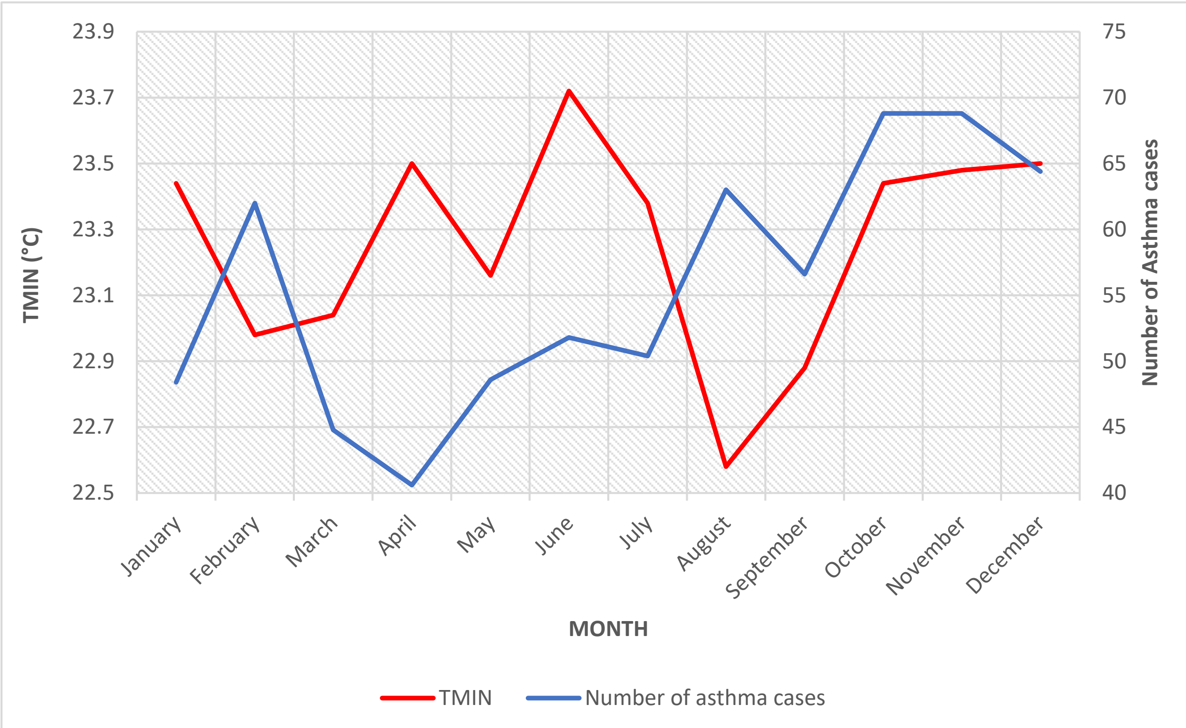

Figure 41: Correlation between asthma and windspeed in the Savanes region

4.2.Discussion

The findings from this investigation revealed notable associations between asthma and various climatic and environmental factors, including vegetation, wind speed, minimum temperature, maximum relative humidity, and sunshine duration.

4.2.1. Climatic and environmental parameters influencing asthma in the Savanes region

The analysis demonstrates a positive correlation between the incidence of asthma cases in the Savanes region and vegetation, while it reveals negative correlations with minimum temperature and wind speed. These results signify that heightened vegetation, reduced wind speed, and lower temperatures create favorable climatic conditions conducive to the occurrence of asthma attacks.

4.2.1.1. Link between vegetation and asthma

The findings of our study demonstrate a parallel increase in asthma cases with the vegetation index. This phenomenon can be attributed to the capacity of pollen from flowers, trees, and grasses to induce allergic reactions in susceptible individuals, thereby exacerbating asthma symptoms. Furthermore, certain plant species emit volatile chemical substances, such as essential oils, which can irritate the airways of asthma patients, leading to asthma attacks. Annesi-Maesano et al. (2010) observed that specific plant species, notably deciduous trees, were associated with a heightened prevalence of asthma in children. Biel et al. (2007) investigated the impact of allergenic plants like ragweed on the prevalence of asthma in farmers and found an association between ragweed exposure and an increased prevalence of asthma in this group.

The work by Zock et al. (2005) supported the adverse effects of vegetation on asthmatics by studying the influence of airborne allergens, including those originating from plants, on the exacerbation of asthma symptoms. Their study revealed that exposure to certain allergens like pollen could contribute to the worsening of asthma symptoms in susceptible individuals.

Furthermore, other researchers, such as Heinrich et al. (2005), confirmed the detrimental impact of vegetation on individuals with asthma. Heinrich et al. (2005) explored the relationship between exposure to vegetation and the development of asthma in children, and their results indicated that certain microbial components within vegetation, such as endotoxins, could be associated with an elevated risk of asthma.

Nevertheless, it is essential to acknowledge that some studies present results that contradict our findings. For instance, research by Reese et al. (2007) examined the presence of vegetation around dwellings and its impact on asthma prevalence in adults. They found that adults residing in areas with higher vegetation coverage had a lower prevalence of asthma compared to those in less green areas. Similarly, other studies conducted in 2009 by the same authors, focusing on the role of urban parks in alleviating asthma symptoms in children, indicated that children living near urban parks experienced a reduction in asthma symptoms. These results suggest that the presence of vegetation in green spaces may have beneficial effects on the health of individuals with asthma by enhancing air quality and reducing pollution levels.

4.2.1.2. Link between minimum temperature and asthma

Our study reveals that a decrease in minimum temperatures is associated with an increased likelihood of the onset or exacerbation of asthma. These findings align with those of Song et al. (2021), who observed that a decrease in temperature correlated with a rise in emergency department visits for asthma among children in South Korea. Similarly, Bloomfield et al. (2018) discovered that periods of severe cold were linked to an upsurge in emergency department visits for asthma in children in Atlanta, USA, indicating that colder temperatures may exacerbate asthma symptoms.

Furthermore, other authors investigating respiratory infections, such as Ferrari et al. (2012), have reported a 1% increase in outpatient consultations for Chronic Obstructive Pulmonary Disease (COPD) for every degree Fahrenheit decrease in Bavaria. Tseng et al. (2013) also noted an increase of 0.8% in the number of outpatient consultations for COPD for each 1°C drop in temperature during their studies in Taiwan, accompanied by a rise in emergency room consultations in colder regions.

The exacerbation of asthma symptoms in cold weather can be attributed to several factors. Inhaling cold air has the potential to irritate airways, inducing bronchial constriction in some individuals with asthma, leading to symptoms like coughing, shortness of breath, and wheezing. Additionally, Monto (2000) has noted that acute respiratory infections, including respiratory viruses like rhinoviruses and influenza viruses, are more prevalent during colder periods. These infections can trigger asthma symptoms in susceptible individuals, as individuals with asthma may be more susceptible to respiratory infections when exposed to colder temperatures, thus worsening their asthma symptoms.

It is also noteworthy that during the colder months, people tend to spend more time indoors, where the concentration of specific asthma triggers, such as dust mites, mold, and animal dander, can be higher. These allergens and irritants have the potential to provoke asthma symptoms in sensitive individuals, as evidenced by Dharmage (2019), who analyzed data from a large cohort of Australian children and found an association between early exposure to pet hair and an increased risk of asthma.

Moreover, Tischer et al. (2018) examined the association between exposure to mold in homes and children's respiratory health, suggesting that exposure to mold and its compounds may contribute to respiratory problems in children. This finding was consistent with the observations of Sordillo et al. (2018), who explored the relationship between the gut microbiome of infants and the risk of asthma. Their results indicated that factors such as exposure to environmental allergens, including mold and animal hair, can influence the composition of the gut microbiome and contribute to the development of asthma. Additionally, cold weather is a meteorological factor that can act as a trigger for or an aggravator of asthma attacks.

4.2.1.3. Link between wind speed and asthma

Our data analysis has unveiled a compelling association between low wind speed and an upswing in asthma attacks. These findings are in consonance with the research of several other authors, including Sunyer et al. (2000), who investigated the relationship between wind speed and respiratory symptoms in elderly individuals. They observed that days characterized by low wind speed were linked to an increased incidence of respiratory symptoms, including asthma. The plausible explanation for this association lies in the phenomenon that, as wind speed diminishes, the air tends to stagnate. Such stagnation can foster the accumulation of various pollutants, including fine particles, allergens, chemical irritants, or toxic gases in the atmosphere. Inhaling these substances can incite asthma symptoms in susceptible individuals. Similarly, Gavett et al. (2003) noted in their study that days featuring low wind speeds were correlated with an escalation in respiratory symptoms, including asthma. They pointed out that fine particles of air pollution are typically less dispersed on low-wind-speed days, exacerbating respiratory symptoms.

In line with these findings, Gupta et al. (2017) conducted an evaluation of the impact of weather conditions on asthma emergency visits in India. They established that low wind speed was linked to an increase in asthma emergency visits, suggesting a connection between limited pollutant dispersion and the exacerbation of asthma symptoms. Consistent observations were also made in China by Xu et al. (2014), who identified that low wind speed was associated with a heightened risk of asthma attacks in children, particularly in the presence of elevated air pollution levels.

However, it is imperative to acknowledge that, despite our results showcasing a positive correlation between low wind speeds and an increase in asthma attacks, some studies paradoxically reveal that high wind speeds can also induce the aggravation or initiation of asthma attacks. In this context, Halonen et al. (2010), following a study involving asthmatic children, disclosed that strong winds were linked to an augmentation of asthma symptoms. This suggests that high wind speeds can result in a greater dispersion of allergens in the air, thereby triggering asthma attacks in susceptible individuals. For Rönmark et al. (2011), robust winds might lead to an amplification in the dispersion of atmospheric pollutants, thereby intensifying asthma symptoms. According to Herrera-Van Oostdam et al. (2016), strong winds could facilitate the dispersion of pollutants such as vehicle exhaust fumes, dust storms, or sandstorms. These conditions can irritate airways and incite asthma symptoms in certain individuals with asthma.

4.2.2. Climatic parameters influencing asthma in Grand-Lomé region

As in the Savanes region, asthma exhibits correlations with specific climatic parameters. Asthma displays a positive correlation with both maximum relative humidity and insolation, implying that heightened levels of both maximum relative humidity and insolation are climatic conditions conducive to the occurrence of asthma attacks.

4.2.2.1. Link between maximum relative humidity and asthma

Our study findings suggest that increased relative humidity can serve as a triggering factor for asthma symptoms or exacerbate existing ones. High relative humidity tends to foster the proliferation of common asthma triggers, such as molds and dust mites. Furthermore, mold spores and dust mite allergens can permeate indoor air, resulting in elevated exposure and a potential worsening of asthma symptoms. Chen et al. (2018) also noted a connection between high relative humidity and increased hospitalizations for asthma in adults. They proposed that relative humidity might influence indoor air quality by promoting mold growth and the release of volatile organic compounds, which can worsen asthma symptoms. A study in Tunisia by Denguezli et al. (2020) uncovered a correlation between high relative humidity and the prevalence of asthma in children, suggesting that relative humidity may favor the growth of house dust mites a common source of allergens for asthma sufferers that also thrive in damp environments. These mites are often found in household dust and can trigger asthma symptoms upon inhalation.

A meta-analysis conducted by Zhang et al. (2019) substantiates a significant association between high relative humidity and an upsurge in asthma symptoms. The same authors propose that this link can be attributed to the role of relative humidity in promoting the proliferation of allergens and irritants within indoor environments, thereby constituting factors that either trigger or exacerbate asthma attacks. Research carried out in Japan unveiled an association between high relative humidity and increased airway inflammation in asthma patients. Some individuals with asthma possess airways that are particularly sensitive to changes in relative humidity. Elevated relative humidity levels can result in airway swelling, heightened mucus production, and increased bronchial reactivity, culminating in asthma symptoms like coughing, shortness of breath, and wheezing. This suggests that relative humidity can act as a stressor on the airways, aggravating asthma symptoms. It is worth considering that individuals residing in regions characterized by low relative humidity may exhibit increased sensitivity to sudden spikes in relative humidity. These abrupt shifts in atmospheric relative humidity can lead to airway constriction in people with asthma, culminating in heightened symptoms such as wheezing, shortness of breath, and coughing.

4.2.2.2. Link between insolation and asthma

Extended exposure to sunlight appears to induce or exacerbate asthma attacks. Prolonged exposure to high temperatures can elevate respiratory rates and lead to shallow breathing, resulting in breathing difficulties for individuals with asthma. Additionally, as indicated by Silverman et al. (2014), excessive sun exposure may contribute to airway inflammation, thereby increasing the risk of asthma attacks. It is worth noting that prolonged exposure to sunlight can heighten the risk of dehydration. Dehydration, in turn, can lead to the thickening of bronchial secretions, which has the potential to worsen asthma symptoms.

For other researchers, such as Castro-Rodriguez et al. (2019), the onset or exacerbation of asthma attacks due to prolonged sun exposure can be attributed to bronchial reactivity. According to their findings, ultraviolet rays may enhance airway sensitivity to various stimuli, including allergens or physical exertion, potentially aggravating asthma symptoms in susceptible individuals. Hajat et al. (2014) uncovered that prolonged exposure to intense sunlight can be associated with increased air pollution, particularly elevated ozone levels. These heightened ozone concentrations can irritate the airways and trigger asthma attacks in individuals with heightened sensitivity.

4.2.3. Comparison of Asthma prevalence between the Grand-Lomé region and the Savanes region

Numerous factors may contribute to variations in asthma prevalence across different geographic regions, particularly when comparing coastal and Savanes areas.

Coastal environments typically exhibit higher humidity levels, fostering the proliferation of molds. This phenomenon may elucidate the elevated concentration of common asthma triggers, such as pollens, molds, and dust mites, in coastal areas. Furthermore, coastal regions often host major economic centers, rendering them more susceptible to air pollution stemming from industrial activities, vehicular traffic, and maritime operations. This air pollution, characterized by fine particulates and noxious gases, has the potential to exacerbate asthma symptoms and elevate the risk of asthma development. Distinct climatic patterns between coastal areas and Savanes can also influence asthma prevalence. Coastal regions tend to experience greater relative humidity, milder temperatures, and variable weather conditions, all of which can impact the frequency and severity of asthma cases.

Socioeconomic disparities between these regions may additionally contribute to variations in asthma prevalence. Limited access to healthcare in rural or Savanes areas can result in delayed diagnosis and treatment of asthma, thus affecting the overall prevalence of the disease.

4.3.Partial conclusion

The findings underscore a notably robust association between climatic parameters and Asthma, with temperature, relative humidity, insolation, vegetation density, and wind speed emerging as the principal contributing factors to the ailment. Lower temperatures can incite heightened airway inflammation, exacerbating Asthma symptoms. Elevated relative humidity fosters the proliferation of common Asthma triggers, including dust mites and mold. Intense solar radiation can lead to the generation of air pollutants, intensifying the severity of respiratory issues. The density of vegetation can elevate pollen concentrations, a significant allergen for individuals afflicted by Asthma. Additionally, wind speed can shape the dispersion of atmospheric pollutants, thereby exacerbating Asthma symptoms.

Moreover, this investigation has unveiled an incongruity in the prevalence of Asthma between the Grand-Lomé region, characterized by its coastal climate, and the Savanes region, marked by its Sahelian climate. The Grand-Lomé region exhibits a higher Asthma prevalence, attributable to a constellation of factors including heightened population density, greater exposure to air pollutants stemming from urban industrial and transport activities, disparate living conditions, and discrepancies in healthcare accessibility. Consequently, these findings underscore the imperative of integrating climatic and environmental parameters into the management of Asthma, particularly within regions where these factors wield significant influence.

CHAPTER 5: RESULTS AND DISCUSSION OF AXIS 2

This research axis aims to assess the perceptions of individuals affected by asthma and health practitioners regarding climate and environmental triggers that exacerbate asthma crises in the study areas. This objective seeks to capture qualitative insights into how climate-related factors such as air quality, pollen levels, and weather changes are perceived to impact asthma episodes. The result is divided into two stages. The first stage presents the result of the perceptions of health practitioners and the second presents the result of the asthmatics perceptions.

5.1.Results

5.1.1. Perceptions of health practitioners

5.1.1.1.Profile of participants and their level of knowledge on climate change and air pollution

This section summarizes the socio-professional characteristics of the surveyed healthcare workers as well as their level of knowledge on climate change and air pollution (Table III).

Taking into account the participants' profile, the survey reached more nurses (49.6%) than doctors (23%), with medical assistants and other healthcare professionals representing 27.4%. The study population exhibits a clear male predominance with 53%, and 47% of women. Moreover, participants primarily come from the departments of pediatrics (22.6%), internal medicine (37.8%), pulmonology (24.9%), and maternity (14.7%).

Regarding participants' involvement in climate change training, the results revealed that 39.2% of them had undergone at least one training, while 60.8% had not had this opportunity. Thus, the relatively high percentage of beneficiaries of climate change training may indicate a growing awareness of the importance of this issue in the current context and their manifest willingness to deepen their understanding of the challenges related to climate change. This may also demonstrate their commitment to environmental protection and combating the adverse effects of climate change in general, and specifically on health. However, the knowledge acquired by this relatively high proportion of 39.2% is generally obtained through readings, personal research, or informal discussions.

Participants then assessed their level of knowledge on climate change and air pollution. Regarding climate change, the results indicate that the majority of respondents (46.6%) are beginners in this field, while 30.4% consider themselves to have an average knowledge. Only 7.7% claimed to have an advanced level of knowledge, while 15.3% have no knowledge in this field. These results are encouraging as they indicate that a large majority of respondents have at least some understanding of this crucial issue. However, efforts deserve to be made towards a better understanding of this complex issue. Conversely, regarding their knowledge levels on air pollution, the results show that the majority of participants (83.4%) have some knowledge of air pollution, while 16.6% responded negatively. Awareness of this environmental problem is encouraging, as air pollution is a major concern associated with many respiratory infections, including asthma. Knowledge of air pollution is essential for understanding its causes, its health effects, and the measures to be taken to reduce it. By being aware of the sources of air pollution and the harmful substances it contains, healthcare workers will be better prepared to take preventive and mitigative measures in caring for their patients.

Table III : **Profile of participants and their level of knowledge on climate change and air pollution**

Category	Value
Distribution by sex	
Male	53%
Female	47%
Distribution by function	
Nurses	49.6%
Medical assistant	27.4%
Doctors	23.0%
Medical department of surveyed participants	
Paediatrics	22.6%
Internal Medicine	37.8%
Pneumology	24.9%
Maternity	14.7%
Training on climate change and health	
Beneficiaries	39.2%
Non-beneficiaries	60.8%
Level of knowledge about climate change and health	
None	15.3%
Beginner	46.6%

Intermediate	30.4%
Advanced	7.7%

5.1.1.2.Links between climate change and asthma

Health professionals were also questioned about their perception of the influence of climate change on asthma attacks (Table IV). In this regard, the majority of them (75%) asserted that climate change contributes to triggering asthma attacks, while 13.3% responded negatively, and 11.7% indicated they did not know.

Regarding the impact of air quality on asthma attacks, participants unanimously (100%) agreed that prolonged exposure to poor air quality can also have adverse effects on lung function. This unanimity underscores the importance of taking measures to preserve air quality and reduce pollution levels. It is therefore important to intensify awareness campaigns about the relationship between climate change, air pollution, and asthma, as well as the need to take measures to reduce these risks and improve the respiratory health of asthmatic individuals.

Table IV : **Influence of climate change and air quality on asthma attacks**

Category	**Value**
Does climate change contribute to the onset of asthma attacks?	
Yes	88.2%
No	3.8%
Don’t know	8.0%
Does air quality contribute to the onset of asthma attacks?	
Yes	100.0%
No	0%
Don’t know	0%

5.1.1.3.Favourable periods for asthma exacerbations throughout the year with highest hospitalisation cases

Asthma is a chronic inflammatory disease of the bronchi characterized by fluctuating episodes of symptom-free periods and exacerbations. Thus, the following (Table V) highlights the periods of the year when a significant increase in asthma cases is observed in consultations, providing an insight into the impact of climate change on this respiratory condition. Consequently, the harmattan period was identified by 56.7% of healthcare professionals as a time when they receive more asthma cases in consultations and hospital admissions. This increase is often associated with plant flowering and increased pollen exposure, a common trigger for allergic asthma attacks. 41.8% and 42.8% of participants respectively reported an increase in asthma cases during the dry season and hot periods. Moreover, harmattan carries dust triggering allergic reactions in asthmatics. The increased presence of air pollutants (such as fine particles during the dry season) can also worsen asthma symptoms. Similarly, respiratory infections, more prevalent during the dry season, can trigger asthma exacerbations in asthmatic individuals. However, albeit in a smaller proportion, 22.3% of respondents claim to have received more asthma cases during the rainy season, 23.2% during cooler periods, and 14.9% during high humidity periods.

Regarding asthma triggers, several have been identified. Participants unanimously (100%) agree that dust is an asthma trigger. Other identified factors include smoke (59.1%), bushfires (43.7%), exhaust fumes (48.3%), cool temperatures (32.3%), humidity and strong winds (28.6%), and heat (45.5%).

Table V : **Favourable periods for asthma exacerbations and trigger factors**

Category	Value
Period within the year with most asthma hospitalisations	
Rainy season	22.3%
Dry season	41.8%
Harmattan	56.7%
Heat period	41.8%
Cold period	23.2%
High humidity	14.9%
Asthma triggering factors	
Heat	45.5%
Bush fire	43.7%
Cold	32.3%
Fume	59.1%

Exhaust gas	48.3%
Humidity	28.6%
Low wind speed	39.7%
Dust	100%

5.1.1.4.Prevalence of asthma over the past 5 years

Regarding the evolution of asthma prevalence, the majority of respondents (38.2%) perceive an increase over the past 5 years, while 8.8% indicated a decrease in prevalence. Furthermore, 26.5% noted stability, and 26.5% also admitted not knowing how the trend had evolved. These latter responses reveal some variability in the perception of asthma prevalence evolution within the surveyed group. Although some have observed a decrease or stability, a significant portion of participants (38.2%) have noticed a notable increase in asthma prevalence in recent years, sounding the alarm bells.

As for the potential link between the increase in asthma prevalence and climate change, the majority of participants (84.6%) acknowledge a possible correlation between the rise in asthma prevalence and climate change, while 15.4% admitted not knowing. These results reflect a significant awareness of the potential relationship between climate change and increased asthma prevalence. Such perception underscores a growing concern regarding the impact of climate change on respiratory health, particularly concerning asthma (Table VI).

Table VI : Asthma prevalence and potential link with climate change

Category	**Value**
Changes in asthma prevalence over the last 5 years	
Decrease	8.8%
Constant	26.5%
Increase	38.2%
Don't know	26.5%
Link between increasing asthma prevalence and climate change	
Yes	84.6%

No	0%
Don't know	15.4%

5.1.1.5.Integration of climate counseling in asthma treatments

Regarding the integration of climate counseling in their treatment approach for asthma patients, 9 out of 10 participants (90.3%) responded positively, indicating that they effectively utilize this approach, while 9.7% do not integrate it into their practices. These results demonstrate a significant awareness and adoption of climate counseling among the surveyed healthcare professionals. The utilization of this approach reflects the recognition of the importance of climate change and its impact on respiratory health, particularly in the case of asthma.

Participants who have integrated climate counseling into asthma treatment have conveyed various messages to patients regarding the relationship between climate, pollution, and asthma. These messages aim to inform and raise awareness among patients about preventive measures and adaptation strategies to mitigate the effects of climate change on their respiratory health.

Healthcare professionals emphasize the importance of creating a conducive indoor environment by advising patients to ventilate their rooms well and to identify and avoid allergens in their surroundings. They also recommend avoiding places exposed to dust, strong winds, and humidity. During rainy periods, limiting outdoor activities and always keeping asthma inhalers handy is recommended. Additionally, the significance of dressing appropriately in cold weather is highlighted. Patients are encouraged to avoid places with generally polluted air, as well as strong perfumes and odors. They are advised to identify their specific allergens and be mindful of dust in their environment. Avoiding crowded places and gatherings is also recommended. Guidance on the use of fans and air conditioning is provided to optimize respiratory comfort.

The importance of thorough room dusting is emphasized while educating patients about the nature of their condition. Healthcare professionals remind that air pollution and cold weather are factors that can trigger an asthma attack. Patients are encouraged to protect themselves against both internal and external environmental factors that promote asthma attacks by adopting appropriate preventive measures. It is recommended to take extra precautions during periods conducive to attacks.

In summary, the messages conveyed to patients regarding the link between climate, pollution, and asthma aim to inform them about triggers, peak crisis periods, and protective measures to adopt. This educational approach contributes to strengthening asthma management by considering climate and environmental aspects, thereby enabling patients to better manage their condition and reduce the risks associated with climate change on their respiratory health.

5.1.1.6.Existence of national asthma surveillance and management documents

The results indicate that the majority of participants (82.8%) are not aware of the existence of national asthma surveillance and management documents, and 10.3% affirm the non-existence of such national documents. This suggests a lack of information or awareness regarding the existence and accessibility of these documents at the national level. It is noteworthy that 6.9% of participants asserted the existence of national asthma management documents, namely the National Plan for Acute Respiratory Diseases and the National Operational Plan for Asthma Management.

Furthermore, almost all respondents (95%) do not know if these documents take into account climate and environmental aspects, while the remaining 5% confirm the non-inclusion of climate and environmental aspects.

5.1.2. Perceptions of asthmatics

5.1.2.1. Profile of participants and their level of knowledge on climate change and air pollution

This section summarises the socio-professional characteristics of the respondents as well as their level of knowledge on climate change and air pollution (Table XII).

The distribution by gender of the surveyed patients shows a predominance of males, representing 57.1% of the sample, while females represent 42.9%. 84.5% of the respondents have an education level ranging from high school diploma to master's degree. This indicates a certain degree of formal education within the sample. However, it is concerning to note that 13.5% of patients have an education level below high school diploma, which may limit their access to information on environmental factors related to asthma and their understanding of associated risks. The most represented age group is 18-30 years old, constituting 78.6% of the sample. This suggests that young adults are particularly affected by asthma in this region.

Regarding their level of knowledge on climate change and air pollution, the results reveal that nearly 24.5% of patients have no knowledge of climate change and air pollution. Furthermore, 49% of patients are at a beginner level of knowledge, indicating an urgent need for education and awareness on these issues. Only 6.9% of patients have an advanced level of knowledge, highlighting a lack of deep understanding of the relationship between climate variability and respiratory diseases among asthmatic patients in the region.

Table VII : Profile of surveyed patients

Category	Value
Gender distribution of surveyed patients	
Male	57.1%
Female	42.9%
Age group distribution of surveyed patients	
[0–17]	1.0%
[18–30]	78.6%
[31–40]	13.4%
[41–50]	4.7%

>50	2.3%
Education level of surveyed patients	
< Bachelor’s degree	13.5%
[Bachelor–master’s degree]	84.5%
> Master’s degree	2.2%
Beneficiary status (as reported in the source table)	
Beneficiaries	39.2%
Non-beneficiaries	60.8%
Level of knowledge about climate change and health	
None	24.5%
Beginner	49.0%
Intermediate	19.7%
Advanced	6.9%

5.1.2.2.Perception of the link between asthma attacks and climate change and air pollution

Nearly half of the participants (49.5%) believe that their discomfort or asthma attacks are attributable to climate and pollution. However, it is noteworthy that a significant proportion (13.8%) of participants reject this idea and believe that their discomfort or asthma attacks are not related to climate and pollution. Finally, approximately 38.7% of participants responded with “Don’t know” to the question (Table XIII).

Table VIII : Influence of climate change and air quality on asthma attacks

Category	Value
Do you think your discomfort/asthma attacks are also attributable to climate and pollution?	
Yes	49.5%
No	13.8%
Don’t know	38.7%

5.1.2.3.Perception of asthma exacerbation periods and trigger factors

The survey results among asthmatic patients in Togo reveal a significant trend regarding the time of year when discomfort or asthma attacks are most pronounced (Table IV). The dry season appears to be the most critical period, with 45.8% of participants reporting an increase in asthma symptoms during this time. Conversely, the rainy season and the harmattan (a dry, dusty wind) are also sensitive periods, with 16.9% and 37.7% of participants respectively experiencing heightened respiratory issues. Regarding the triggering factors for asthma attacks, heat is identified as the primary trigger, with 54.7% of participants citing this factor. Other triggers include exhaust fumes (49.7%), smoke (36%), and dust (80.2%), suggesting an increased sensitivity to environmental conditions among asthmatic patients in Togo.

Table IX : Asthma-favorable periods and trigger factors

Category	Value
Period within the year with most asthma hospitalisations	
Rainy season	16.9%
Dry season	45.8%
Harmattan	37.77%
Heat period	61.9%
Cold period	32.6%
High humidity	11.9
Asthma triggering factors	
Heat	54.7%
Cold	36.0%
Bush fire	32.3%
Fume	42.6%
Exhaust wind	49.7%
Gas	30.0%
Dust	80.2%

5.1.2.4.Cooking energy sources and building cooling systems

The survey conducted among asthmatic patients in Togo reveals important information about cooking energy sources and building cooling systems, which are potential environmental factors that can influence asthma symptoms (Table X).

Natural gas is the most used cooking energy source, accounting for 74.4% of responses. Charcoal is also widely used, with 59.3% of participants indicating it as their cooking energy source. These results suggest that the combustion of these fuels may contribute to indoor air pollution, which can worsen asthma symptoms in patients.

In terms of Building Cooling Systems, fans are the most widely used cooling system, with 65.3% of participants reporting their use. However, only 22.1% use air conditioners, and an even smaller proportion use room humidifier 4.2%.

These results suggest that indoor temperature and humidity conditions can vary significantly, which may also impact asthma symptoms.

Table X : Cooking energy sources and building cooling systems

Category	Value
Cooking energy source	
Gas	74.4%
Charcoal	59.3%
Wood	13.4%
Petroleum	18.8%
Other	0.7%
Building cooling system	
Fan	65.3%
AC	22.1%
Humidifier	4.2%
None	18.8%
Other	1.9%

5.1.2.5.Attendance at healthcare centers for the control and management of asthma

The results of this survey among asthmatics in Togo reveal an interesting pattern regarding attendance at healthcare centers for asthma control. Approximately 60% of participants stated that they attend healthcare centers for the control of their asthma. This suggests good medical care and a willingness to undergo regular treatment to control the disease.

However, nearly 40% of participants reported that they do not attend healthcare centers for the control of their asthma (Table XI). This could be concerning as regular medical follow-up is essential for effective asthma management.

Table XI : Attendance rates at healthcare centers by asthmatics

Category	Value
Do you attend care centres to manage your asthma?	
Yes	50.1%
No	40.9%

5.1.2.6.Zooming in on asthmatics who have experienced at least 10 crises in the past 12 months

The results of this survey, specifically focusing on asthmatics who have experienced at least 10 crises in the past 12 months, provide crucial information on several aspects related to asthma management and associated environmental factors (Table VII).

Regarding the level of knowledge about climate change and air pollution, it is concerning to note that a significant proportion of participants (53.8%) report having no knowledge on these subjects. This underscores an urgent need for education and awareness, especially among populations most affected by asthma, to better understand the links between these environmental factors and respiratory health.

Results concerning regular attendance at health centers reveal a positive trend, with over half of the participants (54.8%) reporting regular consultations at these establishments for asthma monitoring and control. This indicates an awareness of the importance of medical monitoring in disease management and may contribute to improving symptom management.

Regarding the cooking energy source, a large majority of participants (85%) use charcoal and firewood. This cooking method is associated with incomplete combustion, which can lead to increased indoor air pollution and worsen asthma symptoms.

Regarding age distribution, it is noteworthy that most participants (75%) fall within the age group of 0 to 30 years. This information can guide awareness programs and interventions aimed at improving asthma management and reducing associated environmental risks in this specific population.

Table XII : Profile of asthmatics who have experienced at least 10 crises in the past 12 months

Category	Value
Level of knowledge of asthmatics about climate change and air pollution	
None	53.8%
Beginner	26.8%
Intermediate	14.4%
Advanced	5.6%
Regular attendance at health centres for asthma monitoring and control	
Yes	54.8%
No	45.2%
Cooking energy source	
Gas	15%
Charcoal and firewood	85%
Age group	
[0–30]	75%
[31–40]	15%
[41 and above]	10%

5.1.2.7.Asthmatics adaptation situations

Adaptation strategies used by asthmatics vary depending on various factors such as their environments and available resources. Here are some commonly used strategies:

The adaptation strategies employed by asthmatics vary depending on factors such as their environments and available resources. Here are some commonly utilized strategies: avoiding densely populated areas and smoke, regularly wearing face masks in polluted or dusty environments, donning warm clothing during cooler weather, seeking consultation with specialists to identify and mitigate risk factors, staying hydrated during hot temperatures, carrying asthma medications regularly, dampening floors before sweeping to reduce dust, using fans judiciously, covering the head and ears before bedtime to prevent morning chill-induced asthma attacks, maintaining and improving living spaces, limiting outdoor activities during periods of high heat, dust, and dry weather, and ensuring regular visits to healthcare centers for monitoring and management.

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5.2.Discussion

5.2.1. Discussion of healthcare practioners perceptions

This investigation highlights a statistical association between climate change, air pollution, and the risk of exacerbating respiratory diseases, notably asthma. The survey results potentially indicate links between meteorological events such as heatwaves, dust storms, high humidity, and air pollution on respiratory health.

Hu et al. (2022) find that events and exposures related to climate change can impair lung function, increase allergic responses, and trigger the onset of asthma or lung cancer in the general population. Elevated temperatures pose increased risks of hospitalizations and mortality for respiratory illnesses. In other words, when populations are exposed to high temperatures or extreme heat, it can trigger respiratory symptoms requiring additional use of rescue medications, visits to general practitioners or emergency departments, hospitalization, or even intensive care with respiratory support (Schinasi et al., 2022). Pawankar et al. (2020) also estimate that rising temperatures combined with increased humidity constitute an additional burden, especially for asthmatic and allergic patients. The authors also find that breathing warm and humid air feels "heavy" and more difficult to breathe, leading to increased respiratory rate and ventilation frequency in healthy subjects. This also causes irritation of the airways and coughing in patients with allergic rhinitis and bronchoconstriction and coughing in asthmatic patients (Carozzi et al., 2023).

Respondents also revealed that air pollution (both indoor and outdoor) is a major environmental concern and that exposure to polluted air can harm the health of asthmatic individuals. According to the European Environment Agency, air pollution is the most significant environmental risk factor, responsible for 6.7 million deaths worldwide in 2019 and 373,000 in Europe. There is an intrinsic link between air pollution and climate change (Lu et al., 2023). Indeed, greenhouse gases and atmospheric pollutants share the same primary sources: the combustion of fossil fuels and biomass (burning wood and coal for energy production and heating and cooking, etc.), methane and greenhouse gases, as well as ammonia emitted by animal production, form particles and can be harmful to patients with respiratory diseases.

Furthermore, meteorological conditions can worsen air quality, already poor, by modifying its dispersion capacity, composition, and toxicity. According to Chen et al.,(2020), higher temperatures and prolonged sun exposure increase the formation of tropospheric ozone, a potent pulmonary irritant that can trigger asthma and mortality due to respiratory diseases. According to Hayes et al., (2012), the majority of the world's population lives in areas with high air pollution. This exposure to high levels of air pollution can have adverse effects on health. According to Sillmann et al., (2021), fine particulate air pollutants, less than 2.5 microns, are capable of depositing in the lower respiratory tract and damaging structures such as lung alveoli. The authors further indicate that ozone is a dangerous pollutant that damages the tissues of the airways and lungs. Khosravi et al., (2014) indicate that over the next 30 to 50 years, climate change is expected to have a significant impact on respiratory health, with potential consequences such as a 15% increase in respiratory deaths due to ozone by 2100. Thus Lachgar et al., (2023), in evaluating the effect of air pollution on respiratory diseases in the Casablanca region of Morocco, found that road traffic (increased O_3) and urban industry (increased SO_2 and MP10) are the main causes of respiratory diseases in the region. According to Schinasi et al., (2022), atmospheric pollutants such as particles (PM2.5, PM10), nitrogen dioxide (NO2), nitric oxide (NO), nitrogen oxides (NOx), sulfur dioxide (SO2), ozone (O3), ammonia (NH3), and carbon dioxide (CO) can have adverse effects on respiratory health. Zhang et al., (2019) show that the significant reduction in anthropogenic activities during the COVID-19-related lockdown led to improved air quality, as indicated by lower levels of these key pollutants. This suggests that reducing anthropogenic activities, especially those related to transportation, could potentially improve air quality and, consequently, public health.

In their study on the effect of climate change on respiratory diseases, Howard et al., (2019) find that atmospheric pollutants can lead to decreased lung development in individuals under 18 years of age and increase the risk of respiratory diseases in the future. The authors also show that global temperature rise leads to an increase in allergens and their potency, thus resulting in more exacerbations in individuals with extrinsic/allergic asthma. They finally demonstrated that thunderstorms generate a higher number of airborne allergens, especially in the early part of the storm. Mirsaeidi et al., (2016), in their epidemiological studies, indicate that climate change and indoor air pollution affect respiratory health, particularly by increasing the prevalence of allergic diseases and asthma. Carozzi et al., (2023) find that in the world's most populous regions, the burden of outdoor and indoor pollutants as well as domestic pollutants is enormous, increasing the risk factors for allergic diseases. This is strongly linked to urbanization and a range of environmental factors. Moreover, geographical differences in exposure to air pollution and the effects of climate change play an important role in the risk of respiratory diseases. According to Howard et al., (2019), several factors contribute to these differences, including regional climate variations, land use patterns, and local policies. Indeed, urban areas generally record higher levels of air pollution due to transportation, industries, and urbanization (Lu et al., 2023).

In a retrospective study conducted from 2011 to 2012 in China, Hayes et al., (2012) showed that early childhood allergic symptoms were mainly associated with indoor environmental exposures, and allergic diseases diagnosed by a physician later in life were linked to both ambient air pollution and indoor environmental exposures. According to Gherasim et al., (2023), climatic and meteorological conditions will continue to change and could have devastating effects on our planet. According to the authors, this is the greatest global health threat of the 21st century.

5.2.2. Discussion of asthmatics perceptions

The results obtained from asthmatics have led to somes findings that deserve thorough discussion. Indeed, the analysis of these results has shed light on several crucial aspects related to asthma crises and environmental factors.

The results of this study have revealed that asthma is a condition that affects all age groups. According to WHO (2020), the disease is prevalent across all age groups and affects approximately 300 million people worldwide, causing 250,000 deaths annually.

The predominance of men, particularly in the age group of 18-30 years, in the studied sample can be partly attributed to socio-cultural factors and beliefs. Men, being more involved in professional activities, are often exposed to polluted urban and industrial environmental conditions as well as intense physical activities, which can affect their health. Additionally, their higher utilization of healthcare facilities could also be explained by their greater financial means and workplace health insurance coverage, facilitating easier access to healthcare facilities. In contrast, women, sometimes due to lack of financial means or spiritual beliefs, may prefer traditional or spiritual practices for asthma treatment.

Although several studies, including those by Pinheiro (2011), reveal that asthma can be exacerbated by environmental factors such as air pollution or climate change, a significant proportion of the surveyed asthmatics either reject or remain uncertain about this potential link. This could be attributable to a lack of awareness and education regarding the severity of the effects of climate change and air pollution on respiratory health. This underscores a lack of access to information, gaps in educational programs, or linguistic and cultural barriers. Moreover, the very low proportion of participants with advanced knowledge levels highlights a general lack of comprehensive understanding of the links between climate change, air pollution, and respiratory diseases, which may require increased efforts to promote environmental education and understanding of associated health risks.

However, when asked to identify the periods favorable for exacerbating their asthma crises and triggering factors, the results indicated increased sensitivity to environmental conditions, especially heat and dust, which are identified as the primary triggers of asthma attacks. The dry season is also highlighted as a critical period, which may be linked to increased air pollution and weather conditions conducive to the spread of allergens. Extreme heat and high humidity have been shown to trigger asthma symptoms, and prolonged exposure to sunlight increases the formation of tropospheric ozone, a potent lung irritant that can trigger asthma and respiratory disease mortality. Furthermore, changes in meteorological parameters significantly increase respiratory morbidity and mortality among adults with common chronic lung diseases such as asthma and other serious lung diseases. Moreover, cyclones have also been linked to asthma exacerbations.

An overview of the cooking energy source and building cooling system used by asthmatics reveals a predominance of the use of charcoal and firewood. The widespread use of charcoal and firewood as cooking energy sources can contribute to indoor air pollution, thus aggravating asthma symptoms. Similarly, the low usage of air conditioners and room humidifiers can lead to temperature and humidity variations indoors, which can affect respiratory health. According to the 2020 report of European Environment Agency, air pollution (both indoor and outdoor) is the most significant environmental risk factor, responsible for 6.7 million deaths worldwide in 2019, including 373,000 in Europe. Greenhouse gases and air pollutants share the same major sources, such as the combustion of fossil fuels and biomass (notably wood and coal for energy production, heating, cooking, etc.). Additionally, a systematic review by Annesi-Maesano et al., (2013) found that the link between indoor air chemical pollutants and respiratory manifestations appears strengthened.

In summary, these results highlight the importance of awareness, education, and access to healthcare for effective asthma management, especially in the context of environmental challenges such as climate change and air pollution.

5.3.Partial conclusion

The findings from both healthcare practitioners and asthmatics underscore a growing recognition of the impact of climate change and environmental factors on respiratory health, particularly asthma. Climate-related phenomena such as rising temperatures, increased air pollution, and extreme weather events have been shown to exacerbate asthma symptoms and provoke crises, confirming the need for an integrated and anticipatory approach to climate change in order to better protect vulnerable populations.

While healthcare professionals widely acknowledge the link between climate change and asthma exacerbation, a significant proportion of asthmatic respondents remain uncertain or sceptical about this connection. This discrepancy highlights the urgent need for comprehensive environmental education and awareness initiatives, particularly among affected communities. Such efforts should promote a better understanding of how environmental triggers like heat, dust, and pollution especially prevalent during the dry season can worsen respiratory symptoms.

Moreover, socio-cultural dynamics, economic disparities, and gender-specific factors influence exposure levels and healthcare access. The use of polluting energy sources such as charcoal and firewood indoors, coupled with limited climate control in homes, further amplifies risks for asthmatic individuals. These findings suggest that adaptation strategies must address not only medical and environmental dimensions but also socio-economic barriers.

In summary, mitigating the adverse effects of climate change on respiratory health requires a multidimensional approach: the evaluation of innovative technologies and environmental policies, targeted public health interventions, and improved access to healthcare. Promoting sustainable behaviours and educating both the public and healthcare professionals will be essential to fostering informed decision-making and improving long-term asthma management in climate-vulnerable regions.

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CHAPTER 6: RESULTS AND DISCUSSION OF AXIS 3

This axis aims to develop prediction models for asthma cases, considering the influence of climatic, environmental, and pollution-related parameters.

6.1 Results

6.1.1 Results in Savanes region

6.1.1.1. Selection of climate and environmental variables correlated with asthma through Principal Component Analysis (PCA)

The results reveal twelve principal components (PCs), each indicating the amount of variance explained within the dataset (Figure 42). The first principal component (PC1), with an eigenvalue of 5.02, accounts for 32.80% of the total variance, capturing the most significant variations in the data. The second component (PC2), with an eigenvalue of 4.16, explains 27.19% of the variance, underscoring its importance in representing the dataset. Together, PC1 and PC2 account for a cumulative 59.99% of the variance, which is relatively high, justifying the use of these two primary components to simplify the data while retaining substantial information.

The subsequent components, from PC3 to PC5, capture progressively smaller proportions of the variance (12.07%, 7.91%, and 5.77%, respectively). Collectively, the first five components explain nearly 85% of the variance. The eigenvalues of the remaining components (PC6 to PC15) are less than 1, suggesting they add minimal information, with relatively low percentages of explained variance. These components may therefore be excluded in a more streamlined model, as they contribute only marginally to the additional information.

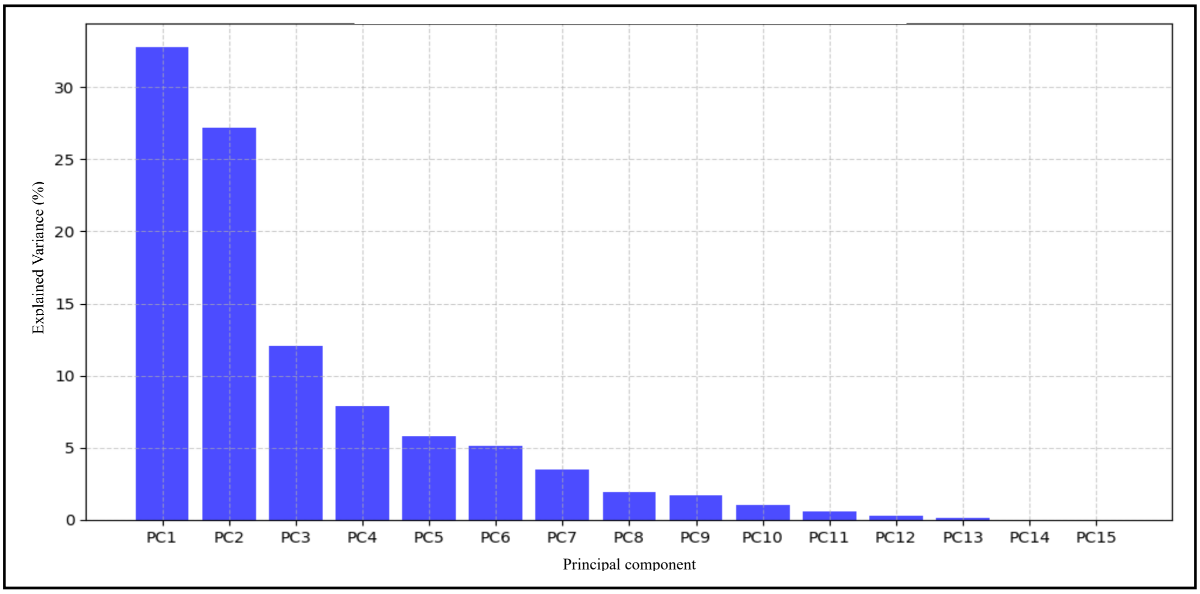

Figure 42: Principal Component Analysis in Savanes region

The contributions of each variable to the principal components PC1 and PC2 reveal the influence of climatic and environmental factors (Table XIII). PC1 is primarily dominated by variables such as AI (72.12%), Tmin (79.77%), Tmax (66.44%), and Tmoy (70.60%), along with humidity parameters including Umin (63.70%), Umax (60.92%), and Umoy (62.09%). Conversely, PC2 is influenced by variables such as CO (80.10%), SO_2 (81.03%), Inso (85.93%), and NDVI (64.04%), with a substantial contribution from RR (69.78%) as well. The wind variable appears balanced between the two components, with respective contributions of 51.17% and 48.82%.

Table XIII : Contribution of each variable to PC1 and PC2 in Savanes region

Variables	PC1 (%)	PC2(%)
CO	19.902008	80.097992
AI	72.123625	27.876375
SO2	18.974867	81.025133
O3	38.350918	61.649082
NO2	40.663646	59.336354
RR	30.217445	69.782555
Tmin	79.773743	20.226257
Tmax	66.436989	33.563011
Tmoy	70.602995	29.397005
Umin	63.699967	36.300033
Umax	60.921564	39.078436
Umoy	62.089945	37.910055
Vent	51.177302	48.822698
NDVI	35.956798	64.043202
Inso	14.073627	85.926373

6.1.1.2. Statistical performance

Analysis of the performance of the RFM and PRM models reveals significant differences in statistical metrics. The RFM model, with a coefficient of determination (R^2) of 0.13, explains only 13% of the variance in asthma cases, indicating limited explanatory power. In contrast, the PRM model has an R^2 of 0.36, accounting for 36% of the variance, which represents a notable improvement over the RFM in terms of explanatory capacity. However, this enhanced ability to explain variance comes at the cost of prediction accuracy: the PRM model shows a mean squared error (MSE) of 352.74 and a root mean squared error (RMSE) of 18.78, both higher than those of the RFM model, which has an MSE of 225.21 and an RMSE of 15.03.

In conclusion, the PRM model proves superior in explaining the variance in asthma cases, while the RFM model remains the most accurate for predictions, with lower associated errors (Table XIV).

Table XIV : Statistical performance in Savanes region

Model	R2	MSE	RMSE
RFM	0.13	225.21	15.03
PRM	0.36	352.74	18.78

6.1.1.3. Seasonal representation capacity

The analysis of the prediction results for the models reveals specific characteristics in terms of seasonal representation (Figure 43). The PRM model demonstrates reasonably good overall performance in capturing peaks and moderate fluctuations. It successfully reproduces the general upward trend from March to October; however, it fails to capture the trend shifts at the end of the year, which marks the major increase from November to December.

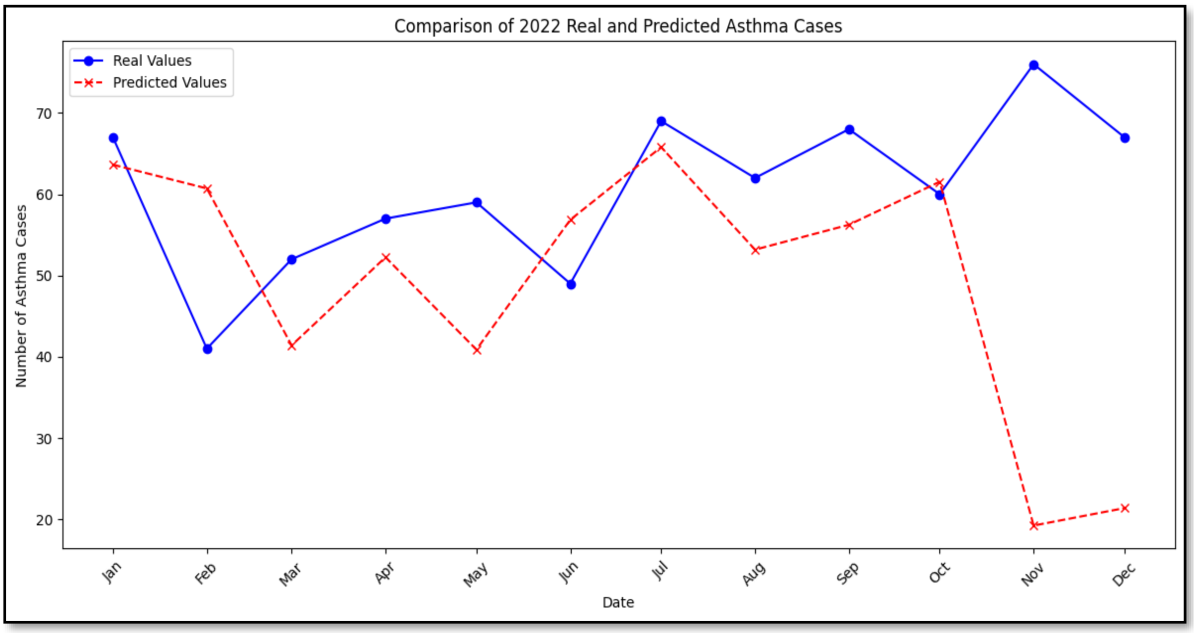

Figure 43: PRM seasonal representation in Savanes region

The Random Forest model (RFM) demonstrates relatively good performance in capturing peaks, troughs, and seasonal transitions in asthma case incidence (Figure 44). The model accurately detects the asthma peak in May, predicting 70 cases, very close to the observed 75 cases, resulting in a slight underestimation of 6.7%. It also anticipates the October peak with a prediction of 65 cases, compared to an actual count of 70, leading to an underestimation of 7.7%. In March, the model predicts 52 cases against 55 observed cases, amounting to an underestimation of 5.5%.

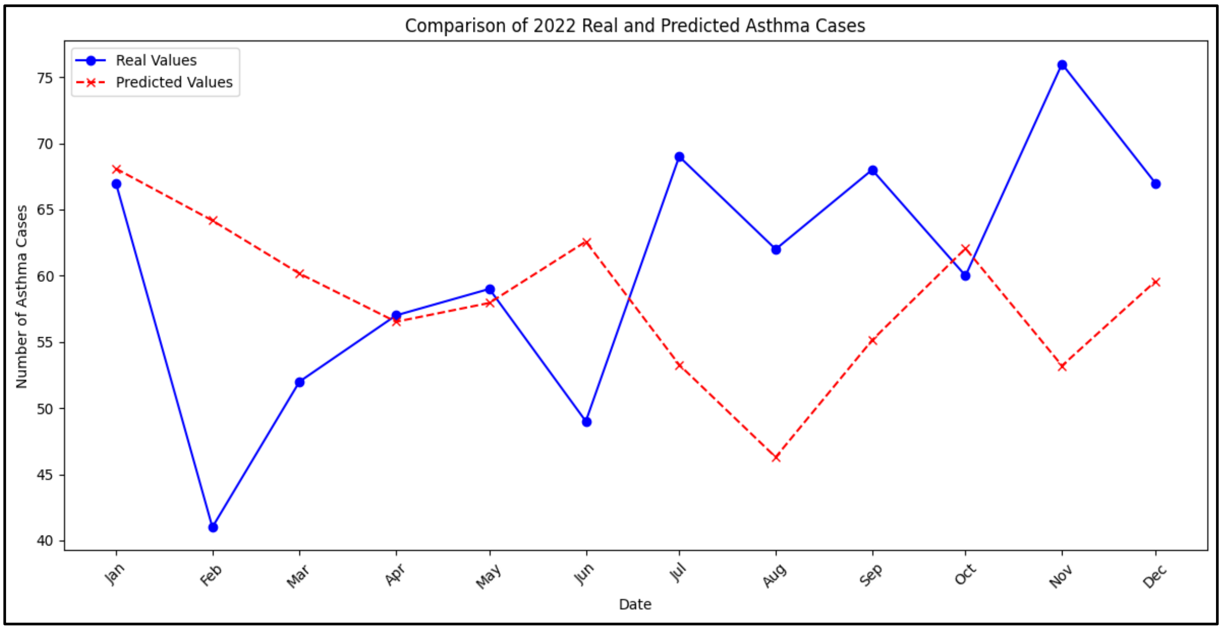

Figure 44 : RFM seasonal representation in Savanes region

However, the model appears less effective during trough periods; for instance, in January, it predicts 45 cases while 40 were observed, representing an overestimation of 12.5%. Discrepancies during trough periods, such as in January and August, generally show moderate differences, typically around 5 cases, equating to a margin of less than 10%. Overall, the model handles the onset and conclusion of peaks well, adjusting seasonal transitions accurately throughout the year, despite some forecasting errors. The results suggest that the model is effective at capturing seasonal trends.

6.1.1.4. Selection of the best model

While the polynomial regression model (PRM) achieves the highest R^2 value (0.36), indicating a better ability to explain data variance, it exhibits certain limitations. This model tends to significantly overestimate peaks and misses critical transitions between rising and falling periods, which affects the accuracy of its forecasts. Additionally, its RMSE (18.78) is higher than that of the Random Forest model, reducing its practical reliability. The Random Forest model (RFM), despite having a lower R^2 (0.13), demonstrates overall solid performance, capturing peaks and troughs and handling seasonal transitions well. It maintains low error levels (RMSE = 15.03), making it the most suitable model to retain.

6.1.2. Results in the Grand-Lomé region

6.1.2.1. Selection of climate and environmental variables correlated with asthma through PCA

The results reveal twelve principal components (PCs), each indicating the amount of variance explained in the dataset (Figure 45). The figure shows the variance explained by each principal component derived from a principal component analysis (PCA). The first principal component (PC1) stands out by capturing nearly 50% of the total variance, indicating that it summarizes a substantial portion of the key variations in the data. The second principal component (PC2) contributes an additional 10–15% of variance, highlighting its importance as a complementary dimension to the information captured by PC1. Together, PC1 and PC2 explain approximately 60% of the variance, which justifies their use in reducing the dimensionality of the data without significant information loss.

The subsequent components, from PC3 to PC5, account for more modest proportions of the variance, each ranging between 5% and 10%. Beyond the fifth component, contributions become increasingly negligible, as evidenced by the small bars on the graph. These components, although containing marginal information, could be disregarded in a simplified modelling approach without substantial information loss. In conclusion, the figure indicates that reducing to two or five principal components is a reasonable approach. Using the first two components (PC1 and PC2) allows for effective simplification while retaining approximately 60% of the variance.

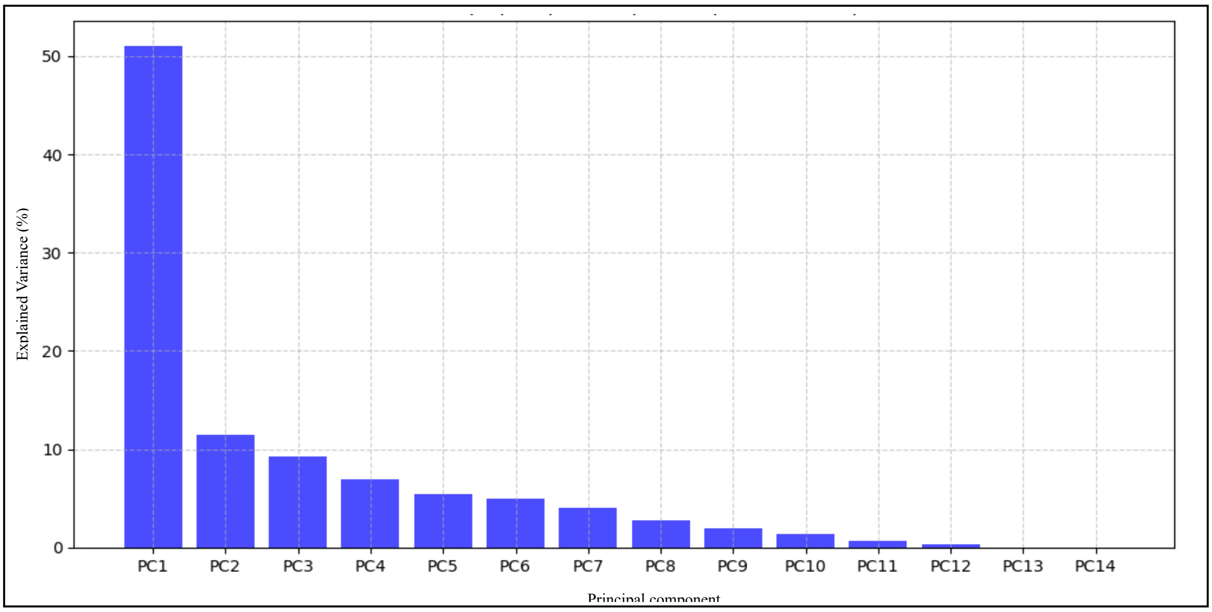

Figure 45: Principal Component Analysis in Grand-Lomé region

The contributions of each variable to the principal components PC1 and PC2 reveal the influence of climatic and environmental factors (Table XV). PC1 is primarily dominated by variables such as O_3 (99.79%), Umin (99.99%), Umoy (95.82%), NDVI (98.24%), and maximum temperature Tmax (63.20%). In contrast, PC2 is influenced by variables such as RR (72.98%), Tmin (78.94%), and Windspeed (96.88%). The variables CO, NO_2, Tmoy, and Umax appear balanced between the two components, with respective contributions of 48.14% and 51.86%; 48.63% and 51.37%; 44.44% and 55.56%; and 44.49% and 55.51%.

Table XV : Contribution of each variable to PC1 and PC2 in Grand-Lomé region

Variables	PC1	PC2
CO	48.138044	51.861956
AI	41.145159	58.854841
SO2	40.652213	59.347787
03	99.785307	0.214693
NO2	48.626956	51.373044
Rainfall	27.019991	72.980009
Tmin	21.05674	78.94326

Tmax	63.201794	36.798206
Tmoy	44.437148	55.562852
Umin	95.819235	4.180765
Umax	44.485956	55.514044
Umoy	99.998647	0.001353
windspeed	3.115126	96.884874
NDVI	98.243443	1.756557

6.1.2.2. Statistical performance

Analysis of the performance metrics for the RFM and PRM models reveals significant differences in their statistical outcomes (Table XVI). The Random Forest model (RFM), with a coefficient of determination (R^2) of 0.20, explains only 20% of the data variance, indicating its limited explanatory power. Additionally, it exhibits a mean squared error (MSE) of 8501.46 and a root mean squared error (RMSE) of 92.22, reflecting substantial prediction errors.

In contrast, the polynomial regression model (PRM) shows an R^2 of 0.4123, suggesting it explains 41.23% of the variance, which marks a notable improvement in explanatory capability over the RFM. In terms of prediction accuracy, the PRM model has an MSE of 6235.98 and an RMSE of 78.96, both lower than those of the RFM.

Table XVI : Statistical performance of the models in the Grand-Lomé region

Model	R2	MSE	RMSE
RFM	0.20	8501.46	92.22
PRM	0.4123	6235.98	78.96

6.1.2.3. Seasonal representation capacity

The analysis of the seasonal cycle for the models reveals several specific characteristics (Figure 46). The PRM model presents more linear forecasts that are less responsive to observed variations. It demonstrates moderate ability in capturing the seasonality of asthma cases. Incidence peaks, particularly in July, are reasonably well reflected in the forecasts; however, the overall trend of predicted values is less responsive to monthly fluctuations. Although the model successfully captures some peaks and troughs, it shows limitations in precision, with overestimation and underestimation rates ranging between 2.1% and 50%.

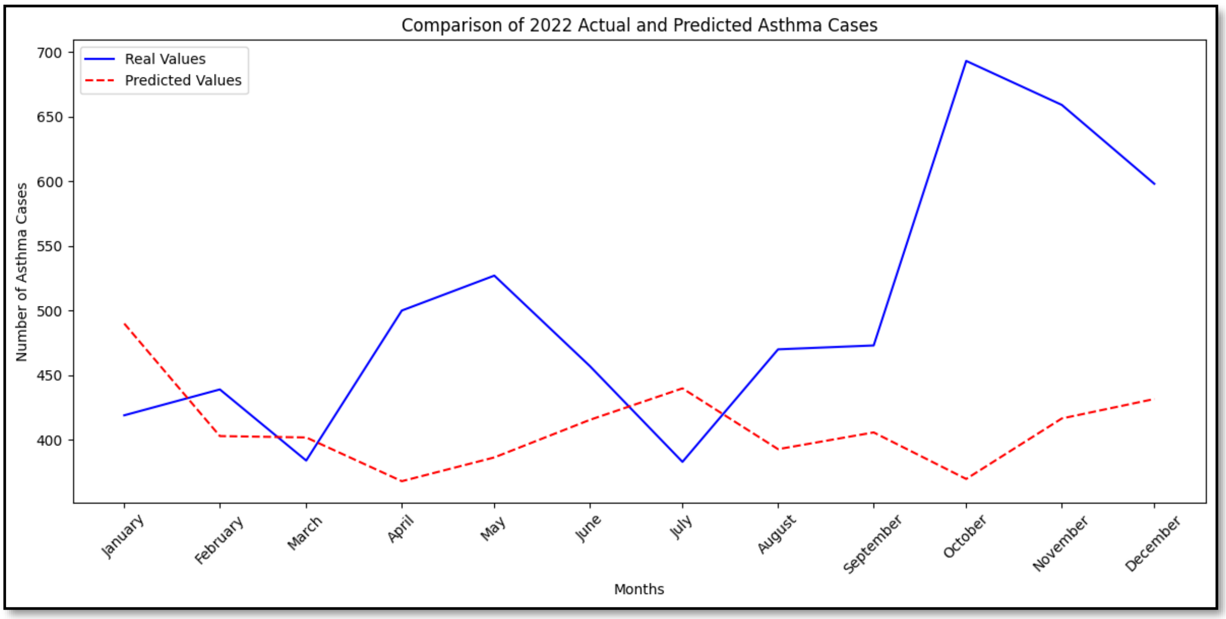

Figure 4612 : PRM seasonal representation in Grand-Lomé region

The RFM model also shows significant limitations in its ability to capture seasonality and monthly variations (Figure 47). Notable discrepancies are observed, particularly during months with high peaks, such as May and October. For instance, in May, real values reach around 550 cases, while the model predicts approximately 400 cases, resulting in an underestimation of 150 cases and an error rate of 27.3%. In October, another peak month, actual values are close to 680 cases, whereas the model predicts only 420 cases, creating an underestimation of 260 cases with an error rate of 38.2%.

In contrast, for months like March and July, where case numbers are more stable, the model slightly overestimates, with moderate but consistent errors around 5–10%. Overall, the model tends to produce flatter predictions, with limited responsiveness to marked seasonal fluctuations. This analysis indicates that the model is less effective during periods of high variation, showing significant errors during peak months (May and October) and moderate overestimations during low-incidence months (January, March, July). Monthly underestimation and overestimation rates vary, often falling between 5% and 38% relative to actual values.

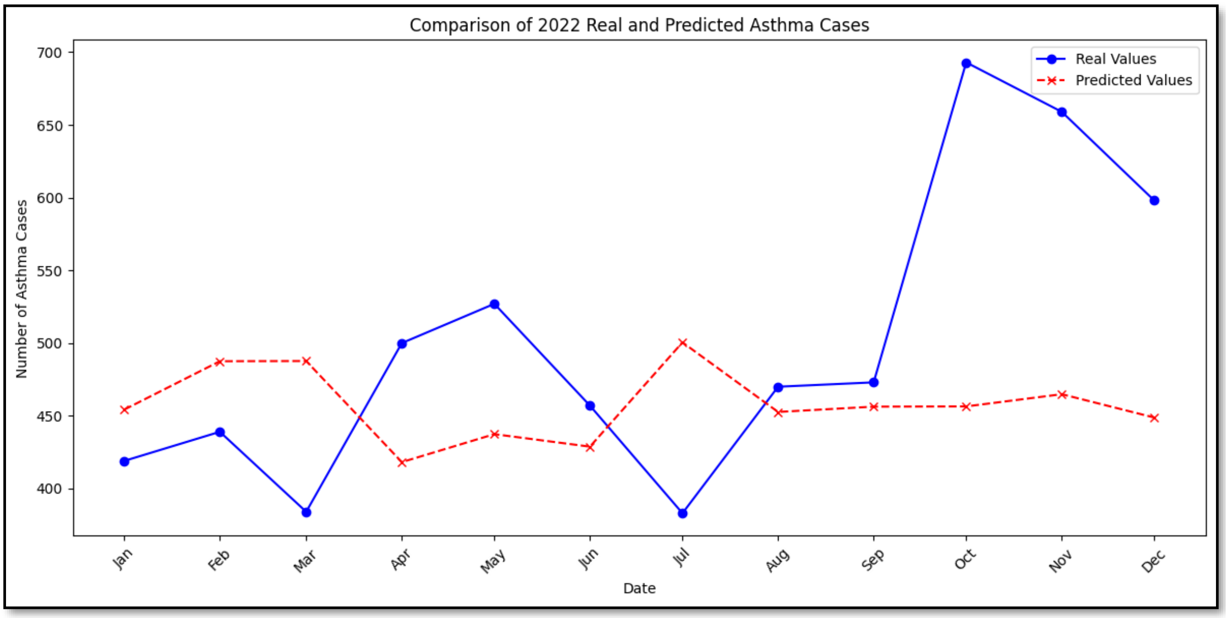

Figure 47: RFM seasonal representation in Grand-Lomé region

6.1.2.4. Selection of the best model

Although the polynomial regression model (PRM) achieves the highest R^2 value (0.41), indicating a superior ability to explain data variance, it has significant limitations in representing the seasonality of the disease. Unlike the PRM, the Random Forest model (RFM) better captures critical transitions between periods of increase and decrease. Under these conditions, RFM emerges as the more reliable choice.

6.1.3. Asthma impact chain

The impact chain of asthma (Figure 48) illustrates the primary hazard, exposure, and vulnerability factors that contribute to an increased risk of mortality and morbidity associated with this respiratory condition. Danger factors include air pollution and specific climatic conditions. Pollution is exacerbated by various elements, including wind, vegetation, aerosols, fine particulate matter, arid periods, as well as dust and smoke, creating an environment laden with pollutants that aggravate asthma symptoms. Concurrently, climatic conditions such as variations in temperature, humidity, and sunlight contribute to the exacerbation of symptoms and can trigger asthma attacks. Exposure to these hazards concerns the entire population, meaning that every individual is potentially at risk, although certain groups exhibit heightened vulnerability. This vulnerability manifests in different forms. First, generic susceptibility includes low-income individuals, those living in poorly ventilated or unsanitary environments, who face increased exposure to pollutants. Secondly, biological susceptibility particularly targets asthmatic individuals, who are more sensitive to climatic variations and pollution. Furthermore, a lack of anticipatory capacity, due to insufficient awareness, inadequate hygiene, and the absence of strategic disease management documents, limits these populations' ability to effectively protect themselves against risks. Finally, the inability to recover intensifies the hazards for vulnerable populations, due to limited access to healthcare and medications, as well as a lack of available healthcare personnel to manage crises. In summary, this impact chain highlights how the interaction between exposure and vulnerability leads to an increased risk of mortality and morbidity for asthmatic individuals. Consequently, pollution regulation policies, awareness initiatives, and improved access to healthcare are essential for mitigating the adverse effects of asthma, particularly in heavily polluted areas or those subjected to extreme climatic conditions.

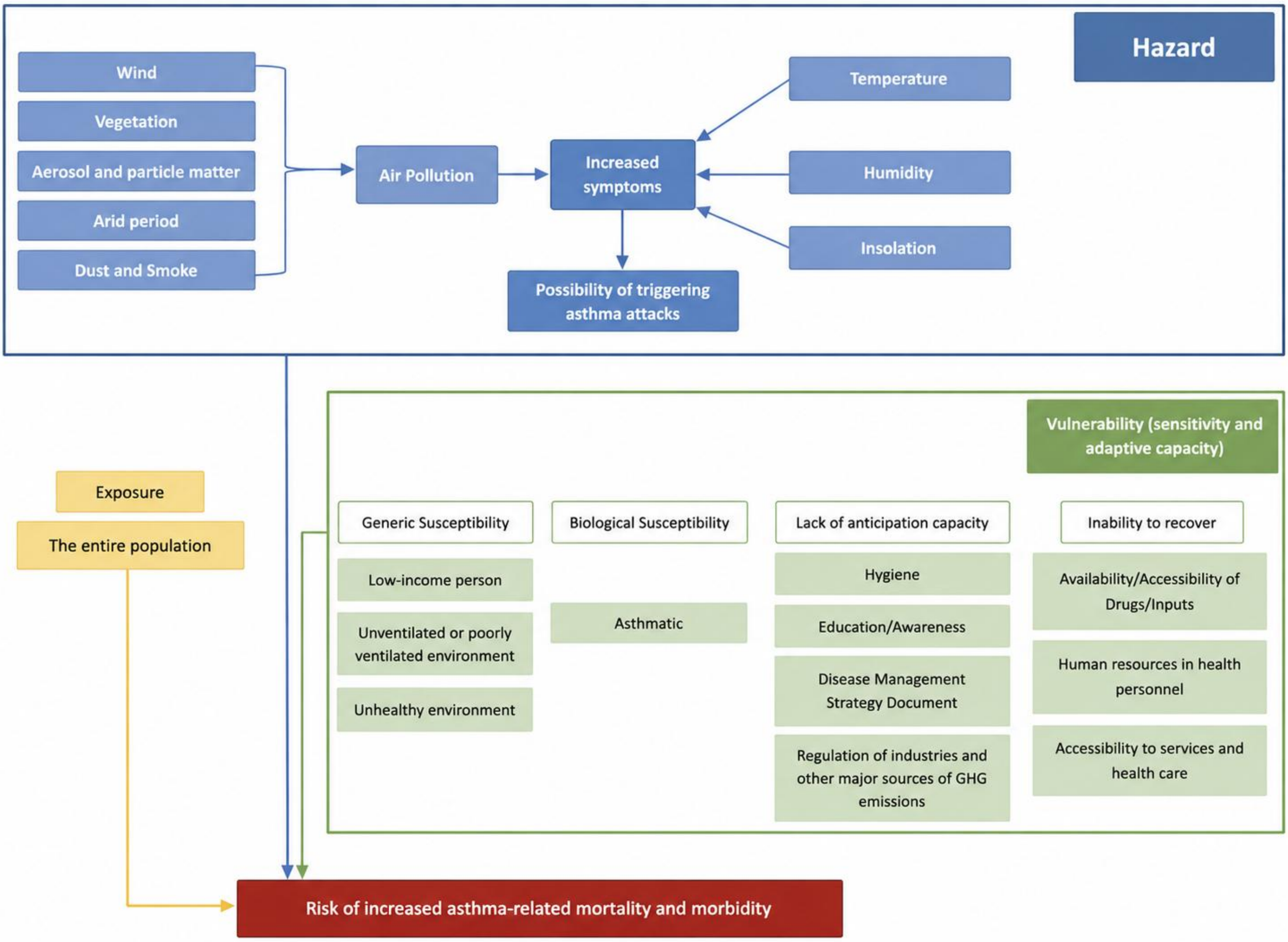

Figure 48: Asthma impact chain

6.2. Discussion

Asthma and other respiratory diseases pose a major public health challenge in sub-Saharan Africa, particularly in regions where climate change exacerbates existing vulnerabilities. In Togo, climate variability characterized by rising temperatures, increasing air pollution, and seasonal dust storms has been linked to a rise in respiratory diseases, particularly asthma.

This study aims to enhance the understanding of the link between climate and asthma to improve its monitoring and management. Findings from the Savanes Region highlight the relationship between climatic and environmental variables and asthma incidence. Principal Component Analysis (PCA) identified key influencing factors, including temperature (Tmin, Tmax, Tmoy), humidity (Umin, Umax, Umoy), and air pollutants (CO, SO_2), which significantly impact asthma cases. These results align with previous studies emphasising the role of meteorological conditions and air pollution in asthma exacerbation (Kanannejad et al., 2023) PCA results indicate that the first principal component (PC1), explaining 32.80% of the variance, is primarily influenced by temperature and humidity, supporting the findings of (Hajat & Kosatky, 2010), who demonstrated that these factors play a crucial role in asthma hospitalisations. The second principal component (PC2), accounting for 27.19% of the variance, is dominated by air pollutants (CO, SO_2, NO_2), reinforcing established links between air pollution exposure and increased asthma risks, particularly in urban environments (D'amato et al., 2016).

Moreover, the relationship between asthma incidence and climatic conditions fits into a broader global context concerning climate change and respiratory health (Deng et al., 2020). Rising temperatures and humidity levels facilitate the proliferation of airborne allergens and pollutants, contributing to increased asthma cases (Beasley et al., 2015). The study also supports findings from the Aphekom project, which identified traffic-related pollution as a major factor in asthma morbidity (Harlan & Ruddell, 2011). Additionally, the Normalised Difference Vegetation Index (NDVI) and rainfall (RR) influence asthma incidence in the Savanes Region. Higher NDVI values, indicative of denser vegetation, are associated with lower asthma prevalence, supporting the hypothesis that urbanisation and reduced green spaces contribute to increased asthma risks (Jendritzky & Tinz, 2009). Similarly, the positive correlation between rainfall and asthma, as highlighted by (D'amato et al., 2015), may be attributed to increased mould growth and allergen dispersion during wet conditions.

Seasonal analysis of asthma incidence reveals that while the PRM model effectively captures general trends, it struggles with abrupt seasonal transitions, particularly towards the end of the year. Additionally, Kinney et al., (2022) demonstrated the effectiveness of machine learning techniques, such as Random Forest, in predicting asthma trends based on environmental exposures. Furthermore, the ability of these models to forecast asthma peaks, particularly during the harmattan season, highlights their practical application for early warning systems in high-risk areas. These findings align with global research on the effects of climatic and environmental variables on respiratory health. Deng et al., (2020) noted that urban areas with high levels of air pollution and frequent extreme weather events experience elevated rates of asthma exacerbations, particularly among vulnerable populations. In Grand-Lomé, where industrialization and vehicular emissions contribute to poor air quality, asthma prevalence increases during periods of high temperatures and humidity. These observations are consistent with the work of Kunkel et al., (2014), who found that heatwaves combined with poor air quality exacerbate asthma attacks and increase hospitalization rates.

Although the predictive models developed in this study require further refinement, they offer a promising tool for healthcare systems in Togo to anticipate asthma surges linked to seasonal climatic patterns. Adapting these predictive tools to Togo's specific climatic and environmental conditions could significantly enhance asthma management and alleviate pressure on healthcare facilities during peak periods, like models successfully used in Europe to predict pollen-induced asthma peaks (Kusaka et al., 2017).

6.3. Partial conclusion

This study aims to predict asthma occurrences by incorporating climate, environmental, and pollution variables, with the goal of enhancing the management of this climate-sensitive disease in a context where populations are especially vulnerable to climate variability.

The study highlights the impact of climatic and environmental factors on the incidence of asthma, exploring their contributions through principal component analysis and predictive models. The asthma impact illustrates how interactions between pollution, climatic conditions, and individual vulnerability exacerbate the risk of morbidity and mortality. The analysis of the Savanes and Grand-Lomé regions identified the variables most correlated with variations in asthma incidence, confirming the major influence of air pollution (CO, SO_2, O_3), temperature, and humidity.

The findings indicate that the Random Forest model (RFM) offers the best seasonal prediction capacity, effectively capturing peaks and variations in asthma incidence. However, its explanatory power remains limited (R^2 ranging from 0.13 to 0.20), and its ability to represent the seasonality of asthma remains modest. In contrast, the polynomial regression model (PRM) demonstrates a higher explanatory capacity (higher R^2) but performs less effectively in forecasting seasonal fluctuations.

These findings underscore the importance of adopting a multidimensional approach to anticipate and mitigate the effects of asthma, incorporating pollution reduction policies, climate change adaptation strategies, and awareness-raising initiatives for vulnerable populations. In the long term, enhancing predictive models by integrating new variables and advanced machine learning techniques could improve forecast accuracy and facilitate the implementation of an early warning system for better asthma risk management in the studied regions.

CHAPTER 7: SUMMARY OF FINDINGS AND DISCUSSION

7.1. Summary of findings

This thesis addresses the impacts of climate change on respiratory diseases, particularly asthma, across two geographically and climatically distinct regions of Togo: The Savanes and Grand-Lomé. The study aims to predict asthma occurrences by incorporating climate, environmental, and pollution variables, with the goal of enhancing the management of this climate-sensitive disease in a context where populations are especially vulnerable to climate variability.

The findings indicate significant correlations between specific climate parameters and asthma incidence in both study areas, demonstrating how environmental conditions influence the onset and exacerbation of this condition. In the Savanes region, factors such as minimum temperature and wind speed emerged as closely associated predictors of asthma cases, with correlation coefficients of -0.53 and -0.60, respectively. This suggests that lower temperatures and stronger winds, particularly during the dry season, contribute to worsening asthma symptoms in this region. Conversely, in the coastal and highly industrialized Grand-Lomé region, parameters such as maximum relative humidity and insolation showed the strongest associations, with high correlation values (0.75 and 0.66). These factors, coupled with urban pollutants, contribute to a considerably higher prevalence of asthma in Grand-Lomé (274.8 per 100,000 inhabitants) compared to the Savanes region (64.88 per 100,000 inhabitants). The months from October to February, characterized by cold and dry conditions intensified by the Harmattan winds, were found to be particularly conducive to asthma exacerbations, highlighting a marked seasonality in asthma crises across both regions.

A survey conducted among 250 asthma patients in the Grand-Lomé area revealed a strong perception of the influence of climatic conditions on their symptoms. However, a significant portion of participants (40%) lacked awareness of the effects of climate change and pollution on respiratory health, limiting their ability to adopt effective management strategies to minimize asthma risks. Additionally, a complementary study involving 338 healthcare professionals across the studied regions highlighted a need for increased training: although 75% of professionals acknowledged a link between climate and asthma crises, the majority lacked the resources and knowledge required to integrate this dimension into their daily clinical practice, thereby underscoring a critical need for capacity building in this domain.

To enhance public health responses to climate-related challenges, predictive models were developed to anticipate asthma peaks based on climatic conditions. The Random Forest model

(RFM) demonstrated promising capacity to capture seasonal variations in asthma, though its explanatory power (R^2 ranging from 0.13 to 0.20) and his capacity to represent the seasonality of asthma remains modest. While this model could be improved, it provides a foundation for an early warning system that could be incorporated into health programs to inform the population of high-risk periods, thereby supporting better anticipation and management of asthma peaks.

In conclusion, this research highlights the urgent need for strengthened environmental and health policies, specifically tailored to address the impact of climate variability on respiratory diseases. Information generated through this work will be pivotal in guiding public health decisions and fostering climate-resilient health systems, particularly in developing countries like Togo, where the burden of climate-sensitive diseases like asthma continues to rise.

7.2. Summary of discussion

This study first focused on the identification of key climatic and environmental variables that influence asthma exacerbations. Air pollution, temperature fluctuations, and humidity were found to be the primary climatic drivers of asthma episodes and especially during the harmattan season, characterized by intense dust. This aligns with other studies conducted in West Africa, such as Landrigan et al., (2018), which linked the harmattan's dust-laden winds to higher rates of respiratory diseases, including asthma. Dust particles, particularly PM10 and PM2.5, penetrate deep into the respiratory system, aggravating asthma symptoms, especially in vulnerable populations like children and the elderly. The study also found that temperature variations during the rainy season in Grand-Lomé, combined with poor air quality from traffic emissions, significantly contributed to asthma exacerbations. This is consistent with findings by D'Amato et al. (2016), who identified similar patterns in coastal West African cities, where urban heat island effects and high levels of air pollution exacerbate respiratory diseases.

Additionally, the study highlighted the seasonality of asthma in Togo, with distinct peaks during the harmattan and dry seasons. This finding is corroborated by research across the Sahelian region, where fine particulate matter has been linked to acute respiratory issues, as reported by Annesi-Maesano et al. (2013). Dust particles, including silica and allergens, during the harmattan season are a significant cause of asthma flare-ups in both rural and urban settings.

The second axis of the study focused on the perceptions of healthcare professionals regarding the management of asthma in the context of climate change. Most healthcare providers (90.3%) indicated that they included climate-related advice in their consultations with asthma patients, but many lacked formal training on climate-health links. Only 39.2% of healthcare workers had received training on the health impacts of climate change, and 82.8% were unaware of national asthma management and surveillance guidelines. This gap highlights the need for educational initiatives to enhance the resilience of the healthcare system in managing climate-sensitive diseases. These findings align with research from Li et al. (2015), which emphasizes the importance of training healthcare professionals in low-resource settings on climate adaptation strategies, particularly in the face of extreme weather events.

The findings of this study are consistent with global research on the impacts of climatic and environmental variables on respiratory health. D'Amato et al. (2016) noted that urban areas with high levels of air pollution and frequent exposure to extreme weather events are prone to higher rates of asthma exacerbations, especially among vulnerable populations. In Grand-Lomé, where industrialization and vehicular emissions contribute to poor air quality, the prevalence of asthma increases during periods of elevated temperatures and humidity. The study also supports the findings of Kinney and Pinkerton (2022), who observed that heatwaves combined with poor air quality could lead to severe asthma attacks, resulting in higher rates of hospitalization.

In the third part of the study, predictive models were developed to forecast asthma cases based on climatic and environmental data. RFM was chosen as the best model comparing to PRM. In addition, the use of Principal Component Analysis (PCA) allowed the identification of variables such as AI, temperatures, humidity, CO, SO_2, Inso, NDVI, RR, and wind as significant predictors of asthma prevalence through the RFM. These findings are consistent with the work of Kinney et al. (2022), who demonstrated that machine learning techniques, like Random Forest, are highly effective in predicting asthma outcomes based on environmental exposures. Also, the ability of these models to forecast asthma outbreaks during the peaks and specially in harmattan season suggests their practical application for early warning systems in high-risk areas.

Although the predictive models developed in this study need to be performed, it however offer a valuable tool for healthcare systems in Togo to anticipate asthma surges linked to seasonal climatic patterns. This is particularly important as similar approaches have been successfully used in Europe to predict pollen-induced asthma surges, as demonstrated by D’Amato et al. (2015). Adapting these predictive tools to Togo’s specific climatic and environmental conditions could significantly enhance asthma management and reduce the burden on healthcare facilities during peak seasons.

7.3. Practical implications for Public Health

The results of this study have significant implications for public health policy in Togo. First, the integration of climate-resilient health strategies is essential for addressing the increasing burden of respiratory diseases like asthma. Public health authorities should focus on mitigating air pollution, particularly in urban centres like Grand-Lomé, by implementing emission control policies and promoting clean energy solutions. Second, the creation of early warning systems based on predictive models of asthma can help communities prepare for periods of high risk, particularly during the harmattan and dry seasons. The development of respiratory diseases management plans that account for seasonal variations in climatic conditions could also improve the capacity of healthcare professionals to respond to exacerbations.

Finally, the study suggests the need for increased education and training for healthcare workers on the link between climate change and respiratory health. As shown in this thesis, 82.8% of healthcare workers were unaware of national guidelines for asthma management in the context of climate change. Therefore, it is critical to include climate-health training in medical education and to develop public health campaigns that raise awareness about the health impacts of climate variability on asthma and other respiratory diseases.

In conclusion, this study underscores the critical need for public health interventions aimed at mitigating the effects of climate change on respiratory health, particularly in regions like Savanes and Grand-Lomé, where climatic variability plays a crucial role in asthma prevalence and exacerbation. The development of early warning systems, based on predictive models, offers a promising approach to managing this public health challenge by improving preparedness and guiding resource allocation, especially during high-risk periods such as the harmattan season. Community health education programs can enhance public awareness of climate-related respiratory risks, while further training of healthcare professionals on climate-health interactions is essential for building a resilient healthcare system capable of managing the increasing burden of climate-sensitive diseases like asthma. Future research should focus on expanding these predictive models to include other health outcomes and integrating climate data into national health surveillance systems to better respond to the health impacts of climate change.

7.4. Strengths of the study

As with any scientific investigation, this study presents both notable strengths and certain limitations. These aspects are crucial in evaluating the robustness of the research findings and in guiding future research directions and practical applications. Therefore, in terms of strengths:

Comprehensive analysis of climatic factors: The study's in-depth focus on climatic and environmental determinants of asthma, including air pollution, temperature, and seasonal dust storms, provides a comprehensive understanding of the factors that influence asthma exacerbations in the Savanes and Grand-Lomé regions. This allows for the identification of key climatic triggers that can inform public health strategies.

Use of advanced predictive models: The application of PCA, RFM and PRM for predicting asthma prevalence based on climatic and environmental factors is a major strength. These machine learning techniques provide a robust and data-driven approach to understanding how climate affects asthma outcomes.

Regional focus: By focusing on two distinct regions with differing climatic conditions, the study offers region-specific insights into asthma management. This specificity enables the formulation of targeted interventions that are more likely to be effective in addressing localized climate-related health issues.

Practical applications for public health: The study's findings can be directly applied to improve healthcare preparedness and resource allocation. The development of early warning systems for asthma and respiratory diseases based on the models' predictive capabilities is a key strength, as it could help healthcare systems better respond to asthma surges during critical periods like the harmattan.

Interdisciplinary approach: Combining climate science with public health provides a holistic understanding of how environmental factors impact respiratory diseases. This interdisciplinary approach strengthens the relevance of the study in both fields.

7.5. Limitations of the Study

Data and temporal limitations: The study is based on data from 2018 to 2022, which may not be sufficient to capture long-term trends in the relationship between climate change and asthma. A longer-term study would provide more comprehensive insights into the evolving nature of this relationship.

Limited geographical scope: While the study focuses on two key regions, Savanes and Grand-Lomé, the findings may not be generalizable to other regions of Togo or countries with different climatic and environmental conditions. Broader research is required to understand climate-health dynamics across more diverse geographical areas.

Confounding factors: The study primarily concentrates on climatic variables, without fully accounting for other potential influences on asthma, such as socioeconomic status, indoor air pollution, and access to healthcare. These confounding factors could affect the interpretation of the results and should be integrated into future studies.

Training gaps among healthcare professionals: Although the study identifies the importance of training healthcare workers in climate-health interactions, the gap in formal training among professionals represents a limitation. The lack of awareness and preparedness within the healthcare system may impede the implementation of the study's recommendations.

7.6. Future directions and research avenues

The work presented in this thesis opens multiple avenues for future research to deepen understanding and address the highlighted gaps. Specifically:

Short-term research:

- Assessing the impact of public health interventions on asthma exacerbations linked to seasonal air pollution: A focused study on the efficacy of campaigns promoting mask use and indoor air purifiers during peak pollution periods in urban areas.
- Examining indoor air quality in households using biomass fuels: Given the high prevalence of charcoal use (59.3%), a detailed study on its contribution to indoor air pollution and the consequent impact on respiratory health in both urban and rural settings would provide actionable insights for local health policies.

Mid/long-term research:

- Impact of climate change on asthma and respiratory diseases: economic consequences and links to absenteeism.
- Comprehensive national study on climate change and health outcomes in Togo: A large-scale study to assess the long-term impacts of climate variability on overall respiratory health across multiple regions in Togo, contributing to the development of national policies on climate adaptation in health.
- Effects of climate change on asthma prevalence in Togo: A multi-year, cohort-based study following individuals with asthma in both the Savanes and Grand-Lomé regions to establish stronger causal links between environmental changes and asthma exacerbations.

CHAPTER 8: GENERAL CONCLUSION AND RECOMMENDATIONS

8.1. Conclusion

This thesis set out to explore the complex interplay between climate change and respiratory health, focusing specifically on asthma in two climatically and geographically distinct regions of Togo: Savanes and Grand-Lomé. By integrating meteorological, environmental, and air pollution data with health records, the research aimed to deepen the understanding of how climate variability influences the occurrence and severity of asthma. Through a combination of statistical analyses, predictive modeling, and stakeholder surveys, this study has contributed meaningful insights into a pressing public health challenge, one that is expected to intensify under ongoing climatic shifts.

The analysis confirmed that environmental and climatic factors have a measurable influence on asthma incidence, though the specific variables and their effects differ by region. In the Savanes region, lower temperatures and stronger winds during the dry season were found to exacerbate asthma symptoms, while in Grand-Lomé, the combination of high humidity, strong solar radiation, and urban air pollution significantly increased asthma prevalence. These findings point to the importance of context-specific approaches in public health planning, as the drivers of disease can vary significantly even within the same country.

Beyond statistical correlations, this research shed light on the lived experiences and perceptions of both asthma patients and healthcare professionals. The survey of patients in Grand-Lomé revealed a notable gap in knowledge about the links between climate change and respiratory health, highlighting the need for targeted education and awareness campaigns. Similarly, while most healthcare providers recognized the connection between climate and asthma, many lacked the tools, training, or institutional support to effectively incorporate this knowledge into their daily practice. These insights underscore the importance of capacity building and the integration of climate-health education into medical and community health systems.

The development and application of predictive models, particularly the Random Forest Model, provided a practical tool for forecasting asthma peaks in response to climatic conditions. Although the model's explanatory power was modest, it showed potential for supporting early warning systems and anticipatory health interventions. Future refinement of such models, possibly through the inclusion of additional socio-environmental variables or the application of hybrid modeling techniques, could improve predictive accuracy and operational usefulness.

This research contributes to a growing body of evidence that calls for climate-sensitive health systems, particularly in regions vulnerable to both environmental degradation and limited healthcare infrastructure. In Togo and similar developing contexts, the rising burden of climate-related diseases like asthma demands a coordinated response involving policy makers, health professionals, environmental scientists, and local communities. Strengthening public health responses will require not only robust scientific data but also institutional commitment, intersectoral collaboration, and sustained investment in health and environmental resilience.

In closing, this thesis highlights the need for a more integrated and proactive approach to managing respiratory diseases in the face of climate change. By illustrating the specific environmental drivers of asthma in Togo, it provides a foundation for informed policymaking, improved public awareness, and the development of targeted intervention strategies. It is hoped that the findings and recommendations offered herein will support national efforts to build a more responsive, climate-resilient health system, one that protects the most vulnerable and anticipates the challenges posed by a rapidly changing climate.

8.2. Recommendations

Based on the findings of this thesis, the following recommendations are proposed to mitigate the impacts of climate variability and pollution on asthma in the Savanes and Grand-Lomé regions of Togo:

Data Centralization for Asthma Cases: Encourage the creation of centralized and secure databases specifically for asthma patients. This would facilitate long-term access to essential information such as diagnosis history, treatment plans, and environmental triggers, enabling better research and public health planning.

Digitization and Staff Training on Asthma Recordkeeping: Promote the digitization of asthma-related hospital records and train healthcare staff on accurate data collection for asthma cases. Emphasis should be placed on recording patient contact details, asthma severity, and environmental exposure to support follow-up and preventive care.

Promoting clean cooking solutions: Given the high percentage of households (59.3%) using charcoal for cooking, transitioning to cleaner cooking solutions, such as LPG (liquefied petroleum gas), improved or electric stoves, is imperative. Government-led initiatives could focus on subsidies or incentives to encourage the adoption of these cleaner alternatives, especially in rural areas. This would reduce indoor air pollution and, consequently, the risk of asthma exacerbation.

Public health education and community awareness: Widespread community-based education campaigns should be implemented to raise awareness about the link between climate, pollution, and respiratory diseases (almost 40% of asthmatics lacked awareness of the effects of climate change and pollution on respiratory health). These campaigns should focus on preventive care, the importance of regular medical consultations, and the use of asthma medications.

Strengthening air quality monitoring systems: The establishment of a robust air quality monitoring network across both urban and rural areas is essential. Real-time data should be made accessible to the public via mobile applications or SMS alerts to allow individuals, especially asthmatics, to take precautionary measures on days with high pollution levels.

Targeted health interventions during critical seasons: Seasonal variations in asthma prevalence, particularly during the Harmattan and dry seasons, call for targeted health campaigns during these periods. Asthma patients should be educated on the use of preventive measures such as wearing masks during dust storms and limiting outdoor exposure during extreme heat. Additionally, healthcare systems should be prepared for an influx of asthma-related cases during these peak periods by ensuring adequate medication and emergency response capabilities.

Capacity building for health professionals: Training healthcare professionals to recognize and treat climate-sensitive respiratory diseases, such as asthma, is critical. This training should focus on understanding environmental triggers and incorporating climate-related risks into treatment plans. Additionally, medical professionals should be trained to provide personalized advice to asthma patients on how to manage their condition during periods of high air pollution or extreme weather.

Policy advocacy and legislative framework: There is a need for stronger environmental and public health policies to address the rising health burden due to climate variability. Legislation should mandate pollution control measures in urban centers, encourage the reduction of vehicle emissions, and promote green infrastructure to reduce dust and air pollution. Collaboration with the Ministry of Health, the Ministry of Environment, and other stakeholders will be crucial in implementing these measures.

Research and development of climate-resilient health systems: Investments in research on the long-term impacts of climate variability on public health, particularly respiratory diseases, are essential. Collaboration between national and international research institutions could help in building more climate-resilient health systems, ensuring that they are better prepared to handle the increasing health challenges posed by climate change.

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Appendix 1: Five articles published

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Impacts of Climate Change on Respiratory Health, Case of Asthma: A Comprehensive 24-Year Review (2000 To 2023) of Current Trends and Future Perspectives

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Abstract Climate change, recognized as one of the major challenges of our time by the United Nations, poses an unprecedented threat to global health. This scientific article examines the multiple facets of the impact of climate change on respiratory health, with a particular focus on asthma. Through a detailed review of existing literature over the past 24 years, we explore the complex relationships between climate variations, environmental factors, and respiratory diseases. We analyze data from various sources, including epidemiological studies, epidemiological models, and public health surveys. In addition to providing the current assessment of the impact of climate change on asthma, this review explores future perspectives. The results show an increasing correlation between these climate changes and the worsening of asthma symptoms, as well as an increase in asthma-related hospitalizations. Furthermore, potential scenarios include an intensification of extreme weather events, variations in allergen distribution, and changes in air quality, all of which have the potential to exacerbate the challenges already posed by asthma. The implications of these emerging trends underscore the crucial importance of developing adaptation and mitigation strategies. Multidisciplinary approaches, involving healthcare professionals, climate scientists, and policymakers, are necessary to devise sustainable solutions aimed at protecting respiratory health in the face of the challenges posed by climate change.

Keywords: *climate change, respiratory health, asthma, current trends, future perspectives*

Cite This Article: Essoninam Passike Pokona, Essohanam Boko, Pascal Yaka, and Brama Kone, "Impacts of Climate Change on Respiratory Health, Case of Asthma: A Comprehensive 24-Year Review (2000 To 2023) of Current Trends and Future Perspectives." American Journal of Public Health Research, vol. 12, no. 1 (2024): 1-7. doi: 10.12691/ajphr-12-1-1.

Chapter 15
Climate Variability and Asthma Attacks in Two Climatic Zones in Togo: The Case of the Savanes Region in a Unimodal Sahelian Area and the Case of the Grand-Lomé Region in a Bimodal Coastal Area

Essoninam Passike Pokona, Essohanam Boko, Pascal Yaka, and Brama Kone

Abstract Climate change and climate variability trigger certain respiratory conditions, but the extent of its effect is still poorly understood, especially from one geographical area to another. The present study was conducted on Asthma using five (05) years of data from 2018 to 2022 in two climatic areas in Togo, namely the Savanes region in a unimodal Sahelian zone in the north and the Grand-Lomé region in a bimodal coastal zone in the south. The methodology employed consisted of an analysis of the correlation coefficient and the significance at 5% of the p-values; identifying environmental parameters, in particular the Normalized Difference Vegetation Index (NDVI) and climatological parameters, namely rainfall (RR), maximum (TMAX) and minimum (TMIN) temperatures, maximum (HMAX) and minimum (HMIN) relative humidity, wind speed (Windspeed) and insolation (Inso), which are strongly correlated with asthma in each region of the study area. The results indicated that NDVI, TMIN and Windspeed are strongly correlated with Asthma in the Savanes region with correlation coefficients and p-values of 0.063 at 2.6%, − 0.53 at 4.2% and − 0.60 at 3.5% respectively. In contrast to the Grand-Lomé region, the correlation between UMAX and Inso for Asthma was established, with (r) and

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Breathe In, Breathe Out: Asthmatics and Environmental Challenges in Grand-Lome, Togo

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Abstract:- Over recent decades, interest in the impact of climate change and air pollution on respiratory conditions has significantly increased. Despite this attention, patients, as a vulnerable group, remain relatively uninformed about the potential links between climate, pollution, and their health. This study aimed to assess the perception of asthmatics in Togo regarding the relationship between climatic variables, air pollution, and the severity of their asthma attacks. Conducted in healthcare centers in the Grand-Lome regions, the survey revealed a predominance of young adults, mainly males aged 18 to 30 years. Most participants have attained an education level ranging from high school diploma to bachelor's degree, but a significant portion has an education level below high school diploma. Regarding knowledge about climate change and air pollution, a quarter of participants have no knowledge on the subject, while a minority possess an advanced level of knowledge. Nearly half of the participants attribute their asthma attacks to climate and pollution, with critical periods being the dry season, rainy season, and harmattan, with major triggers including heat, exhaust fumes, and dust. The majority of participants use charcoal and firewood as cooking energy sources, exacerbating asthma symptoms. Although 60% of participants regularly visit healthcare centers for asthma control, nearly 40% do not, citing social beliefs that asthma is a spiritual disease and should be treated in convents or prayer places. Financial constraints also contribute to non-attendance. Among those who experienced at least 10 attacks in the last 12 months, over half have no knowledge of climate change and air pollution, mainly within the under 30 age group, highlighting the need for targeted awareness and intervention programs for this demographic.

***Keywords :-** Perception, Climate Variability, Air pollution , Asthmatic, Togo.*

I. INTRODUCTION

By the end of the 21st century, a global temperature increase of 1.5°C to 4.8°C is likely to have a negative impact on climate, human health, and the economy [1]. Consequently, the human health sector is one of the most vulnerable sectors to climate change, given that weather events (heatwaves, storms, droughts, floods, and wildfires) strain the already fragile healthcare system in less developed countries [2]. Additionally, individuals with respiratory diseases will be affected by extreme weather conditions [3]. According to the same authors, these climate variabilities and changes coupled with deteriorating air quality will exacerbate morbidity and mortality associated with respiratory diseases, including asthma. In 2019, 4.1 million deaths were attributed solely to ambient air pollution, while indoor air pollution from cooking with polluting fuels caused approximately 2.3 million deaths during the same period [4].

The World Health Organization (WHO) defines asthma as a chronic lung condition that affects people of all ages. It is caused by inflammation and constriction of the muscles around the airways, making breathing more difficult. Approximately 300 million people worldwide suffer from asthma, and according to the WHO, 495,000 people die from asthma each year, with prevalence in Africa ranging from 4% to 22% depending on the country [5].

Asthmatics, being among the most vulnerable, find themselves somewhat helpless in the face of this public health emergency, which often hinders their well-being. Understanding and addressing these issues are therefore crucial, and asthmatics must actively engage with them. Accordingly, investigating the effects of climate variability and change on the environment and their impact on respiratory diseases could provide additional insights to improve the daily lives and public habits of asthmatics. This study aims to address the current misunderstandings of asthmatics regarding the potential impacts of climate on their health by thoroughly exploring the specific aspects of the link between climate change, air pollution, and respiratory diseases. The goal is to inform concrete measures to mitigate

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Healthcare Professionals' Perception of the Link Between Climate Variability and Respiratory Diseases in Northern and Southern Togo: A Case Study of Asthma in Savanah Region and Grand-Lome

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Abstract The impact of climate change and air pollution on respiratory diseases has garnered significant attention over the past decades. Despite this heightened interest, it remains the case that key stakeholders in the healthcare domain still lack comprehensive understanding of the potential existential links between climate, pollution, and health. This article aims to elucidate the level of comprehension regarding the relationship between climatic variables and atmospheric pollutants on the severity of asthma crises in Togo. Within the framework of this study, a survey was conducted in healthcare centers in the Savanah and Grand-Lomé regions, involving 338 healthcare professionals, comprising 65.4% males and 34.6% females, with surveyed profiles predominantly distributed as follows: 23% physicians, 49.6% nurses, and 27.4% medical assistants from various medical departments including pulmonology, pediatrics, and internal medicine services. The findings revealed that approximately 39.2% of participants had undergone training in climate change, indicating a growing awareness of the significance of this subject. However, the majority (46.6%) considered themselves to be beginners in the field of climate change. Regarding air pollution, 83.4% of participants exhibited some level of knowledge, indicating encouraging awareness. Most participants believed that climate contributes to asthma crises (75%) and acknowledged that air quality influences lung function (100%). Periods conducive to asthma crises included the harmattan season (56.7%), dry season (41.8%), with triggering factors including dust (100%) and smoke (59.1%). The integration of climate counseling in asthma treatment was reported by 90.3% of participants, highlighting significant awareness among healthcare professionals. However, the study revealed that the majority (82.8%) were unaware of the existence of national asthma surveillance and management documents. Furthermore, 95% of those aware of such documents were uncertain whether these documents consider climatic and environmental aspects. In conclusion, the study underscores the necessity for climate-proofing national strategic health documents, increased awareness, ongoing training, and integration of modules on the climate-health nexus into medical curricula

Keywords: *Climate variability, respiratory diseases, perception, asthma, healthcare professionals, Togo*

Cite This Article: Essoninam Passike Pokona, Essohanam Boko, Pascal Yaka, and Brama Kone, "Healthcare Professionals' Perception of the Link Between Climate Variability and Respiratory Diseases in Northern and Southern Togo: A Case Study of Asthma in Savanah Region and Grand-Lome." *American Journal of Public Health Research*, vol. 12, no. 2 (2024): 33-39. doi: 10.12691/ajphr-12-2-3.

1. Introduction

The climate change and atmospheric pollution constitute one of the paramount threats to global health in our era, with their impacts on human health and well-being being considerable and worsening (https://www.cdc.gov/climateandhealth/). They affect ecosystems, resulting in direct and indirect impacts on patients suffering from allergic and respiratory diseases [1]. According to [2], the impact of climate change on health is considered the most significant global public health issue and the threat to humanity of this century. Its magnitude and severity on health vary depending on the locations, primarily due to the state of preparedness, vulnerability levels, and adaptability of populations. [3,4] further argue that, besides the current warming and evolving climate-related hazards, existing societal challenges such as social inequalities, progressive urbanization, aging populations, will exacerbate the health burden attributed to climate change. For instance, climate

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Research Article

Bridging Climate Science and Public Health: Predicting Asthma for Better Respiratory Health Management in Togo

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Abstract

Climate change and air pollution are major environmental and public health concerns, particularly in developing countries. Respiratory diseases such as asthma are significantly influenced by variations in temperature, humidity, and air quality. This study examines the relationship between climate, pollution, and asthma prevalence in two distinct regions of Togo: Grand-Lome (urban and coastal) and the Savanes region (rural and arid). We analyse data from 2018 to 2022, including meteorological variables (temperature, humidity, rainfall, wind speed) and air pollutants (CO_2, NO_2, SO_2, O_3), to assess their impact on asthma cases. A Principal Component Analysis (PCA) is conducted for variable selection, followed by two predictive modelling approaches: Random Forest Model (RFM) and Polynomial Regression Model (PRM). Model accuracy is evaluated using statistical indicators such as R^2, Mean Squared Error (MSE), and Root Mean Squared Error (RMSE). Results showed that in the Savones region, PRM explains 36% of asthma variance ($R^2 = 0.36$) but has higher prediction errors, while RFM ($R^2 = 0.13$) better captures seasonal variations. In Grand-Lomé, PRM performs better ($R^2 = 0.41$) compared to RFM ($R^2 = 0.20$). Although PRM offers higher explanatory power, RFM demonstrates superior reliability for seasonal trend forecasting, making it more suitable for asthma prediction in Togo. Furthermore, the impact chain approach highlights the complex interactions between climate, pollution, and asthma prevalence. Rising temperatures and air pollution exacerbate respiratory distress, while socio-economic factors influence healthcare access and exposure levels. Understanding these interdependencies is crucial for designing effective adaptation strategies. These findings emphasize the need for targeted policies to improve air quality and healthcare strategies. Implementing early warning systems based on climate and pollution indicators could help mitigate asthma risks, especially in vulnerable populations.

Keywords: Climate variability, Air pollution, Asthma, Impact chain, Predictive modelling, Togo

Abbreviations: AI: Air Quality Index, CO_2: Carbon Monoxide, SO_2: Sulphur Dioxide, O_3: Ozone, NO_2: Nitrogen Dioxide, PCA: Principal Component Analysis, RFM: Random Forest Model, PRM: Polynomial Regression Model, R^2: Coefficient of Determination, MSE: Mean Squared Error, RMSE: Root Mean Squared Error, NDVI: Normalized Difference Vegetation Index, Tmin: Minimum Temperature, Tmax: Maximum Temperature, Tmoy: Average Temperature, Umin: Minimum Relative Humidity, Umax: Maximum Relative Humidity, Umoy: Average Relative Humidity, Inso: Sunshine, RR: Rainfall, PRM: Polynomial Regression Model

Appendix 2: Ethics Committee approval

MINISTERE DE LA SANTE DE L'HYGIENE PUBLIQUE ET DE L'ACCES UNIVERSEL AUX SOINS

REPUBLIQUE TOGOLAISE

Travail – Liberté – Patrie

COMITE DE BIOETHIQUE POUR LA RECHERCHE EN SANTE

EVALUATION DE PROTOCOLE DE RECHERCHE

TITRE DU PROJET : « **Prédiction des maladies respiratoires sensibles au climat en Afrique de l'Ouest par l'utilisation d'informations et de modèles climatiques : cas de l'asthme dans les régions du Grand Lomé et des Savanes au Togo** »

Date du protocole : Version non indiquée

Promoteur : Université de Lomé, Faculté des Sciences de l'Homme et de la Société, Programme de recherche doctorale en changements climatiques et gestion des risques de catastrophe

Equipe technique :
- **M. Essoninam PASSIKE,** étudiant doctorant
- **Pr Essohanam BOKO,** superviseur principal
- **Dr Pascal YAKA,** co-superviseur de thèse
- **Dr Brama KONE,** co-superviseur de thèse

AVIS N° 011/2023/CBRS du 16 mars 2023

Le Comité de Bioéthique pour la Recherche en Santé (CBRS) s'est réuni le 16 mars 2023 pour évaluer le protocole de recherche relatif à l'étude suivante : « **Prédiction des maladies respiratoires sensibles au climat en Afrique de l'Ouest par l'utilisation d'informations et de modèles climatiques : cas de l'asthme dans les régions du Grand Lomé et des Savanes au Togo** ».

A l'issue de la mise en commun des rapports d'étude présentés par des personnes ressources, le CBRS s'est prononcé sur :

1- La présentation du dossier
- Documents du protocole d'étude : les documents sont bien présentés.
- Les outils de collecte de données sont disponibles et bien élaborés.

2. La validité scientifique du dossier

Conception scientifique : L'étude est scientifiquement bien conçue.

Hypothèse : La problématique est bien définie. Elle est articulée en trois points : (i) l'asthme a une saison propice dans l'année où l'incidence est élevé dans les régions du Grand Lomé et des Savanes et les paramètres climatologiques et environnementaux lui

1

sont corrélés ; (ii) les asthmatiques et les praticiens de la santé ont des connaissances sur les facteurs déclenchant l'asthme ; (iii) un modèle à court et long terme peut être généré sur la base de paramètres climatologiques et environnementaux corrélés dans les régions du Grand Lomé et des Savanes.

Méthodologie : La méthodologie est bien décrite et est adaptée à ce genre d'étude.

Faisabilité : Ce protocole est réalisable.

Objectifs : Les objectifs sont clairs et précis. L'objectif principal de l'étude est de contribuer à une meilleure compréhension du lien entre la variabilité des facteurs environnementaux et climatiques et la dynamique de l'asthme afin d'améliorer son suivi ainsi que sa prise en charge.

Intérêt de l'étude : L'intérêt de ce travail pour la santé publique est indéniable.

Références scientifiques : Les références scientifiques sont fournies.

3. L'acceptabilité éthique

La notice d'information des participants et le formulaire de consentement ne sont pas disponibles. Le CBRS recommande au promoteur de rendre disponibles ces documents avant le début de l'étude.

4. La conclusion

Le CBRS, à l'unanimité de ses membres présents, a émis un **AVIS FAVORABLE** pour l'exécution au Togo du protocole d'étude suivant : « **Prédiction des maladies respiratoires sensibles au climat en Afrique de l'Ouest par l'utilisation d'informations et de modèles climatiques : cas de l'asthme dans les régions du Grand Lomé et des Savanes au Togo** ».

NB : A la fin de l'étude le promoteur devra déposer au secrétariat du CBRS le rapport final en 5 exemplaires.

Fait à Lomé, le 16 mars 2023

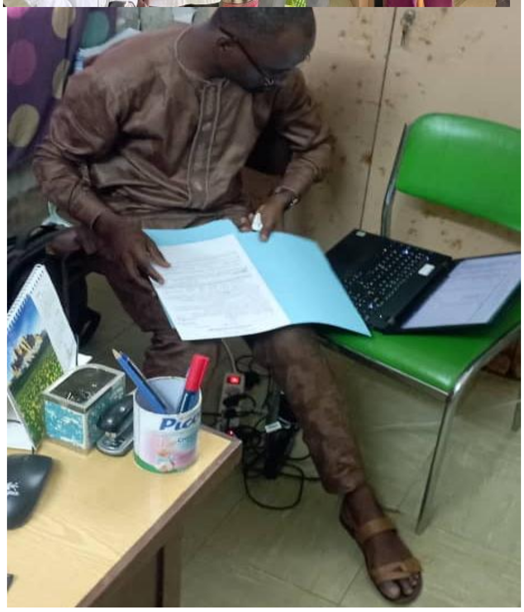
Le Rapporteur :

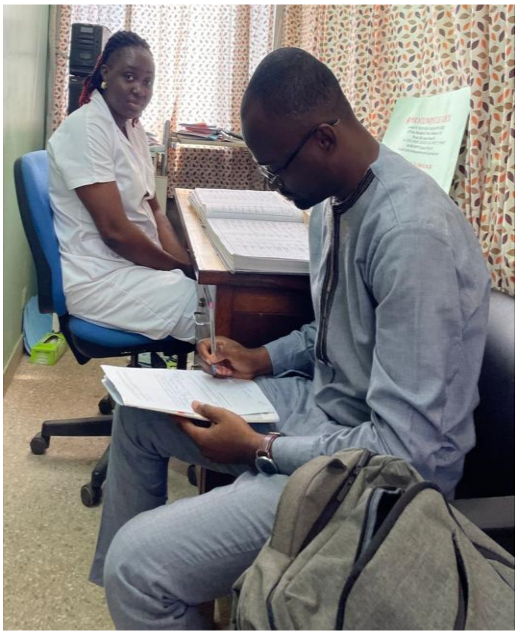
ALEZA Mazabalo

La Présidente

Professeur
Mireille PRINCE-DAVID

Appendix 3 : Some pictures during health data collection





Abstract
This study investigates the relationship between climate and asthma to improve monitoring and healthcare management. The study focuses on three areas: examining the link between climatic and environmental variables and asthma based on statistical correlation, assessing the perceptions of healthcare practitioners and asthma patients through questionnaire and interview, and predicting asthma occurrences using climatic data. The research is based on five years of data (2018-2022) from two regions in Togo: The Savanes region (northern Sahelian zone) and the Grand-Lomé region (southern coastal zone). Key findings included the identification of significant correlations between climate factors and asthma. In the Savanes region, normalized vegetation index (NDVI), minimum temperatures (TMIN), and wind speed were strongly linked to asthma. In Grand-Lomé, maximum humidity (UMAX) and insolation were key factors. Asthma prevalence was higher in the coastal region (274.8 per 100,000) compared to the Savanes (64.88 per 100,000), with exacerbations occurring in the colder, dry months from december to february. Patient surveys revealed that despite 60% regularly seeking medical care, financial and cultural barriers limited access for some. Among healthcare professionals, 39.2% had training in climate change, but many were unaware of national asthma management guidelines that integrate climate factors. An impact chain analysis demonstrated how climate hazards like temperature variations and pollution exacerbate asthma risk, particularly for vulnerable groups such as children and the elderly. Predictive models, including Random Forest and Polynomial Regression, were developed to forecast asthma cases, with Random Forest selected as the most effective model for both regions due to its ability to capture seasonal variations. The study recommends better integration of climate considerations into health strategies, including early warning systems and public awareness campaigns.

Keywords: *Climate variability, Asthma, Air pollution, Modelling, Togo.*

Thème : ***"Prédiction des maladies respiratoires climato-sensibles en Afrique de l'Ouest sur la base des informations climatiques : cas de l'asthme dans le nord (région des Savanes) et le sud (région du Grand-Lomé) du Togo"***

Résumé
Cette recherche étudie les liens entre le climat et l'asthme afin d'améliorer le suivi et la gestion des maladies respiratoires climato-sensibles. L'étude, menée dans deux régions du Togo, la région des Savanes au Nord et celle du Grand-Lomé au sud a porté sur trois objectifs : (i) examiner le lien entre les variables climatiques et environnementales et l'asthme sur la base des test de correlation, (ii) évaluer les perceptions des professionnels de santé et des asthmatiques sur le nexus climat et santé respiratoire à travers des enquêtes basées sur des questionnaires et interview, et (iii) générer un modèle de prédiction de l'asthme en utilisant des données climatiques et environnementales. Les données utilisées dans le cadre cette étude sont de type climatiques, environnementales et sanitaires ; et ont couvert une période de cinq années allant de 2018 à 2022. Les résultats clés incluaient l'identification de corrélations significatives entre les facteurs climatiques, environnementales et l'asthme. Dans la région des Savanes, l'indice de végétation normalisé (NDVI), les températures minimales (TMIN) et la vitesse du vent étaient fortement liés à l'asthme. Au Grand-Lomé, l'humidité maximale (UMAX) et l'insolation étaient des facteurs clés. La prévalence de l'asthme était plus élevée dans la région côtière (274,8 pour 100 000) par rapport aux Savanes (64,88 pour 100 000), avec des exacerbations survenant pendant les mois plus froids et secs de décembre à février. Les enquêtes bien que 60 % des patients consultent régulièrement dans les centres de santé, des barrières financières et culturelles limitaient l'accès aux soins pour d'autres patients. Parmi les professionnels de santé, 39,2 % avaient reçu une formation sur le changement climatique, mais beaucoup ignoraient les directives nationales sur la gestion de l'asthme intégrant les facteurs climatiques. Une analyse de la chaîne d'impact a démontré comment les variations de température et la pollution, aggravent le risque d'asthme, en particulier pour les groupes vulnérables comme les enfants et les personnes âgées. Deux modèles prédictifs notamment le modèle de Random Forest et la régression polynomiale ont été développés pour prévoir les cas d'asthme. Le Random Forest s'est montré plus fiable pour les deux régions en raison de sa capacité à capturer les variations saisonnières interannuelles. L'étude recommande une meilleure intégration des considérations climatiques dans les stratégies de santé, y compris des systèmes d'alerte précoce et des campagnes de sensibilisation.

Mots-clés : *Variabilité climatique, Asthme, Pollution de l'air, Modélisation, Togo*